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REPORT

Sprout initiation and growth for three years after cutting in an abandoned secondary forest in Kyoto, Japan

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Abstract Secondary forests in Japan have been abandoned and the ecosystem has degraded since the high economic growth period. We carried out cutting in January in three small areas of a long-abandoned secondary forest and investigated the sprout initiation and growth of woody plants for three years in order to reveal the early stage of sprout regeneration and to understand the sprouting ability and characteristics of each species for effective management. The percentage of sprouted stumps and the number of sprouting shoots was substantially maximized in autumn in the first year. These results suggest that autumn monitoring in the first year after cutting shows the maximum percentage of sprouted stumps and the maximum sprout number when cutting was conducted in the dormant season. With regards to species characteristics, *Eurya japonica* showed a low percentage of sprouted stumps in the lower plot, where the mean diameter at breast height for this species was smaller than in the other plots. The sprouting ability of *E. japonica* was deemed to be influenced by parent tree size. *Ilex pedunculosa* and *Lyonia ovalifolia* var. *elliptica* had high percentages of sprouted stumps and many sprouts. These species are useful for obtaining sprouting shoots (e.g., for firewood), but it is difficult to control their sprouting.

Keywords Suburban secondary forest · Vegetation management · Sprout ability

Introduction

Secondary forests in Japan were traditionally managed to obtain firewood, small timber and fertilizer (Takeuchi 2003). The sustainable management system maintained the unique biodiversity of these forests (Washitani 2003); however, methods of obtaining energy and fertilizer have changed since the high economic growth period, and the value of secondary forests has gradually decreased (Takeuchi 2003). In western Japan, most of these abandoned secondary forests have been changed from pine and deciduous broad-leaved forests to evergreen broad-leaved forests (Morimoto and Morimoto 2003). The National Biodiversity Strategy of Japan, established in 2007, highlights the ecosystem degradation of the rural landscape, including the natural succession of secondary forests, as one of three biodiversity crises (Ministry of the Environment 2007).

Recently, suburban secondary forests have been reevaluated in terms of recreation, environmental education and the conservation of indigenous biodiversity and culture (Hattori et al. 1995). At the site level, vegetation management is conducted by citizen volunteers and local governments (Shigematsu 2002), such as the selective logging of evergreen shrubs and bamboos (Yamazaki et al. 2000; Yamase et al. 2005), and the clearing of underbrush

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and fallen leaves (Hosogi et al. 2001; Kataoka et al. 2003); however, the number of citizen volunteers has been estimated at about 20,000 and they can manage only 0.03% of all of the secondary forest in Japan (Tsunekawa 2003). It is necessary to establish efficient adaptive vegetation management methods in secondary forests.

For vegetation management of secondary forests, it is essential to understand sprouting because secondary forests were utilized and maintained by sprouting regeneration at 15–20-year cut intervals. The early stage of regeneration after cutting is an important period because plant species composition and density change dramatically within several years after cutting (Brokaw 1985; Breugel et al. 2006). At the early stage, sprouts generally grow earlier than seedlings and hinder seedlings from growing (Kennard et al. 2002). We have already reported seedling regeneration after cutting (Imanishi et al. 2009). In the present study, we report the early stage of sprout regeneration.

Sprouting is a major mode of regeneration of woody plants, not only after artificial disturbances such as cutting and burning (Uhl et al. 1981; Kammesheidt 1998), but also after natural disasters such as hurricanes and tornados (Glitzenstein and Harcombe 1988; Peterson and Pickett 1991; Bellingham et al. 1994), and after natural gap creation (Putz and Brokaw 1989). As a result, factors that affect sprouting ability have attracted the interest of researchers and managers. Parent tree age (Kayll and Gimingham 1965; Johnson 1975), parent tree size (Johnson 1975; Jones and Raynal 1987), disturbance season (Blaisdell and Mueggler 1956; Malanson and Trabaud 1988; Babeux and Mauffette 1994), and site quality (Mroz et al. 1985; Forrester et al. 2003) have been reported as factors that influence sprouting ability, and it has been reported that sprouting ability differs among species (e.g., Mroz et al. 1985; Bellingham et al. 1994).

We investigated the sprouting of woody plants for three years after cutting in order to reveal the early stage of sprout regeneration and to understand the sprouting ability and characteristics of each species.

Materials and methods

Study area and experimental design

All research was conducted at Kamigamo Experimental Station (Field Science, Education and Research Center, Kyoto University, Kyoto) in western Japan (35°04′N, 135°46′E) (Fig. 1). The bedrock is sandstone and slate, and the soil type is brown forest soil. The annual mean temperature and the annual mean precipitation in the experimental forest from 1971 to 2000 were 14.6°C and 1,581.8 mm, respectively (Kyoto University Forests 2002).

Three plots were set along a slope of the experimental forest to study the sprouting abilities and growth of woody plants under different light environments. The plots (upper, middle and lower) were 30 × 30, 20 × 30, and 40 × 15 m, respectively (Fig. 1). Cuttings were conducted after measuring stem diameters at breast height (DBHs) within these plots.

The area within and around the plots became part of the experimental forest after being part of a national forest in 1958. There is no accurate data on the stand condition of the area before 1958. However, it was reported that the forest neighboring the area was clearcut around 1925, and then it was dominated by Japanese red pine, *Pinus densiflora* Sieb. et Zucc. (Akai et al. 1986). Furthermore, it was assumed that the area may also have been cut from the 1920s to 1940s, and that Hinoki saplings, *Chamaecyparis obtusa* (Sieb. et Zucc.) Endl, which germinated before

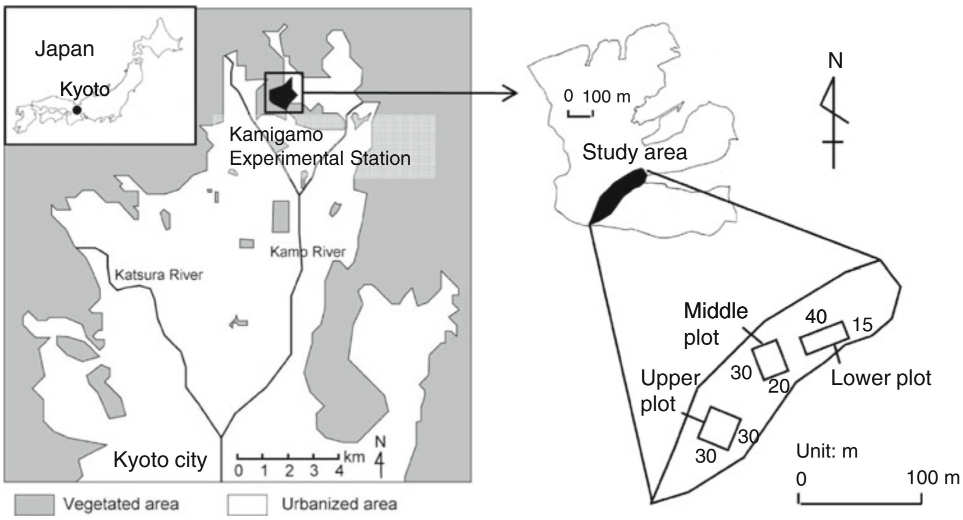

Fig. 1 Study area and locations of cutting plots

cutting, may have grown, based on the results of stem analyses of *C. obtusa* collected in the plots (Yanagimoto et al. 2000). After 1958, the area was left to grow under natural conditions. From the 1970s, *P. densiflora* began to die due to pine wilt disease, and most of it died in the early 1990s. This area is now dominated by *C. obtusa*.

To characterize the vegetation in the study area before cutting, we identified all of the trees taller than 1.3 m, and measured the DBHs in the three plots in August 1999. The percentage of total basal area (BA) was calculated for each species in the three plots. The BA of *C. obtusa* in the upper plot was 40.1 m^2/ha, accounting for 88.7% of the total BA (Table 1). The BA for the shrub species was dominated by *Eurya japonica* Thunb. (0.97 m^2/ha; 2.1%) and *Rhododendron reticulatum* D. Don (0.85 m^2/ha; 1.9%) (Table 1). In the middle plot, the BA of *C. obtusa* was 37.7 m^2/ha (93.5%) (Table 1). The BA for the shrub species was dominated by *E. japonica* (0.53 m^2/ha; 1.3%) and *Camellia japonica* L. (0.46 m^2/ha; 1.2%) (Table 1). In the lower plot, the BA was dominated by *C. obtusa* (19.3 m^2/ha; 46.1%) and *Quercus serrata* Thunb. ex Murray (12.3 m^2/ha; 29.3%) (Table 1). The BA for the shrub species was dominated by *Camellia japonica* (4.32 m^2/ha; 10.3%) (Table 1).

Almost all of the trees were cut in January 2000 in order to change the dominant species from *C. obtusa* to *P. densiflora* and/or deciduous broad-leaved trees; however, to improve vegetation recovery after cutting, several mother trees with a DBH >5 cm were left in each of the experimental plots (Table 1).

Sprout measurements

We established survey areas within the three plots to acquire data on sprouts and the light environment by excluding the edges of the plots that were significantly shaded by the surrounding trees so that the survey areas were kept more homogeneous for sprouts. The survey areas were 20 × 20 m in the upper and middle plots and 15 × 25 m in the lower plot. Eight species, with 379 stumps, within the survey areas were surveyed (Table 2).

The number of sprouting shoots per stump within each survey area was recorded in May, September and November 2000, May and November 2001, and May and November 2002. In order to estimate the sprout growth of a stump, the height of the dominant shoot of each stump was measured in May and November 2001 and May and November 2002.

Measurement of solar radiation

On 29 August and 2 September 2002, hemispherical photographs were taken at 47 points (16 in the upper plot, 16 in the middle plot, and 15 in the lower plot). The points were

Table 1 Summary of cutting plots and woody plants pre- and post-cutting

	Upper plot	Middle plot	Lower plot
Cutting area (m × m)	30 × 30	30 × 20	15 × 40
Slope orientation	N 16°E	N 46°E	N 45°E
Elevation (m)	203–214	176–190	144–168
Slope gradient (°)	17.0	28.0	27.0
Pre-cutting (Aug 1999)			
Species richness	18	16	21
Population density (*n*/ha)	7,789	4,717	5,500
Woody plants (DBH ≧1 cm)			
Trees: BA (m^2/ha)	*Chamaecyparis obtusa*: 40.12 *Pinus densiflora*: 1.53	*Chamaecyparis obtusa*: 37.66 *Pinus densiflora*: 0.93	*Chamaecyparis obtusa*: 19.26 *Quercus serrata*: 12.25
Shrubs: BA (m^2/ha)	*Eurya japonica*: 0.97 *Rhododendron reticulatum*: 0.85	*Eurya japonica*: 0.53 *Camellia japonica*: 0.46	*Camellia japonica*: 4.32 *Wisteria floribunda*: 0.19
Post-cutting (Jan 2000)			
Species richness	5	2	5
Population density (*n*/ha)	111	50	400
Remnant trees			
Species: *n*	*Lyonia ovalifolia* var. *elliptica*: 3 *Pinus densiflora*: 2 *Chamaecyparis obtusa*: 2 *Clethra barvinervis*: 2 *Acanthopanax sciadophylloides*: 1	*Chamaecyparis obtusa*: 2 *Pinus densiflora*: 1	*Quercus serrata*: 13 *Acanthopanax sciadophylloides*: 5 *Chamaecyparis obtusa*: 4 *Prunus grayana*: 1 *Clethra barvinervis*: 1

Table 2 Number and DBHs of stumps for each species before cutting

Species	Upper plot		Middle plot		Lower plot	
	n	DBH*	*n*	DBH*	*n*	DBH*
Eurya japonica	71	2.44 ± 0.14a	34	2.58 ± 0.16a	28	1.53 ± 0.19b
Camellia japonica	7	2.75 ± 0.87	10	2.53 ± 0.59a	77	4.41 ± 0.25b
Cleyera japonica	–	–	7	3.36 ± 0.70a	18	1.08 ± 0.16b
Pieris japonica	9	1.85 ± 0.32	–	–	–	–
Ilex pedunculosa	11	6.15 ± 0.74	–	–	–	–
Lyonia ovalifolia var. *elliptica*	16	2.99 ± 0.31a	7	1.81 ± 0.62b	–	–
Rhododendron reticulatum	68	1.88 ± 0.09a	14	2.23 ± 0.21b	–	–
Rhododendron macrosepalum	9	1.56 ± 0.13	–	–	–	–

Different letters indicate significant differences among the plots

* Mean ± SE

set at the centers of the 5 × 5 m quadrats into which each survey area was divided. Hemispherical photographs were taken 1.0 m above ground level in each quadrat using a Nikon Coolpix 995 with a fish-eye lens.

The photographs were analyzed using Gap Light Analyzer v.2.0 software (Frazer et al. 1999) to estimate the relative solar radiation from May to November. The radiation parameter to derive above-canopy solar radiation data was applied to modelled.

Statistical analyses

Relative solar radiation was compared among the plots using analysis of variance (ANOVA) and Tukey's HSD test. DBHs of the parent trees of each species were compared among the plots by the Mann–Whitney test with Bonferroni correction.

The percentages of sprouted stumps among the plots were tested for each species by the chi-squared test and Haberman's residual analysis. The timing of sprout initiation and the death of each species was analyzed in each plot by comparing the numbers of sprouting shoots between survey times using the Wilcoxon signed rank test for matched pairs with Bonferroni correction. The numbers of sprouting shoots in November 2001 were then compared by the Mann–Whitney test between the groups that had significantly decreased in 2002 and those that had not decreased to check whether a greater number of sprouting shoots in the previous year leads to a greater rate of death. The heights of the dominant shoots of each species were compared among the plots by the Mann–Whitney test with Bonferroni correction to see if sprout growth was different among the plots. The relationship between number of sprouting shoots and the height of the dominant shoot in November 2001 was studied by Spearman's rank correlation analysis.

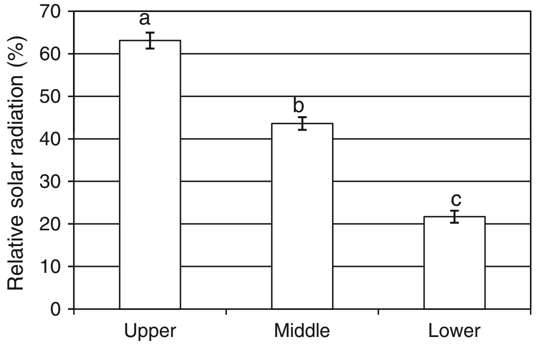

Fig. 2 Relative solar radiation from May to November in each plot, estimated from hemispherical photos. *Error bars* show standard errors. *Different letters* indicate significant differences among plots

Statistical significance was set at $p < 0.05$, and statistical analyses were performed using software (SPSS for Windows, version 13.0J; SPSS Inc. 2004).

Results

Relative solar radiation

Relative solar radiation in the upper plot was significantly higher than in the middle and lower plots (Fig. 2). It was also significantly higher in the middle plot than in the lower plot (Fig. 2).

DBH

For *E. japonica*, the mean DBH in the lower plot was significantly smaller than in the upper and middle plots (Table 2). The mean DBH of *Camellia japonica* was smaller in the middle plot than the lower plot, whereas that of *Cleyera japonica* Thunb. was larger in the middle plot than the lower plot (Table 2). The mean DBH of *Lyonia ovalifolia* (Wall.) Drude var. *elliptica* (Sieb. et Zucc.) Hand.-Mazz. was smaller in the middle plot than the upper plot, whereas *R. reticulatum* was larger in the middle plot than in the upper plot (Table 2).

Percentage of sprouted stumps

The percentage of sprouted stumps in May 2000 differed among species (Fig. 3), varying from 0% of *Camellia japonica* to 100% of *L. ovalifolia* var. *elliptica*. In September 2000, the percentage of sprouted stumps of each species increased to more than 80%, except for *E. japonica* in the lower plot (Fig. 3). In November 2002, there were some dead stumps that had once sprouted (Fig. 3).

For *E. japonica*, the actual percentages of sprouted stumps in the upper and middle plots were significantly higher than the equivalent percentage in the lower plot in November 2002 (Fig. 3).

Number of sprouting shoots

Almost all sprouting shoots initiated during 2000 (Fig. 4). While the two *Rhododendron* species in the upper plot continued to sprout shoots until May 2001, the number of shoots of *Ilex pedunculosa* Miq. in the upper plot and *Camellia japonica* in the lower plot had significantly decreased by May 2001 (Fig. 4). In 2002, the number of shoots of *E. japonica* in the upper and middle plots, *L. ovalifolia* var. *elliptica*, and the two *Rhododendron* species began to significantly decrease (Fig. 4). Species in which the number of sprouting shoots significantly decreased in 2002 had significantly more shoots in November 2001 than the other species (Fig. 5).

Height of the dominant shoot

The height of the dominant shoot increased from May 2001 to November 2002, varying from a 1.3-fold increase in height for *L. ovalifolia* var. *elliptica* to a 2.8-fold increase in height for *Cleyera japonica* in the lower plot (Fig. 6). In November 2002, the height of *E. japonica* in the lower plot was significantly lower than in the upper and middle plots, and the heights of *R. reticulatum* in the upper plot and *Cleyera japonica* in the lower plot were significantly lower than in the middle plot (Fig. 6).

E. japonica and *R. reticulatum* in the upper plot exhibited significant but weak positive correlations between the number of sprouting shoots and the height of the dominant shoot (Table 3). *E. japonica* in the middle plot exhibited significant moderately positive correlation, and *I. pedunculosa* presented significant strongly positive correlation (Table 3).

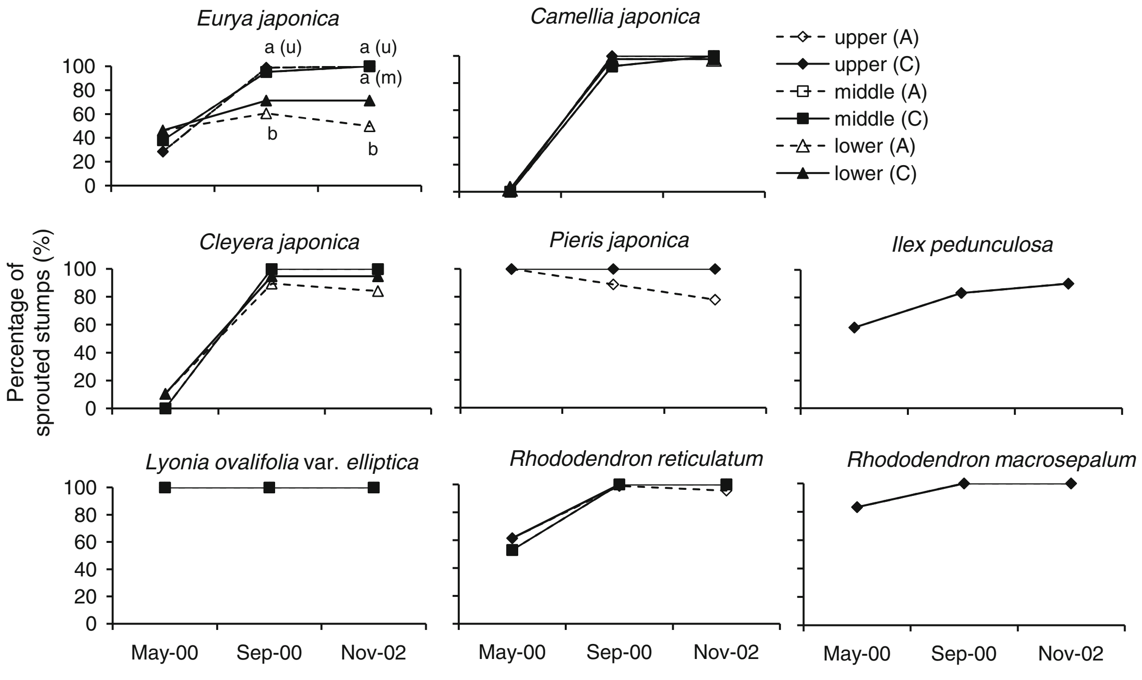

Fig. 3 Percentage of sprouted stumps of each species in May and September 2000 and November 2002. *Different letters* indicate significant differences among plots. *u* and *m* indicate upper plot and middle plot, respectively. *A* and *C* indicate the actual and cumulative percentages of sprouted stumps, respectively

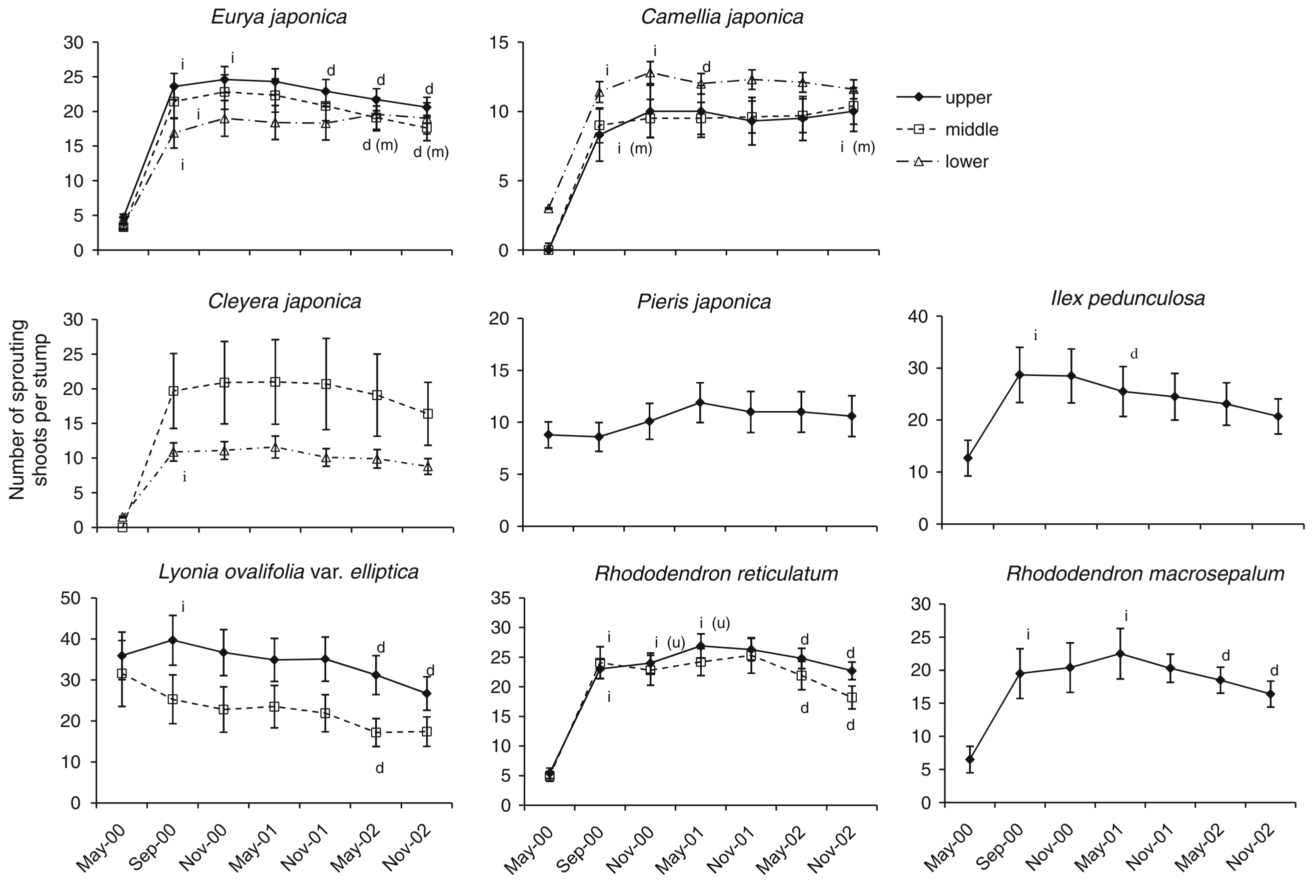

Fig. 4 Mean number of sprouting shoots per stump during the three years after cutting. *Error bars* show standard errors. *i* or *d* shows that the number of sprouting shoots significantly increased or decreased compared to the previous survey, respectively. *u* and *m* indicate upper plot and middle plot, respectively

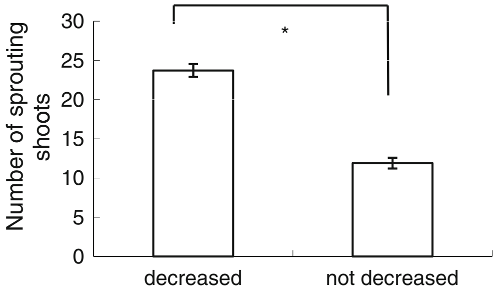

Fig. 5 Mean number of shoots that sprouted in November 2001 of species that significantly decreased (*left column*) or did not significantly decrease (*right column*) in 2002 in comparison to the previous survey. Each *error bar* shows the standard error of the mean. *Significant difference

Discussion

Sprout regeneration for three years after cutting

More than 80% of the stumps of each species, except *E. japonica* in the lower plot, had sprouted by September in the first year after cutting (Fig. 3). The number of sprouting shoots was substantially maximized in the first growing season after cutting, with the exception of two *Rhododendron* species in the upper plot that presented slight increases in the number of sprouting shoots until May 2001 (Fig. 4). Shima et al. (1989) also found that sprout initiation finished in the first year after cutting when cutting was conducted during the dormant season.

In the second or third year after cutting, the number of sprouting shoots began to decrease (Fig. 4). Species with more shoots showed significantly reduced sprout numbers (Fig. 5). Tanaka (1989) and Rydberg (2000) reported that the production of numerous sprouts led to a rapid self-thinning process. However, in the present study, it is not clear whether the decline in sprout number was caused by competition among shoots within a stump or by competition with other stumps and seedlings.

Some studies have found a negative correlation between sprout number and the mean (Katagiri 1986; Manabe et al. 1991) or maximum (Brown 1994) heights of species with numerous sprouts; however, *E. japonica*,

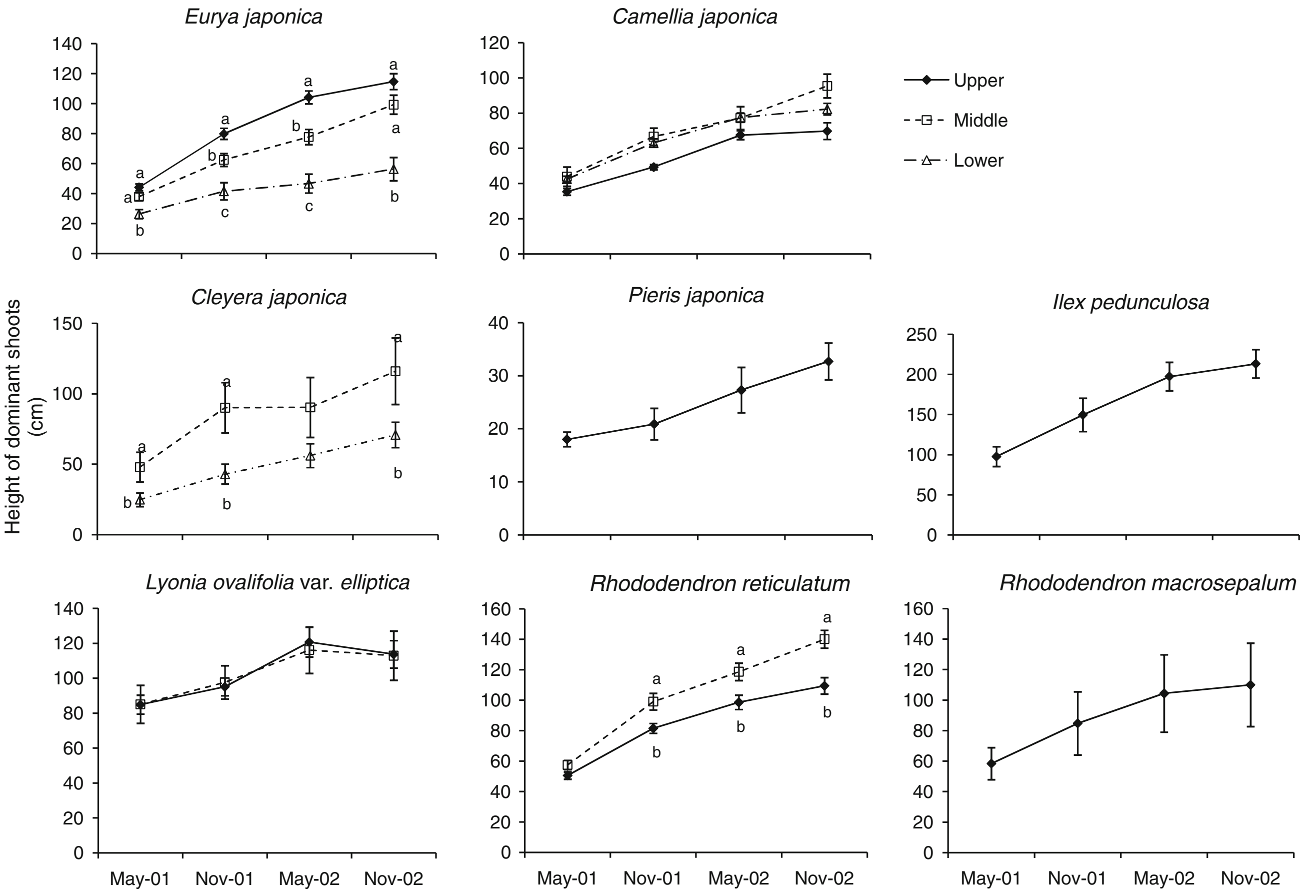

Fig. 6 Heights of dominant shoots (cm) from May 2001 to November 2002. *Error bars* show standard errors. *Different letters* indicate significant differences among plots

Table 3 Spearman's correlation coefficients between the number of sprouting shoots and the height of the dominant shoot in November 2001

Species	*n*	Correlation coefficients
Eurya japonica		
Upper	71	0.30*
Middle	34	0.48**
Lower	28	−0.05
Rhododendron reticulatum		
Upper	68	0.28*
Middle	14	0.12
Cleyera japonica		
Middle	7	0.74
Lower	18	−0.09
Lyonia ovalifolia var. *elliptica*	23	0.30
Ilex pedunculosa	11	0.86*
Camellia japonica	93	0.10

* $p < 0.05$

** $p < 0.01$

I. pedunculosa and *R. reticulatum* in our study site exhibited a significantly positive correlation between sprout number and the height of the dominant shoot (Table 3). One possible reason for this is that this study area had sufficient solar radiation, especially in the upper and middle plots (Fig. 2), so competition among shoots and/or competition with the other stumps and seedlings may not have been severe, and vigorous stumps may have many long shoots.

Species characteristics

Percentage of sprouted stumps

For *E. japonica*, an evergreen species, the percentage of sprouted stumps in the lower plot was significantly lower than in the upper and middle plots in November 2002 (Fig. 3). The main reason for this result was considered to be the mean DBH of *E. japonica* in the lower plot, which was significantly smaller than in the upper and middle plots (Table 2).

Sprout number

As reported, the sprout number varied with species (e.g., Mroz et al. 1985; Bellingham et al. 1994). *L. ovalifolia* var. *elliptica* had an average of more than 30 sprouts per stump at maximum, and *I. pedunculosa* had an average of 28 sprouts per stump at maximum (Fig. 4). Yamase (2000) reported that *L. ovalifolia* var. *elliptica* had many sprouts, and that the sprouts of both *L. ovalifolia* var. *elliptica* and *I. pedunculosa* grew rapidly. Since, in the present study, these species had a high percentage of sprouted stumps (Fig. 3) and grew rapidly (Fig. 6), sprouting regeneration seems an important strategy for their survival in highly managed forests, such as *satoyama*.

Height

For *E. japonica* and *Cleyera japonia*, dominant shoots were significantly lower in the lower plot than in the upper and/or middle plots in November 2002 (Fig. 6). Manabe et al. (1991) reported that the mean sprout length of *E. japonica* was shorter in darker conditions. In the present study, relative solar radiation was significantly lower in the lower plot than in the upper and middle plots (Fig. 2). However, since the mean DBHs of *E. japonica* and *Cleyera japonia* were significantly smaller in the lower plot than in the upper and/or middle plots (Table 2), it is not clear whether the growth increments of these species were dependent on the amount of photosynthesis or on the nutrient reserve in the stump.

Conclusion

We investigated the stump sprouting of eight species for three years after cutting a small area (0.06–0.09 ha). Cutting was conducted in three plots in a secondary forest that had been abandoned for 50 years in January 2000. The percentage of sprouted stumps and the number of sprouting shoots was substantially maximized in autumn in the first year. The mortality of the stumps that had sprouted by September 2000 was 1.7%, partially due to the high solar radiation in our plots. The number of sprouting shoots began to decrease in the second or third year. These results suggested that monitoring in autumn in the first year after cutting is likely to elucidate the maximum percentage of sprouted stumps and the maximum sprout number when cutting is conducted in the dormant season.

With respect to species characteristics, *E. japonica* had dead stumps and showed suppressed growth in the lower plot. *Cleyera japonica* was also suppressed growth in the lower plot. The sprouting abilities of these two species were deemed to be influenced by parent tree size, because the mean DBHs of these species in the lower plot were significantly smaller than those in the upper and/or middle plots. However, since relative solar radiation was also significantly lower in the lower plot than in the other plots, growth increments may be influenced by the amount of photosynthesis as well as the nutrient reserve in the stump.

Sprouting is an important component of the management of suburban secondary forests. It is desirable to manage sprouting appropriately based on an understanding of species characteristics, and to monitor sprout regeneration efficiently after cutting in order to provide feedback to aid management.

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