
Tree Communities of Lowland Warm-Temperate Old-Growth and Neighboring Shelterbelt Forests in the Shikoku Region of Southwestern Japan

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Abstract.—We characterized the tree species composition of a 30 ha old-growth and neighboring shelterbelt (reserved buffer strips among conifer plantations) in warm-temperate forests in the Shikoku region of southwestern Japan. Using a two-way indicator species analysis of data from 28 plots, we identified four structural groups in terms of relative basal area. These structural groups were interior and edge types of a greater than 30 ha old-growth, middle-sized (5- to 15-ha) shelterbelt type, and small-sized shelterbelt (less than 5 ha) type, respectively. Canonical correspondence analysis also showed differentiation of the four structural types along edge-interior gradient and remnant-size gradient.

Introduction

Warm-temperate old-growth forests in southwestern Japan, especially in lowland areas, were often converted into coniferous plantations, farmland, and other land uses (Ito *et al.* 2003, Miyawaki 1982, Nakagawa and Ito 1997). Only a few large old-growth remnant forests remain. Most natural forests remnants are shelterbelts that reserve buffer strips among conifer plantations or clear-cut areas. Natural forests remnants are important to forest restoration and maintaining biodiversity. First, they preserve many plants and animals. Second, they potentially contribute vegetation recovery as seed sources for adjacent clear-cut

or thinned area of plantation forests (Ito *et al.* 2003; Sakai *et al.* 2006). The capacity for maintaining species diversity is strongly influenced by the size and shape of the forest, which many former studies reported as *fragmentation effects* and *edge effects*. (Murcia 1995). Many studies reported the effects of edges facing open sites, such as clear-cut and agricultural lands. The actual role of natural forest adjacent to conifer plantations as the seed source, however, has been little studied (Ito *et al.* 2003). Tree community structure of natural forest remnants is important as an indicator of the edge effects of forest remnants themselves, as well as a determinant of the role of seed source. In this study, we focused on the species composition of trees in natural forest remnants adjacent to conifer plantations in relation to the size of the remnant and other landscape and site environmental attributes.

Study Area and Methods

Study Area

The field survey was conducted in Asizuri peninsula, located on Shikoku Island in southwestern Japan (133 °E, 32 °N). The area is situated in a lowland (approximately 20 to 400 m above sea level), warm-temperate region where the natural vegetation is evergreen broadleaved forest dominated by *Fagaceae*, *Lauraceae*, and *Camelliaceae* species (Miyawaki 1982). Annual mean temperature and precipitation is 17.9 °C and 2,421 mm, respectively.

In the approximate center of peninsula, a wide (greater than 30 ha) undisturbed old-growth forest remains,

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surrounded by conifer plantations consisting of Japanese cedar (*Cryptomeria japonica* D. Don.; Japanese cypress (*Chamaecyparis obtusa* Sieb. et Zucc.), or their mixture; secondary evergreen broadleaved forests; and farmlands. Approximately 20 ha of undisturbed old-growth forest was reserved as the national Sadayama Forest Reserve (SFR) (Kochi National Forest Office 1995). Among compartments of plantations surrounding a wide old-growth forest, including the FSR, reserved buffer strips of evergreen broadleaved forests known as shelterbelts remained. Most conifer plantations were formed in the 1960s and 1970s in the Ashizuri area. Hence, edge formation mainly occurred 30 to 40 years ago.

Tree Census

We settled eight transects in interior and five onsets of plots in the edge of the SFR representing the tree community structure of large-sized old-growth forests in the region. These were designated LOG. We also settled 10 plots in seven randomly selected shelterbelts of different landscape and site environmental attributes representing the tree community structure of shelterbelts. The selected shelterbelts differed in area size from 1.9 to 15 ha. The altitude of all plots ranged from 240 to 340 m above sea level with the exception of two shelterbelts that were approximately 50 m above sea level.

The interior transects of the SFR were 10-m wide and 100-m long rectangles placed in the center part of the reserve more than 60 m from the forest edge to avoid the edge effect (Murcia 1995), and arranged parallel with each other along the topographic gradient from the hilltop to the valley to represent microtopography-mediated variation in species composition of trees (Enoki 2003, Kuramoto and Okuda 2005, Sakai *et al.* 1996). The edge plots of the SFR were placed at five randomly selected points on three edge lines of different direction. Three were places on the South-facing edge line adjoining conifer plantations, while one each was place on the West-facing and North-facing lines.... In each point of edge plots, two 10- by 20-m plots (subplots) were continuously placed along the line from the SFR border toward 20 m inside.

In the case of shelterbelt plots, we set up a 20-m² plot in each narrow shelterbelt less than 20-m wide (less than 5 ha) because it covered the entire part of shelterbelt and represented its community structure of trees. In wider shelterbelts, such as those greater than 5 ha, we set up two 20-m² plots, placed in the center and near the edge line of the shelterbelt, respectively.

In each plots in the LOG and neighboring shelterbelts, all living trees more than 5-cm diameter at breast height (d.b.h.) were recorded with identification of species and d.b.h. measurement.

Data Analyses

The relative basal area of each tree species was calculated for tree census data of each plot. We used each of the eight interior transects in the LOG and each of the ten plots in shelterbelts as one plot data in following analyses. For five onsets of plots in the edge of the LOG, we separately used each of two plots in a point in the following analyses because the extent of edge effect in warm-temperate forest edge is little known. Hence, we used 28 plots of data (8 of interior transects and 10 edge plots in the LOG, and 10 plots in shelterbelts, as reflecting the area size of the forest) in analyses. Two-way indicator species analysis (TWINSPAN) (Hill 1979) was used to classify the tree communities of LOG and shelterbelts, using PC-ORD (McCune and Mefford 1999). To explore the site environmental and landscape attributes relating tree community structure, canonical correspondence analysis (CCA) was done using CANOCO version 4.02 (ter Braak and Smilauer 1999). Site environmental and landscape attributes considered in the analysis—such as stand age (SAG), altitude (ALT), inclination (STE), area size (PAS), width and length of forest (WD and LEN), edge age (EAG), distance from the edge (DFE), and distance from large remnant forest (DFL)—were estimated for each forest from inventory maps of national forest, field observations, and Geographic Information System data (Y. Hirata [unpublished]).

Results

Classification of Tree Community

In 28 plots surveyed, 60 tree species were recorded. In all the plots, *Castanopsis sieboldii* was dominant. Based on TWINSpan, four structural groups (G1–G4) were recognized. Each division of groups corresponded with remnant-size difference, interior-edge contrast, and altitudinal contrast of plots (fig. 1). For example, the first division corresponded with remnant-size contrast in which small-sized remnants (Group4; shelterbelts less than 5 ha) were separated from others. Within small-sized remnants, those located in exceptionally low altitude (Group4B) were separated from others (Group4A) in the next division. In the other side of first division, middle-sized remnants (Group3; 5- to 15-ha shelterbelts) were separated from the large-sized remnant (LOG). Furthermore, the large-sized remnant (LOG) was divided into interior and edge types (Group1 and Group2, respectively). Of edge plots in the LOG, inside plots of onset of plots (10 to 20 m away from the border) were included in interior type (Group1). The division of the four groups, including two subgroups, and principal tree species were follows (table 1):

- Group 1. Interior of LOG. *Quercus acuta*, *Machilus thunbergii* were dominant next to *C. sieboldii*.
- Group 2. Edge of LOG. Instead of *C. sieboldii*, *Q. acuta* was dominant. This group was characterized by the abundance of *Cinnamomum japonicum* and *Neolitsea sericea* with the decrease of species that were abundant in the interior.
- Group 3. Mid-sized shelterbelt. *C. sieboldii* represented more than 50 percent of tree species. This group was characterized by sparseness of LOG species from the interior and edge, and occurrence of *Diospyros morrisiana* and *Rapanea nerrifolia*.
- Group 4. Small-sized shelterbelt. Without *C. sieboldii*, this group had no dominant species. This group was characterized by high species richness and the occurrence of *Daphniphyllum teijsmanii*, *Q. phillyaeoides*, and deciduous species.

Figure 1.—TWINSpan dendrogram of 28 plots in a greater than 30 ha old-growth forest and neighboring shelterbelts. Eigenvalues and indicator species with contribution scores in parentheses for each division are shown. Letters in the terminal boxes of the dendrogram represent a structural group of tree communities.

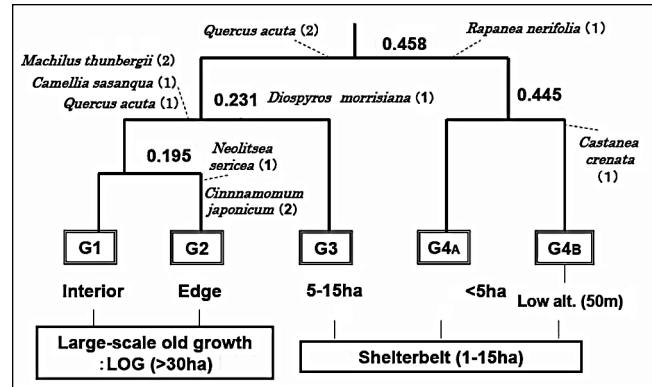


Table 1.—Vegetation groups classified by TWINSpan and relative basal area of tree species for each group.

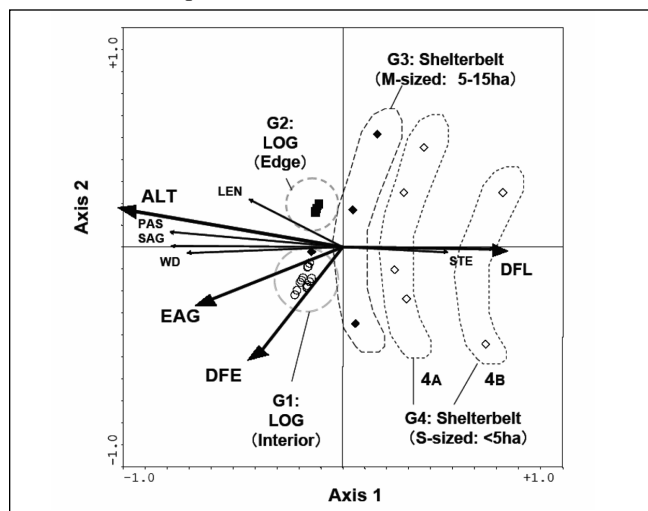
Group	G1	G2	G3	G4	Total
No. of plots	14	4	4	6	28
No. of species	26	23	22	36	60
Dominant among all type					
<i>Castanopsis sieboldii</i> 1	31.1	17.7	58.3	21.9	31.0
Interior (LOG) species					
<i>Quercus acuta</i> 1	27.1	27.3	3.5	0.1	20.0
<i>Machilus thunbergii</i> 2	11.5	9.1	1.2	2.7	8.7
Others (4 species)	12.6	1.0	0.2	0.3	8.4
Edge (LOG) species					
<i>Camellia japonica</i> 3	5.5	7.9	3.0	1.4	4.7
<i>Cinnamomum japonicum</i> 2	2.2	20.4	0.3	0.1	2.8
Others (2 species)	0.0	9.6	0.9	0.6	0.8
Shelterbelt species					
<i>Chamaecyparis obtusa</i> *	—	—	26.9	18.0	5.8
<i>Daphniphyllum teijsmanii</i>	—	0.5	—	5.9	1.1
<i>Prunus jamasakura</i>	—	—	—	4.0	0.7
<i>Quercus phillyaeoides</i> 1	—	—	—	3.0	0.6
<i>Castanea crenata</i> 1	—	—	—	2.0	0.4
<i>Diospyros morrisiana</i>	—	—	1.3	1.4	0.4
<i>Rapanea nerrifolia</i>	—	—	—	1.2	0.2
Others (3 species)	—	—	1.1	2.8	0.6
Others (3 species)	5.7	1.2	0.9	4.2	4.7
total	95.7	94.7	97.5	69.7	91.1

1: Fagaceae, 2: Lauraceae, 3: Camelliaceae, *: planted conifer
Underlined species are "Indicator species" of TWINSpan
Values are percent basal area

Ordination: Environmental Attributes and Tree Communities

In CCA ordination, the first three axes explained 67.3 percent of species-environment relations. The first axis, with a correlation of 0.977 between species and environmental factors, explained 32.2 percent of the total variation and 15.1 percent of species variation. The second axis showed a 0.853 correlation between species and environmental factors, and explained 22.4 percent of the total variation and 10.5 percent of species variation. In the ordination diagram (fig. 2), each structural group of four TWINSpan classifications was separated along two axes. Along the first axis, LOG groups (G1 and G2) were separated from shelterbelt groups (G3 and G4). In LOG groups, interior group (G1) was separated from edge group (G2) along the second axis. On both of two axes, distance from the edge (DFE) and edge age (EAG) showed the first and second highest *t*-value, respectively. Stand age (SAG), area size (PAS), and altitude (ALT) also showed high *t*-value on the second axis.

Figure 2.—CCA ordination diagram with correlation vectors of environmental and landscape variables showing the ordination scores of 33 plots in a greater than 30 ha old-growth forest and neighboring shelterbelts. Size of arrow and letter of each correlation vector represent intensity of contribution. Enclosed aggregations of plots show each structural group of tree community classified by TWINSpan. Open circle, solid square, solid diamond, and open diamond show interior of old-growth forest, edge of old-growth forest, mid-sized shelterbelt plots, and small-sized shelterbelt plots.



CCA = canonical correspondence analysis.

Discussions

Effects of Remnant Size on Tree Communities

Studies have reported that species richness changes with patch size of warm-temperate broadleaved forests (Hattori and Ishida 2000) and tropical rainforests (Laurance *et al.* 1998). In these studies, positive correlation of species richness to area size of forests was detected. In our results, however, the number of tree species was not significantly different between old-growth forest and shelterbelts, with the exception of a 1.5 times higher number in small shelterbelts, in our results. Fukamachi *et al.* (1996) reported the negative relationship between patch size and tree species richness per unit area basis in cool-temperate regions of Japan. Large patches include higher microtopographic and elevational variation (Fukamachi *et al.* 1996, Hattori and Ishida 2000). Change of tree species composition in large forest patches was basically influenced by microtopography and elevation, although the change was gradual. Infrequent species, which contribute to species richness, were actually rare on the basis of each unit's area. If the total area was considered, species richness might be increased. Furthermore, the effects of area size of forests on plant species diversity may be different among strata and life forms as well as forest types.

Most former studies focused on species richness, while detailed change of species was given less attention. Our results documented the drastic change of species of trees from LOG to shelterbelts along with patch-size gradient. In tropical rainforests, which have extra-high species richness, forest fragmentation resulted increase of tree mortality (Laurance *et al.* 1998), indicating that in smaller patches tree mortality was higher. A marked increase in wind-induced tree mortality in edges with decreased area of fragments was reported in a boreal conifer forest (Esseen 1994). Most shelterbelts were situated along the ridge. Our data suggested that tree mortality was higher in shelterbelts.

Species richness was also correlated with tree density (Fukamachi *et al.* 1996). In small-sized shelterbelts (G4), tree density was 3 times that in interior of LOG plots (G1),

and 1.5 times that in edge of LOG plots (G2) and mid-sized shelterbelts (G3) (Kuramoto and Okuda 2005). Mean d.b.h. of trees decreased from large patches to smaller patches in the plots we surveyed. In conifer plantations, breakage of canopy closure caused by thinning or selective cutting induced an increase of light availability and density of understory trees (Kiyono 1990, Suzuki *et al.* 2005). Kiyono (1990) pointed out that deciduous tree species only could establish themselves after cutting events such as thinning, while evergreen tree species could establish themselves even under closed canopy in conifer plantations. Therefore, it was implied that species richness increased in shelterbelts by accelerated establishment of deciduous broadleaved tree species and light-demanding evergreen tree species, compensating for the decrease of old-growth evergreen species induced by edge effect.

Impact of Edge Formation on Principal Canopy Tree Species and Their Response

Several evergreen broadleaved tree species that are common in interior LOG plots apparently decreased in edge of LOG plots and shelterbelts in our results. Of principal species in LOG plots, response to forest fragmentation and edge formation were different among species. *C. sieboldii* was dominant throughout different size of remnants, while *Q. acuta* and *M. thunbergii* were almost extinct in shelterbelts. Sprouting ability, photoinhibition, and potential distribution were suggested as reasons for these different responses. *C. sieboldii* was dominant in the lower part of the warm-temperate forest zone, compared with *Q. acuta*, which was dominant in the upper part. *M. thunbergii* was mainly distributed in the upper slope of LOG plots, where large-sized trees were grown. Most shelterbelts were positioned on the ridge, which suggested low suitability as a growth site for *M. thunbergii*. When the size of forest remnants was small, the edge effect was strong and the impact of direct cutting probably increased. Sprouting ability is important because it compensates for high mortality and other impacts of cutting. *C. sieboldii* had superior sprouting ability (Miura and Yamamoto 2003) over other LOG species. Rapid increase of light availability in shelterbelts and edge plots may cause photoinhibition of shade-tolerant species (Kitao *et al.* 2000).

Tree species that occurred in shelterbelts were quite infrequent in LOG. Many of these species were deciduous broadleaved species, which required the light increase by the canopy opening of adjacent part and reserved belts, as reported of understory development in conifer plantations (Kiyono 1990, Suzuki *et al.* 2005). Evergreen broadleaved species typical in shelterbelts, such as *D. teijsmanii*, *D. morrisiana*, and *R. nerrifolia*, were supposed to be as light demanding as deciduous trees. These species seldom grow over 20 or 30 m high. In shelterbelts, low canopy height induced by high wind stress and low nutrient and water availability, enabled these species not to be suppressed by other canopy tree species.

These facts implied that the function of shelterbelts as the seed source to adjacent conifer plantations were potentially different from LOG at the point of species composition, although species richness was not so different.

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