Tree Species Composition and Diversity in Relation to Forest Management in the Lowlands of Yakushima

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Introduction

We examined the effects of forest management on tree species composition and diversity in the lowland forests of Yakushima, an island in the south of Kyushu, Japan. Virtually all evergreen broad-leaved forests have been logged in Japan, but old-growth forests, which serve as a control treatment, still remain on Yakushima Island. Aiba et al. (2001) compared old-growth forests and secondary forests that were regenerating after the clear-cutting of old-growth forests on Yakushima Island over a range of altitude from 300 to 800 m above sea level. We performed a similar comparison, but restricted the altitude to lowland < 500 m to reduce the variation in environmental conditions, and included both conifer plantations and secondary forests that were regenerating after the clear-cutting of plantations. Conifer plantations have been converted from old-growth forests over the past 75 years or so and are currently one of the most dominant types of land use in the lowlands of Yakushima Island. In future, it may be desirable to reestablish natural forests after harvesting the plantations. However, little is known about what happens following the abandonment of plantations after harvesting (Sakai et al. 2006, Yamagawa and Ito 2006).

Materials and Methods

The study sites were located in the lowland forests (< 500 m above sea level) on Yakushima Island, Kagoshima Prefecture, Japan (30° N 130° E). The lowlands of Yakushima Island were once covered by old-growth evergreen broad-leaved forests. Most of the old-growth forests had been clear-cut by the early 1930s, and plantations of the evergreen conifer *Cryptomeria japonica* were established mainly on lower slopes (Fig. 1). Secondary forests also regenerated in clear-cuts that were not planted with *C. japonica*. Recently, these *Cryptomeria* plantations were again logged, but further afforestation was not conducted. In such areas, low-diversity forests strongly dominated by the deciduous broad-leaved tree *Aleurites cordata* regenerated. In addition to these silvicultural practices, topography affects the tree species composition in the lowland forests on Yakushima Island (Bellingham et al. 1996; Aiba et al. 2001, Tsujino et al. 2006), although *Cryptomeria* plantations and *Aleurites* forests are mainly restricted to lower slopes. We therefore established a total of 24 plots, with four in each of the following categories of forest: (1) old-growth forest on upper slopes, including ridges and steep mid-slopes; (2) old-growth forest on lower slopes, including valleys and gentle mid-slopes; (3) secondary forest on upper slopes; (4) secondary forest on lower slopes; (5) *Cryptomeria* plantation on lower slopes; and (6) *Aleurites* forest on lower slopes. The plot locations were selected in National Forests and privately owned forests using maps from the local Forestry Office and by
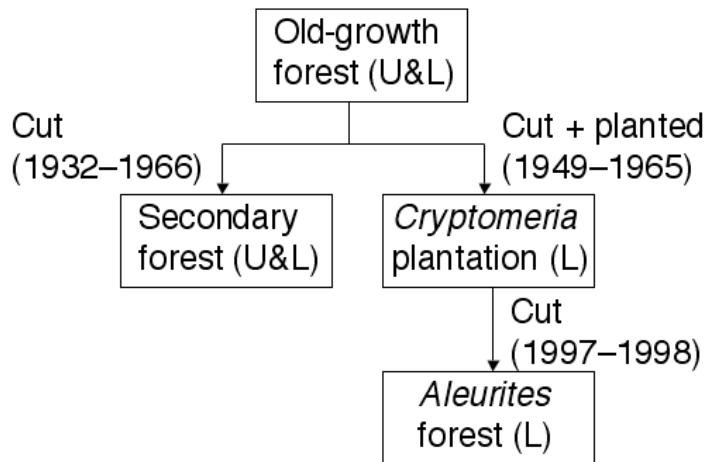
interviewing local people, respectively.

Fig. 1 The relationship among four forest types in relation to forest management in the lowlands of Yakushima Island. Year of logging for the study sites and the topography of each forest type (U, upper slope; L, lower slope) are also shown.

A tree census was conducted from 2006 to 2007. The plot area was 400 m^2 (10 × 40 m or 20 × 20 m), measured on the ground, depending on the availability of similar topography and the spatial extent of the forest type. All stems, including multiple stems, ≥ 2 cm in diameter at breast height (dbh, 1.3 m above the ground) were measured for dbh and identified to species. One old-growth plot on an upper slope, four secondary plots on upper slopes and two secondary plots on lower slopes had been established in 1984 (Kohyama 1988, 1989; Kohyama and Aiba 1997). Of these, two secondary plots on upper slopes and two secondary plots on lower slopes had an initial area of 100 m^2; these plots were expanded to 400 m^2 prior to the 2006–2007 census.

We conducted detrended correspondence analysis (DCA) to summarize the species composition (ter Braak and Smilauer 2002). We added 1 to the relative basal area of each species and log-transformed the input data. *Aleurites* forests (8–9 years old) were much younger than secondary forests (40–74 years old) in 2006–2007, but the secondary forests were 18–52 years old in 1984. We incorporated the 1984 data as well as the 2006–2007 data from the seven plots in the DCA to make the comparison between *Aleurites* forests and secondary forests more meaningful and to examine the temporal change in species composition over 22 years (all seven plots were recensused in 2006). We counted the number of species in each plot and computed Fisher's α, Shannon's index of diversity, and Pielou's index of evenness to evaluate species diversity; natural logarithms and stem numbers were used for the latter two indices (Magurran 2004). Fisher's α represents diversity in terms of the number of species relative to the number of stems, whereas Shannon's index is dependent on both the number of species and the evenness of species abundance.

Results and Discussion

Secondary stands showed forest structure similar to that of old-growth stands, except that the maximum dbh was significantly smaller on both upper and lower slopes and stem density was greater on upper slopes (Fig. 2), suggesting that forest structure had almost recovered to old-growth status 40–74 years after clear-cutting.

This is consistent with the results of Kohyama (1989) and Aiba et al. (2001). *Cryptomeria* plantations had a greater mean dbh than did the other forest types and tended to contain fewer stems per area. They also had a significantly greater basal area than did secondary forests of similar age on lower slopes (both approximately 40–50 years old). All of these differences likely reflect the effects of thinning management. *Aleurites* stands regenerating 8–9 years after the logging of *Cryptomeria* plantations had a significantly lower basal area (mean: 18.9 cm^2 m^{-2}) and maximum dbh (mean: 14.5 cm) than did other forest types. The basal area and maximum dbh of the six secondary forests for which long-term data were available were 39.9–53.9 cm^2 m^{-2} in 1984 (stand age 18–52 years old) and 15.3–39.1 cm, respectively. Therefore, the lower basal area of *Aleurites* forests may be characteristic of this forest type, but the smaller maximum dbh is probably a result of the younger age.
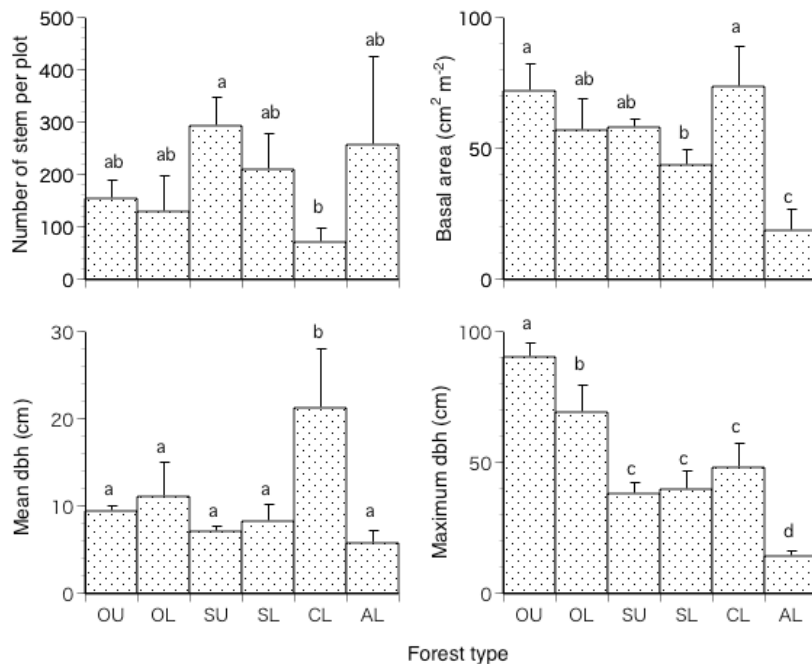

Fig. 2 Forest structure of the six forest-type categories in the lowlands of Yakushima Island.
The sample size was four plots in each forest-type category. Standard deviations are shown as vertical bars. Different letters indicate significant differences among plots at P < 0.05 using Tukey multiple comparisons (OU, old-growth forest on upper slope; OL, old-growth forest on lower slope; SU, secondary forest on upper slope; SL, secondary forest on lower slope; CL, *Cryptomeria* plantation on lower slope; AL, *Aleurites* forest regenerating on clear-cut *Cryptomeria* plantations on lower slope).

On upper slopes, both the old-growth and secondary plots had a high relative basal area (RBA >10%) of *Castanopsis cuspidata* var. *sieboldii*, which was the top dominant species in terms of basal area in three old-growth plots (RBA: 36–45%) and three secondary plots (36–69%). *C. cuspidata* probably regenerated from cut stamps in secondary forests, as suggested by the frequent occurrence of multiple-stemmed individuals. Other top dominants were *Quercus salicina* (RBA: 33%) in an old-growth plot and *Lithocarpus (Pasania) edulis* (36%) in a secondary plot. On lower slopes, no species showed consistently high RBA. The top dominants were *Q. salicina* (two plots, RBA: 23 and 51%), *Distylium racemosum* (27%), and *Schefflera octophylla* (23%) in old-growth plots, and *Aleurites cordata* (43%), *Ardisia sieboldii* (18%), *Fagara ailanthoides* (36%), and *Litsea acuminata* (31%) in secondary plots. As might be expected, plantations were strongly dominated by *Cryptomeria japonica*, exhibiting high RBA of 86–100%. One of the *Cryptomeria* plantations was well managed and contained only *C. japonica*. The other three plantations

were less managed and contained other species, mainly in the understory. *Aleurites cordata* stands that developed after the logging of *Cryptomeria* plantations were strongly dominated by *A. cordata*, exhibiting high RBA of 42−100%.

We are aware of only two studies that have documented the natural vegetation regeneration after the clear-cutting of conifer plantations in the warm-temperate region of Japan. Yamagawa and Ito (2006) compared tree species composition before and after clear-cutting of *Chamaecyparis obtusa* plantations in Miyazaki Prefecture, Kyushu, and pointed out the importance of both advanced regeneration (surviving and resprouting stems) and new regeneration from seedlings; advanced regeneration reflected the abundant understory vegetation in the plantations. Sakai et al. (2006) found that evergreen oaks, including *C. cuspidata* and *Q. salicina*, successfully regenerated after clear-cutting of *C. japonica* and *C. obtusa* plantations in southern Shikoku and considered that this was caused by advanced regeneration. However, in the *Aleurites* forests of Yakushima, regeneration was very poor, probably because of poorly developed understory vegetation in the original plantation, where advanced regeneration appeared to be lacking. Only *Ardisia sieboldii*, which occurred as multi-stemmed individuals, had a potential for advanced regeneration by resprouting.

The eigenvalues of axes 1 and 2 of the DCA were 0.70 and 0.31, respectively, and cumulatively explained 27% of the variance. Along axis 1, three broad groups of forest were separated in order of increasing score (Fig. 3): (1) *Cryptomeria* plantations and *Aleurites* forests, (2) old-growth and secondary forests on lower slopes, and (3) old-growth and secondary forests on upper slopes. Along axis 2, further compositional differences were found between *Cryptomeria* plantations and *Aleurites* forests and between old-growth and secondary forests on lower slopes, but the difference between old-growth and secondary forests was unclear on upper slopes. Temporal changes in the species composition over 22 years were slight compared to the variation among the forest types *Aleurites* forests 8−9 years old were distinctively different from secondary forests both in 1984 (18−52 years old) and in 2006−2007 (40−74 years old).
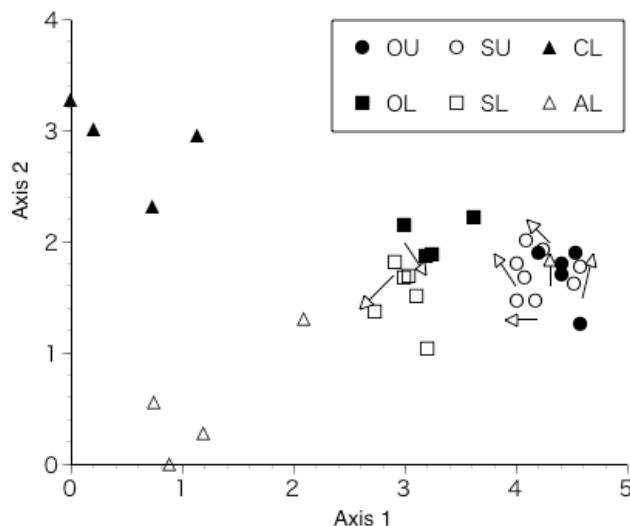

Fig. 3 DCA ordination diagram of plot scores. Arrows indicate the change in species composition from 1984 to 2006−2007 for seven long-term plots. Other plots were censused only in 2006−2007. See Fig. 2 for abbreviations of forest types.
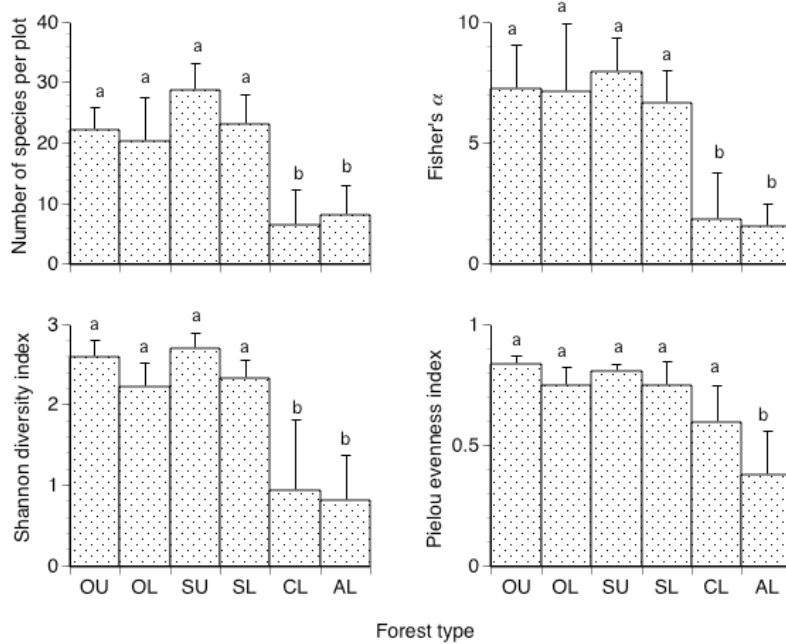
Fig. 4 Species diversity evaluated using various diversity indices for six forest-type categories. The sample size was four plots in each forest-type category, except for Pielou's index for *Cryptomeria* plantations for which n = 3 because one plantation plot contained only one species. Standard deviations are shown as vertical bars. Different letters indicate significant differences among plots at P < 0.05 using Tukey multiple comparisons. See Fig. 2 for abbreviations of forest types.
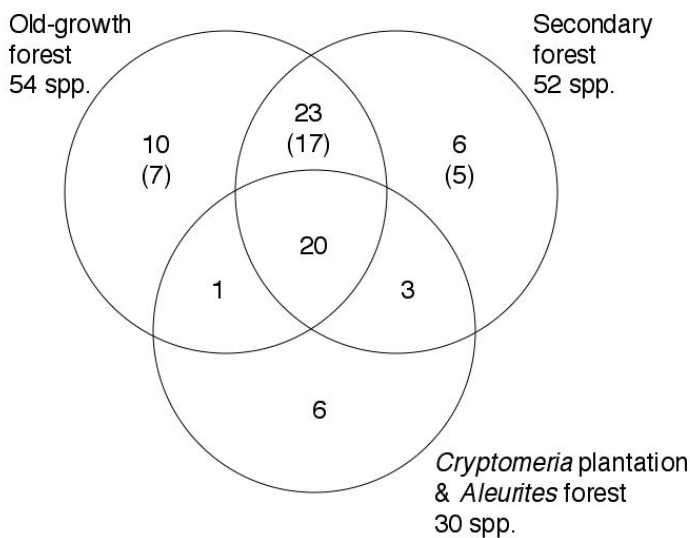

Fig. 5 Venn diagram of species occurrence in three forest-type groups, including old-growth forests on upper and lower slopes, secondary forests on upper and lower slopes, and *Cryptomeria* plantations and *Aleurites* forests (both on lower slopes). For species that are absent from the *Cryptomeria* and *Aleurites* forest group, the numbers of species that occurred on lower slopes are shown in parentheses.

Cryptomeria and *Aleurites* forests were less diverse than secondary and old-growth stands, although *Cryptomeria* plantations did not have significantly lower Pielou's index values than did old-growth or secondary forests (Fig. 4). One of the *Cryptomeria* plantations contained only *C. japonica*, and Pielou's index could not be calculated for this plantation. The differences between secondary and old-growth forests were unclear, which was consistent previous results (Aiba et al., 2001); the differences between upper and

lower slopes were also unclear.

The 4484 stems ≥ 2 cm in dbh in the 24 plots (0.96 ha) censused in 2006−2007 comprised 69 species. We examined the distribution of species among three groups of forests: old-growth, secondary, and *Cryptomeria* plus *Aleurites*. As many as 39 (57%) of the 69 species were absent from the *Cryptomeria* plus *Aleurites* forest group (Fig. 5). Of these, 29 species occurred on lower slopes in old-growth or secondary forests or both, so that their absence from *Cryptomeria* and *Aleurites* forests was not entirely a result of habitat associations. Species that appeared to be unable to invade *Cryptomeria* or *Aleurites* forests included all three Fagaceae species (*Castanopsis cuspidata*, *Lithocarpus edulis*, and *Quercus salicina*) that bear large acorns and are dominant (RBA > 30%) in one or more plots of the old-growth and secondary forests. This indicates that dispersal limitation is partly responsible for the poor species diversity of *Cryptomeria* and *Aleurites* forests.

However, the *Aleurites* forests investigated were all located nearby (approximately 10−50 m) old-growth or secondary forests that can act as seed sources. Thus, dispersal limitation was not the primary reason for the poor species diversity of *Aleurites* forests. Poor advanced regeneration caused by intensive forest management such as thinning and weeding in the understory seemed to be an important factor. Post-harvest disturbance such as soil erosion and herbivory by sika deer may also be important (Sakai et al. 2006). Seeds of *A. cordata* are poisonous to humans, and the species' vegetative parts may also be toxic to mammals. Indeed, Tsujino and Yumoto (2004) did not find evidence of deer herbivory on *A. cordata* saplings in an old-growth lowland forest on Yakushima Island. A lack of herbivory by deer could explain the monodominance of *A. cordata* on clear-cuts of plantations.

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