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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-term 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 suggested that autumn monitoring in the first year after cutting shows the maximum percentage of sprouted stumps and maximum sprout number, when cutting was conducted in the dormant season. For species characteristics, *Eurya japonica* showed low percentage of sprouted stumps in the lower plot, in which the mean DBH of the species was smaller than in the other plot. The sprout ability of *E. japonica* was deemed to be influenced by parent tree size. *Ilex pedunculosa* and *Lyonia ovalifolia* var. *elliptica* had high percentage of sprouted stumps and many sprouts. These species are useful for obtaining sprouting shoots, such as 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 (Washitani 2003); however, the 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 re-evaluated 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 selective logging of evergreen shrubs and bamboos (Yamazaki et al. 2000; Yamase et al. 2005), and clearing underbrush 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 the area of secondary forests 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 had been 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). In the early stage, sprouts generally grow earlier than seedlings and hinder seedlings from growing (Kennard et al. 2002). We reported about seedling regeneration after cutting (Imanishi et al. 2009). In the present study, we will 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, the factor that affects sprouting ability has 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) are reported as the factors that influence the sprouting ability and it was reported that sprouting ability differed 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 1581.8 mm, respectively (Kyoto University Forests 2002).

Three plots were set along a slope of the experimental forest to study sprouting ability and growth of woody plants under different light environments. The plots (upper, middle and lower) were 30 × 30 m, 20 × 30 m, 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 plots became a part of the experimental forest from a national forest in 1958. There is not an accurate data about the stand condition of the area before 1958. However, it was reported that the forest neighboring the area was cut clearly around 1925 and after that, dominated by Japanese red pine, *Pinus densiflora* Sieb. et Zucc. (Akai et al., 1986). Furthermore, it was assumed that the area might be also cut from 1920s to 1940s and the sapling of Hinoki, *Chamaecyparis obtusa* (Sieb. et Zucc.) Endl, which had naturally generated before cutting, might grow from the result of stem analyses of *C. obtusa* collected in the plots (Yanagimoto et al., 2000). After 1958, the area had been left under natural conditions. From 1970s, *P. densiflora* began to be killed by pine wilt disease and most *P. densiflora* died in early 1990s. This area is now dominated by *C. obtusa*.

To characterize the vegetation in the study area before cutting, we identified all trees taller than 1.3 m and measured 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, accounted for 88.7 % of total BA (Table 1). For shrub species, it 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). For shrub species, it 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, it 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). For shrub species, it 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 greater than 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 light environment by excluding 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. 8 species, 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 were 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 set at the center of 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 ver. 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 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 in each species by the chi-squared test and Haberman's residual analysis. The timing of sprout initiation and 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. Then, the numbers of sprouting shoots in November 2001 were compared by the Mann-Whitney test between the groups that had significantly decreased in 2002 and that had not decreased to confirm if greater number of sprouting shoots in the previous year leads to greater rate of death. Heights of 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 height of dominant shoots in November 2001 was studied by Spearman’s rank correlation analysis.

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). In the middle plot, it was significantly higher 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 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 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 other species (Fig. 5).

Height of the dominant shoot

The height of the dominant shoot increased from May 2001 to November 2002, varying from 1.3 times in *L. ovalifolia* var. *elliptica* to 2.8 times in *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 had significantly positive weak correlations between the number of sprouting shoots and the height of the dominant shoot (Table 3). *E. japonica* in the middle plot had significantly positive moderate correlation, and *I. pedunculosa* had significantly positive strong correlation (Table 3).

Discussion

Sprout regeneration for three years after cutting

More than 80 % of 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; the exception being two *Rhododendron* species in the upper plot in which shoots slightly increased 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, 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 numerous sprout productions led to a rapid self-thinning process. However, in the present study, it is not clear that the decline of sprout number was caused by competition among shoots within a stump or competition with the 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) height of species with numerous sprouts; however, *E. japonica*, *I. pedunculosa* and *R. reticulatum* in our study site had a significantly positive correlation between sprout number and the height of dominant shoots (Table 3). One possible reason is that because this study area had sufficient solar radiation, especially in the upper and middle plots (Fig. 2), competition among shoots and/or competition with the other stumps and seedlings might not be severe and vigorous stumps might 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 that the mean DBH of *E. japonica* in the lower plot was significantly smaller than in the upper and middle plots (Table 2).

Sprout number

As reported, 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 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 plot (Fig. 2). However, since the mean DBH of *E. japonica* and *Cleyera japonia* was significantly smaller in the lower plot than in the upper and/or middle plots (Table 2), it is not clear that the growth increment of these species is dependent on the amount of photosynthesis or the reserve nutrient in a stump.

Conclusion

We investigated the stump sprouting of 8 species for three years after cutting a small area (0.06–0.09 ha). Cutting was conducted in three plots in a 50-year abandoned secondary forest 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 stumps 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 maximum sprout number when cutting was conducted in the dormant season.

As 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 sprout ability of these two species was deemed to be influenced by parent tree size because the mean DBH of these species in the lower plot was significantly smaller than in the upper and/or middle plots. However, since relative solar radiation was also significantly lower in the lower plot than in the other plot, growth increment might be influenced by the amount of photosynthesis as well as the reserve nutrient in a stump.

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

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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≧1cm)	Trees	BA (m^2/ha)	Trees	BA (m^2/ha)	Trees	BA (m^2/ha)
		Chamaecyparis obtusa	40.12	*Chamaecyparis obtusa*	37.66	*Chamaecyparis obtusa*	19.26
		Pinus densiflora	1.53	*Pinus densiflora*	0.93	*Quercus serrata*	12.25
		Shrubs	BA (m^2/ha)	Shrubs	BA (m^2/ha)	Shrubs	BA (m^2/ha)
		Eurya japonica	0.97	*Eurya japonica*	0.53	*Camellia japonica*	4.32
		Rhododendron reticulatum	0.85	*Camellia japonica*	0.46	*Wisteria floribunda*	0.19
Post-cutting (Jan 2000)	Species richness	5		2		5	
	Population density (n/ha)	111		50		400	
	Remnant trees	Species	n	Species	n	Species	n
		Lyonia ovalifolia var. *elliptica*	3	*Chamaecyparis obtusa*	2	*Quercus serrata*	13
		Pinus densiflora	2	*Pinus densiflora*	1	*Acanthopanax sciadophylloides*	5
		Chamaecyparis obtusa	2			*Chamaecyparis obtusa*	4
		Clethra barvinervis	2			*Prunus grayana*	1
		Acanthopanax sciadophylloides	1			*Clethra barvinervis*	1

Table 2 Number and DBH of stumps of each species before the cutting

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

*: Mean ± SE

Different letters indicate significant differences among the plots.

Table 3 Spearman's correlation cofficients between number of sprouting shoots and height of 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	

*: $p < 0.05$

**: $p < 0.01$

Figure captions

Fig. 1 Study area and location of cutting plots

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.

Fig. 3 Percentage of sprouted stumps of each species in May and September 2000, 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 percentage of sprouted stumps, respectively.

Fig. 4 Mean number of sprouting shoots per stump during the 3 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 sprouting shoots in November 2001 of species that significantly decreased or not in 2002, comparison to the previous survey

Error bar shows standard error of the mean.

* significant difference.

Fig. 6 Height of dominant shoots (cm) from May 2001 to November 2002

Error bars show standard errors.

Different letters indicate significant differences among plots.

Fig.1

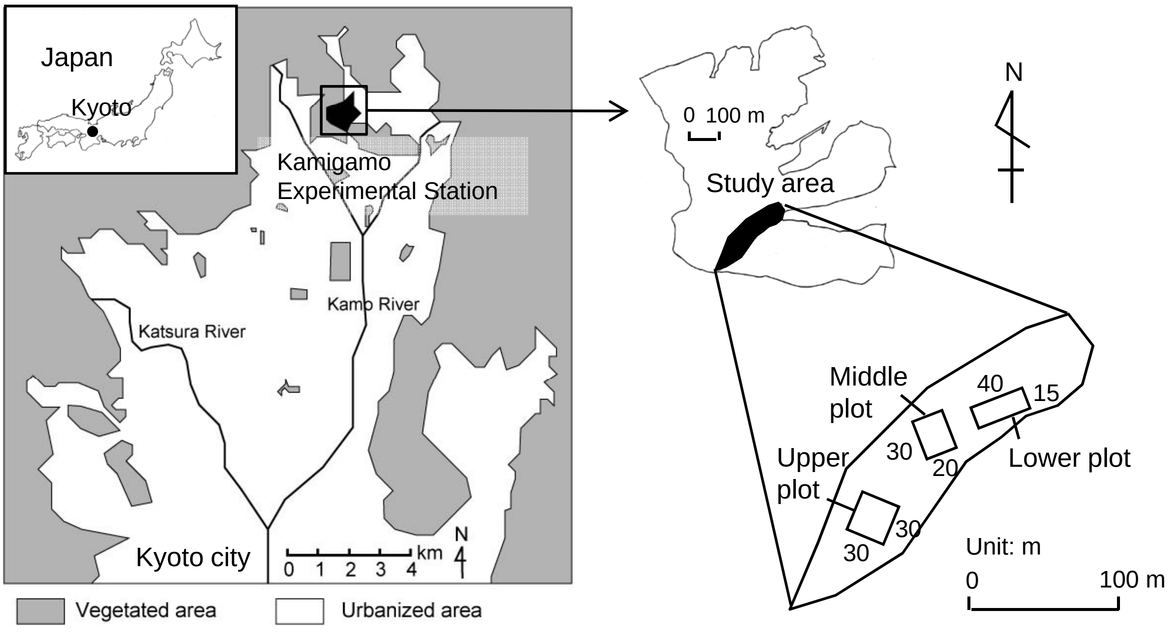
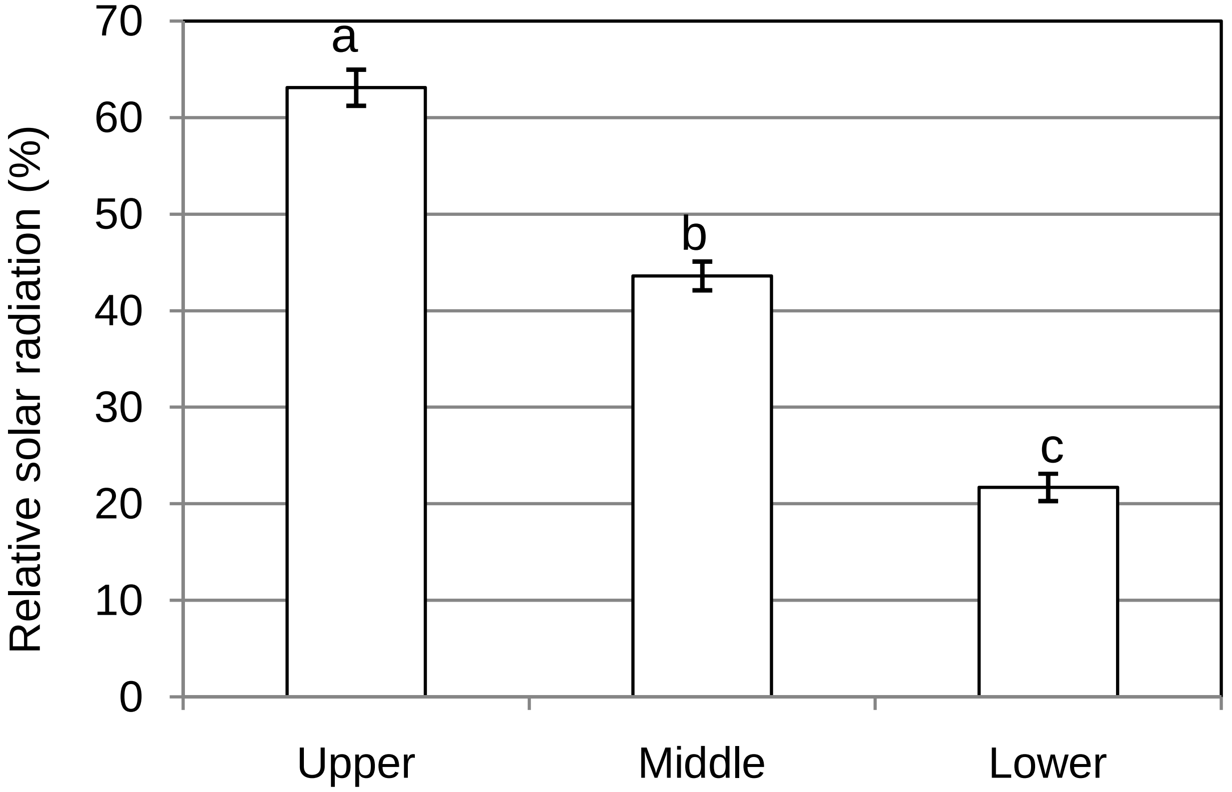

Japan
Kyoto
Kamigamo Experimental Station
Katsura River
Kamo River
Kyoto city
0 1 2 3 4 km
N
Vegetated area
Urbanized area
0 100 m
Study area
N
Middle plot
40
15
30
20
Lower plot
Upper plot
30
30
Unit: m
0
100 m

Fig.2



Relative solar radiation (%)
0
10
20
30
40
50
60
70
a
b
c
Upper
Middle
Lower

Fig.3

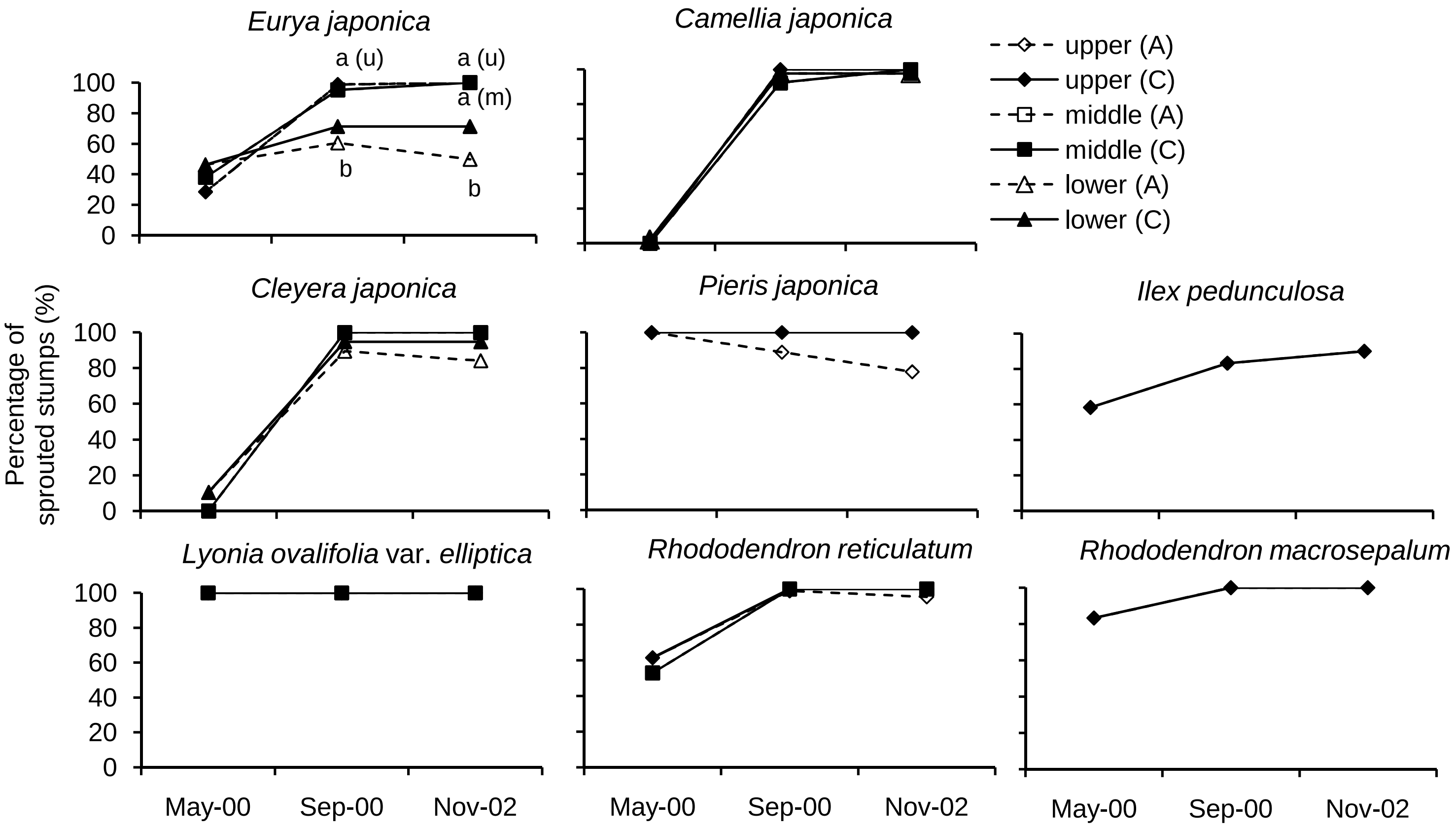

Eurya japonica
a (u)
a (u)
a (m)
b
b
Camellia japonica
upper (A)
upper (C)
middle (A)
middle (C)
lower (A)
lower (C)
Cleyera japonica
Pieris japonica
Ilex pedunculosa
Percentage of sprouted stumps (%)
Lyonia ovalifolia var. elliptica
Rhododendron reticulatum
Rhododendron macrosepalum
100
80
60
40
20
0
May-00
Sep-00
Nov-02

Fig.4

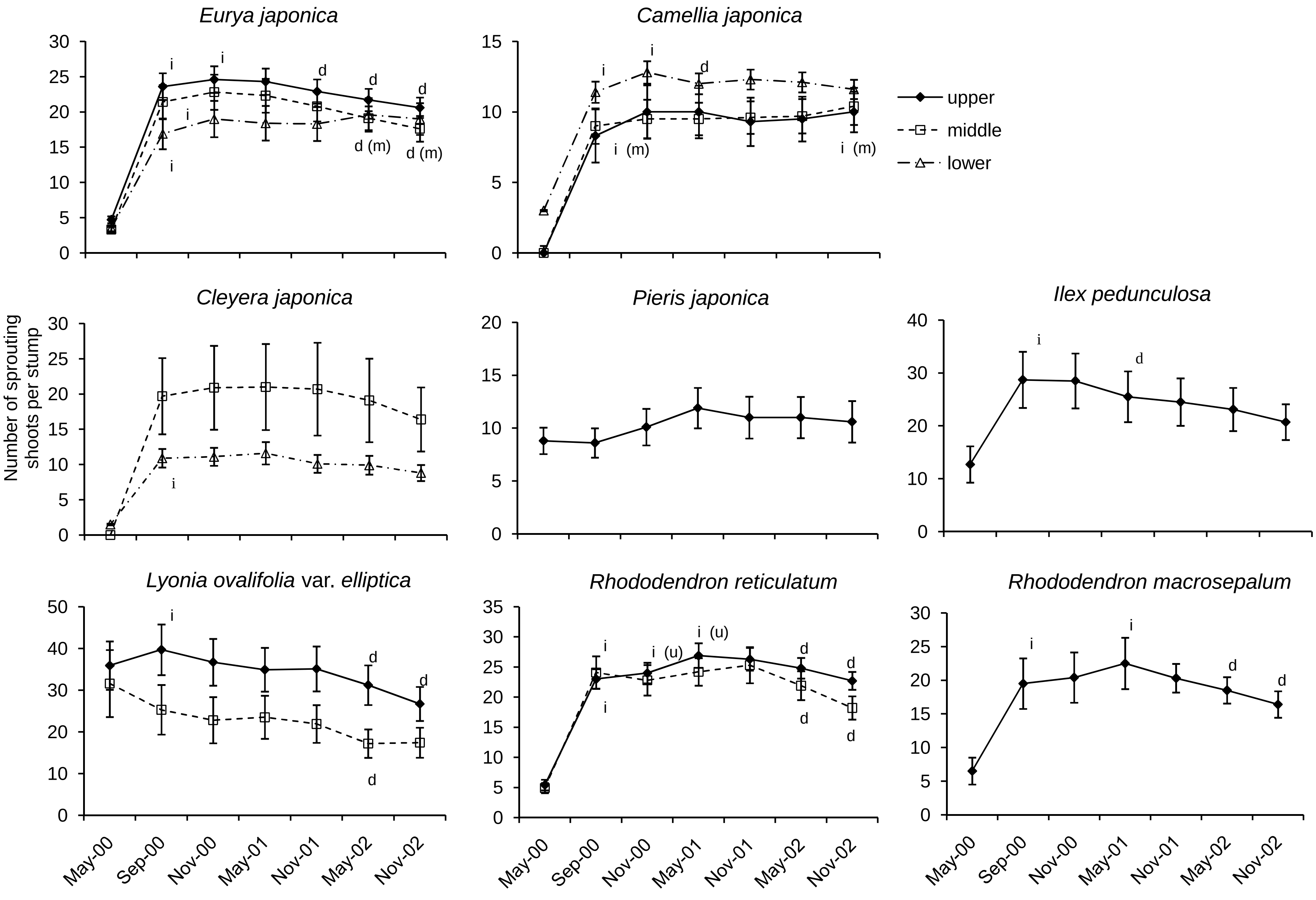

Eurya japonica
Camellia japonica
Cleyera japonica
Pieris japonica
Ilex pedunculosa
Lyonia ovalifolia var. elliptica
Rhododendron reticulatum
Rhododendron macrosepalum
Number of sprouting shoots per stump
upper
middle
lower
i
d
d (m)
i (m)
i (u)
May-00
Sep-00
Nov-00
May-01
Nov-01
May-02
Nov-02
0
5
10
15
20
25
30
35
40
50

Fig.5

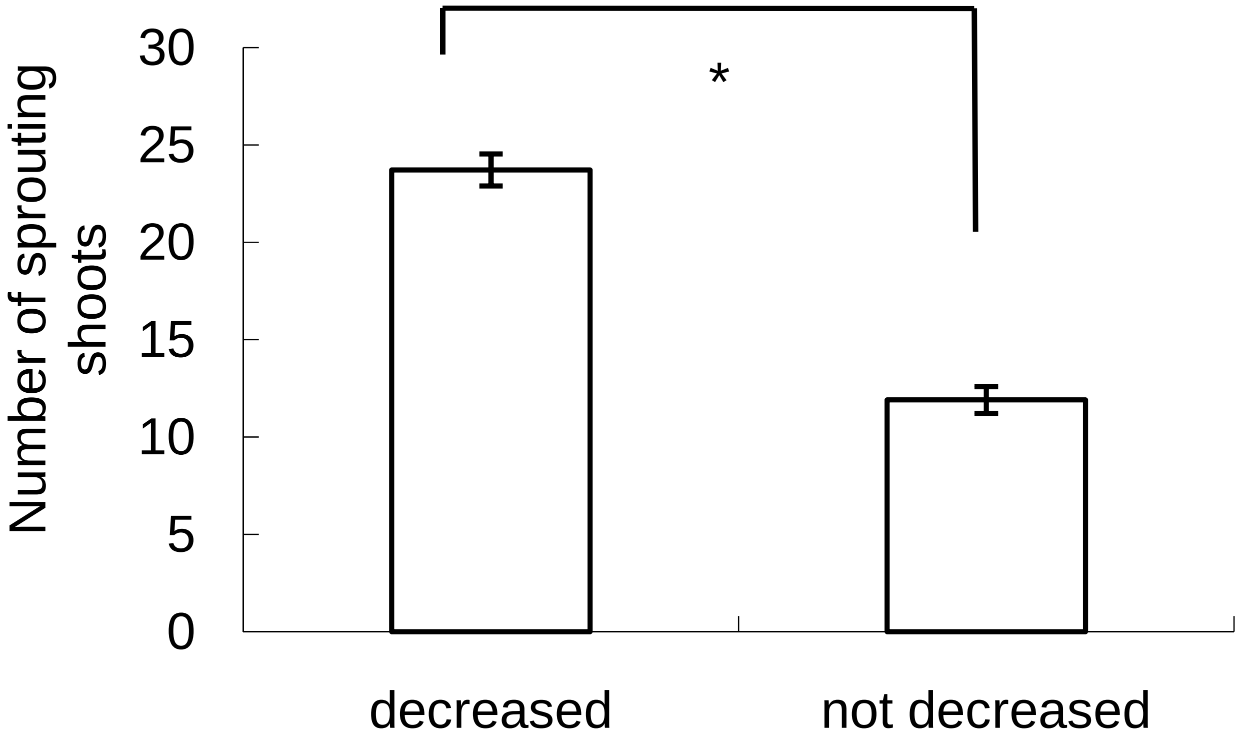
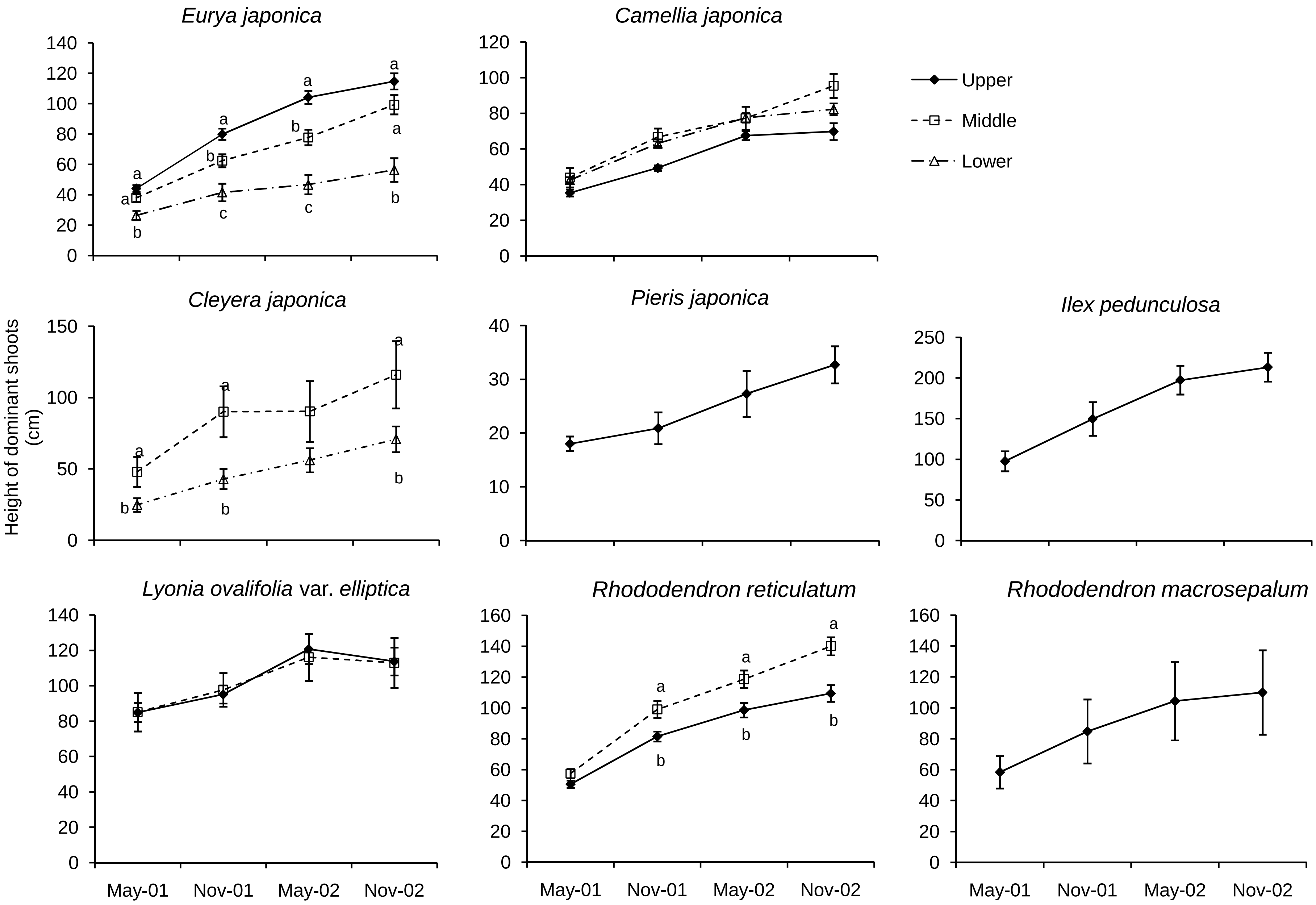

*
30
25
20
15
10
5
0
Number of sprouting shoots
decreased
not decreased

Fig.6


Eurya japonica
Camellia japonica
Upper
Middle
Lower
Cleyera japonica
Pieris japonica
Ilex pedunculosa
Lyonia ovalifolia var. elliptica
Rhododendron reticulatum
Rhododendron macrosepalum
Height of dominant shoots (cm)
0
20
40
60
80
100
120
140
160
10
30
50
150
200
250
a
b
c
May-01
Nov-01
May-02
Nov-02