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METHODS OF SUPPRESSING COLONIZING SEDGE TO HELP TO ESTABLISH TREE SEEDLINGS IN A NATURAL FOREST

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ABSTRACT: Dense bamboo grasses have delayed the growth of tree seedlings after the wind damage in a natural coniferous forest in deep mountains of Kiso District, Central Japan. After suppression treatment of the bamboo grass, a native sedge *Carex oxyandra* replaced them and made the growth of tree seedlings worse. The technique to suppress colonized *Carex oxyandra* is unknown, since this sedge has not ever been a harmful weed to be controlled. Thus, we established first experimental plots for suppressing *Carex oxyandra* by a herbicide, glyphosate potassium salt solution (Roundup Max load) by normal levels of dilution (control without herbicide, diluted to ×25, ×50 and ×100 volume with water) in May 2010. Next experimental plots with above-normal levels (diluted to ×100, ×200, ×400, ×800, ×1,600 and ×3,200) were established in June 2011. Coverage percentage, plant height of *Carex oxyandra* and tree seedlings were measured in each plot in autumn up to 2015. As a result, coverage and plant height of *Carex oxyandra* decreased obviously after a half year in all dilution levels, and the suppressing effect continued during 2 years in the lower dilution from ×25 to ×400. However, withered leaves formed a carpet-like thick mat, which remained several years and was suspected to restrict the germination and growth of tree seedlings. Consequently, the herbicide proved out effective to the sedge for 2 years, but some additional treatment is needed to secure the foundation space for tree seedlings within the mat of withered leaves.

Keywords: Carex oxyandra, Hebicide, Japanese cypress, Seedling, Natural forest

1. INTRODUCTION

In a natural coniferous forest deep in the mountains of Kiso District, central Japan, many old trees including Japanese cypress (*Chamaecyparis obtusa*, known as the famous timber brand ‘Kiso-Hinoki’) were blown down by typhoons in 1959 and 1961. Subsequently, dwarf bamboo (*Sasa* sp.), the dominant species in the forest floor, remained dense on the land surface. In addition, the wet podzolic soil formed by the cool pluvial climate in this district (an average annual temperature of 7°C and an annual precipitation of 3,500 mm at the closest meteorological station at an elevation of 1,300 m) was too humid and nutritionally poor for seedling establishment. Thus, after the wind damage due to the typhoons, the regeneration of trees in this district, especially in the higher-elevation areas, was prevented [1], [2].

In forestry of afforested land, suppressing forest-floor vegetation (dwarf bamboo or other shrubs in Japan) is important [3]. Weeds influence planted trees by interception of light and capture of nutrients and water [3]. In dwarf bamboo, suppression of the community is reported to enhance the species diversity of forest floor vegetation and the density of regenerated trees [4]. If the dwarf bamboo community falls under snow cover, it acts as a sliding surface and induces gliding of the snow cover and avalanches [5]. On the other hand, the dwarf bamboo community plays a significant role in retention of basic cations in the surface soil and prevention of soil acidification [6].

There are several methods for suppressing dwarf bamboo, such as weeding, application of herbicide, and grazing by herbivorous livestock [7]. Application of herbicide, i.e., chemical control, has been preferred because its effects last a long time.

Forest engineers and researchers have suppressed dwarf bamboo by herbicide application since 1967 in Miure Experimental Forest in the Kiso District to promote regeneration of the forest. However, unexpected colonization by *Carex oxyandra*, a native sedge indigenous to this area, was found after the withering of dwarf bamboo following herbicide treatment in higher-elevation areas in 2006. Afterward, almost no tree seedlings could be observed in the newly formed community, which seemed to indicate even poorer regeneration [8].

It has been reported that exposure to light improves germination of Japanese cypress seeds, with a typical germination percentage from 10 to 40%, which varies according to area and year [9]. However, the growth of seedlings requires a shaded habitat with a relative luminous intensity from 2 to 5% (germination is suspected to be impaired at a relative luminous intensity over 10%) [1], [2]. Japanese cypress seeds are reported to lose germination ability after 1 year in field conditions [9], and some seeds suffer predation by animals [10]. Therefore, the seeds must germinate rapidly in the absence of covering vegetation, and then the seedlings need to be shaded by recovered vegetation. The effect of herbicide suppressing dwarf bamboo is estimated to last about 3 years based on remote sensing [7], which is reasonable for the regeneration of Japanese cypress trees: seeds can germinate in a bright environment and then the seedlings can grow while shaded by recovered dwarf bamboo.

However, no method is yet known to suppress *Carex oxyandra*, because harmful colonizing by this sedge is uncommon. Considering the cost and labor for forest management, it is reasonable to employ a method similar to that of suppressing dwarf bamboo as a first approach.

In the present study, we examined the effect of herbicide at various dilution levels on suppressing the community of *Carex oxyandra* in the Miure Experimental Forest within the Kiso National Forest. The influence of suppressing the sedge on the establishment of Japanese cypress seedlings is also discussed.

2. METHODS

2.1 Study Site

The study site was located in forest compartment No. 2630 in the Miure Experimental Forest, the deepest area in the Kiso District, at an elevation of 1,500 m. At the site, most of the dwarf bamboo had already withered or disappeared, and the sedge formed a large-scale community on an almost level land surface (slightly inclined to the north).

2.2 Experiment 1: Herbicide at Normal Levels of Dilution

In May 2010, we applied a generally circulated herbicide, glyphosate potassium salt solution (brand name: Roundup Max load), to the sedge community at four levels of dilution (control without herbicide, and herbicide diluted with water to ×25, ×50 and ×100 by volume).

For each of the four treatments, an application zone of 15 m^2 (3 m ×5 m) involving three fixed-survey 1-m2 plots (1 m × 1 m) were designed, and two blocks were established. The experimental design was a randomized block method with one-way layout (4 dilution levels ×2 blocks = 8 application zones).

After application of herbicide, seeds of Japanese cypress were sown that had been harvested from surrounding trees in 2009. Sowing density was 6,000 seeds per zone (i.e., 400 seeds per m^2).

Coverage percentage and height of *Carex oxyandra* were measured yearly in fall (from mid-October to early November), from 2010 to 2015. In measuring the plant height, we measured 5 plants per plot randomly (or all plants if the number of surviving plants was less than 5) and averaged the values. We also observed and measured the thickness of the carpet-like mat of withered leaves that formed after the application of herbicide (Fig. 1). On the same day, the number of seedlings and height of each Japanese cypress seedling were measured.

Fig. 1 Suppression of *Carex oxyandra* community by herbicide. Top: inside (left) and outside the zone of herbicide application (right). Bottom: carpetlike thick mat of withered leaves. Both photographed in fall 2010, half a year after herbicide application.

2.3 Experiment 2: Herbicide at Above-normal Levels of Dilution

In June 2011, we applied the same herbicide to the sedge community at six more dilute levels (diluted with water at ×100, ×200, ×400, ×800, ×1,600 and ×3,200 by volume).

For each of the six levels, an application zone of 4 m^2 (2 m ×2 m) was established. Only one plot was established for each level, because we intended this experiment as a preliminary one to determine whether above-normal levels of dilution (i.e. lower concentrations of herbicide) would be effective. The plots were established in a community of *Carex oxyandra* near the experimental zones treated at normal dilution levels; the elevation, inclination and landform were similar to them.

Coverage percentage and height of *Carex oxyandra* were measured yearly in fall (from mid-October to early November), from 2010 to 2015.

3. RESULTS

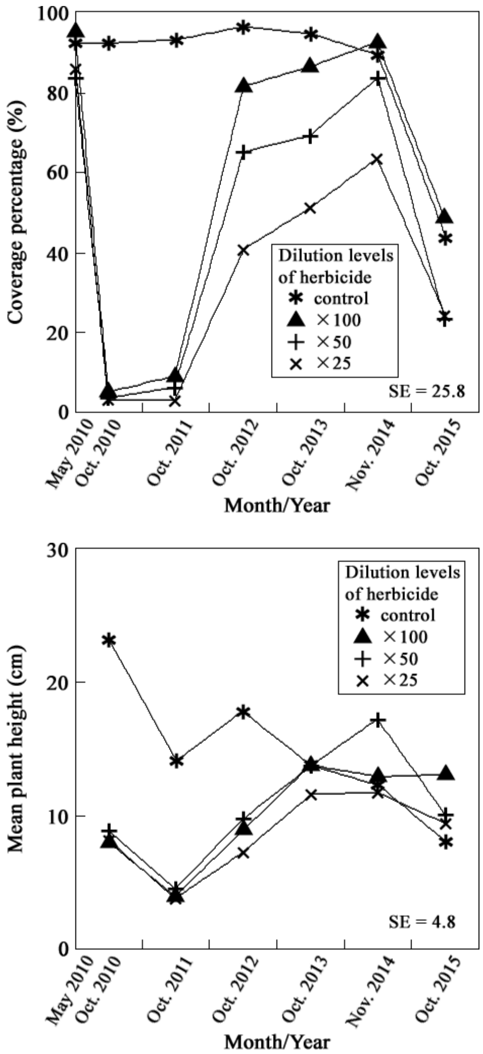

Fig. 2 Changes in *Carex oxyandra* growth after applying herbicide at normal levels of dilution

3.1 Experiment 1: Herbicide at Normal Levels of Dilution

Changes in *Carex oxyandra* growth after treatment are shown in Fig. 2. In fall 2010, the coverage percentage of the sedge decreased to less than 5%, and plant height also decreased by over 10 cm at dilution levels of ×25, ×50 and ×100. The differences from the control in coverage percentage and plant height were significant in fall 2010 and 2011 (Dunnett's test, $p<0.05$). However, after 2012, the sedge recovered and the differences from control became more obscure year by year, and in 2015 reached 60 to 90% of control coverage, and the height of plants reached 11 to 17 cm. However, the extent of sedge coverage had unexpectedly declined on a massive scale in all plots, involving even the control, in 2015.

Table 1 Mean number of Japanese cypress seedlings per m^2 after applying herbicide at normal levels of dilution to a *Carex oxyandra* community. Sowing density of Japanese cypress seeds was 400 seeds per m^2.

Levels	Year	Ranks of plant height (cm)						Total
		0-	2-	4-	6-	8-	10-	
control	2010							0.0
	2011							0.0
	2012							0.0
	2013							0.0
	2014							0.0
	2015							0.0
×100	2010	8.0	13.8	0.3				22.2
	2011		2.2	0.8	0.3			3.2
	2012	0.2	0.3	0.3	0.2	0.2	0.2	1.3
	2013		0.2					0.2
	2014			0.2	0.2	0.3		0.7
	2015			0.2				0.2
×50	2010	5.3	7.8					13.2
	2011		1.2	0.7	0.2	0.2		3.2
	2012		0.7	0.2	0.8	0.2		1.8
	2013			0.3			0.2	0.5
	2014				0.2			0.2
	2015							0.0
×25	2010	2.0	5.2	0.2				7.3
	2011	0.5	0.8	0.2				1.5
	2012		0.3	0.5	0.2			1.2
	2013			0.2				0.2
	2014							0.0
	2015							0.0

Table 1 demonstrates the growth of Japanese cypress seedlings in the experimental plots. In control plots, no seedlings were observed till 2015. In other plots, the lower the concentration of herbicide, the more germinated seedlings were found in fall 2010 (from 7.4 to 22.2 individuals per m^2). However, in 2011, the number of seedlings decreased markedly in each plot (to 1.5 to 3.2 individuals per m^2). In 2012, the number of seedlings also decreased (to 1.0 to 1.9 individuals per m^2), whereas the plants generally increased by approximately 2 cm in height. A gradual decrease in number of individuals and plant height occurred subsequently. Finally, in 2015, seedlings survived only in the plot treated at an herbicide dilution level of ×100 (0.4 individuals per m^2), in which some seedlings elongated by over 10 cm in height.

The thickness of the mat of withered *Carex oxyandra* leaves was 1.5-2.5 cm in each stand in fall 2010 (Fig. 1), half a year after herbicide application at dilutions of ×25, ×50 and ×100. The thickness decreased to 0.5-1.0 cm in 2011, 0.3-1.0 cm in 2012, and 0-0.5 cm in 2013. In 2014, the mat seemed to have decomposed and had disappeared from all stands.

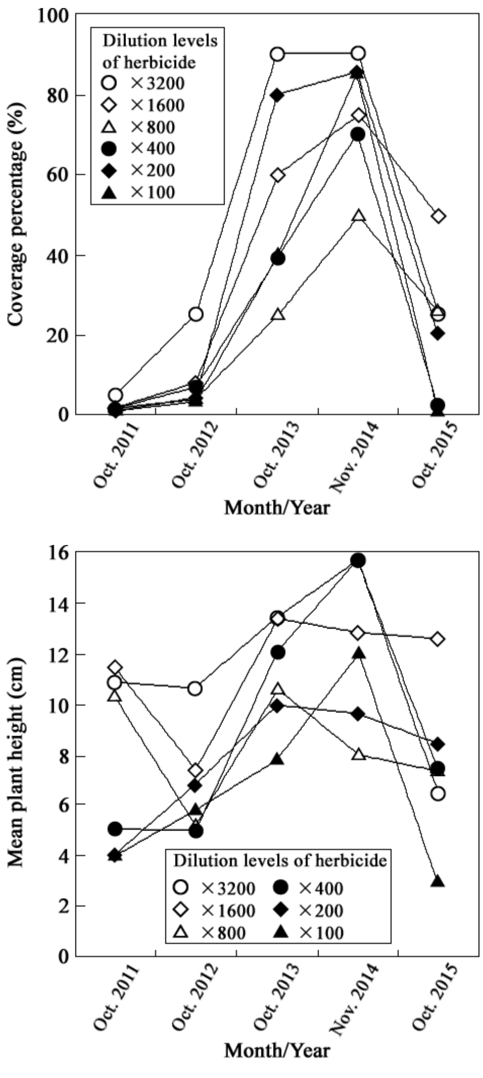

Fig. 3 Changes in *Carex oxyandra* growth after applying herbicide at above-normal levels of dilution

3.2 Experiment 2: Herbicide at Above-normal Levels of Dilution

Changes in *Carex oxyandra* growth after herbicide treatment are shown in Fig. 3. In fall 2011, the coverage percentage of the sedge drastically decreased to less than 5% even in the plot at the highest dilution of ×3,200. The coverage percentage slightly increased in 2012 in the plot treated at lower levels of concentration, and obviously recovered in general in 2013 (25 to 90%) and 2014 (50 to 90%). However, the coverage percentage suddenly decreased in 2015 (to 1 to 50%) due to unknown causes. The coverage percentage was significantly and negatively correlated with the level of dilution of herbicide in 2012 (Spearman's rank correlation, rs =-0.83, p<0.05), but no significant correlation was detected in 2013.

In contrast, plant height showed a complicated fluctuating pattern. During 2011 and 2012, it slightly increased or leveled off in the plots treated at ×100, ×200 and ×400, but decreased or leveled off in the plots at ×800, ×1,600 and ×3,200. The plant height increased in all plots during 2012 and 2013, but showed diverse changes in 2014. In 2015, the plant height had also unexpectedly declined on a massive scale in most plots. Plant height was significantly and negatively correlated with the level of dilution of herbicide in 2013 (Spearman's rank correlation, r_s =-0.93, p<0.05), but no significant correlation was detected in 2014.

4. DISCUSSION

4.1 Suppression of *Carex oxyandra*

In experiment 1, herbicide diluted to normal levels suppressed communities of *Carex oxyandra* in fall 2010 and 2011, i.e., for 2 years after treatment. After 3 years, the sedge steadily recovered and recolonized the area (Fig. 2).

Also in experiment 2, herbicide diluted to above-normal levels suppressed communities of the sedge in fall 2011 and for the whole of 2012, i.e., for 2 years after treatment. After 3 years, the sedge steadily recovered and recolonized the area (Fig. 3).

In both experiments 1 and 2, the plant height was significantly decreased by the herbicide for a limited period. However, the plant height seemed to fluctuate, which is probably attributable to the averaging process used in the study: if some slightly damaged large plant survived among small plants that regenerated after withering, the average plant height would be a middle value between them.

In a similar case of herbicide application to sedge in a natural field, it has been reported that *Carex kobomugi*, an invasive foreign species in coastal dunes, was reduced but not eliminated after repeated herbicide (Roundup) application [11]. In comparison, *Carex oxyandra* was suppressed for approximately two years by herbicide treatment, so careful choice of herbicide and examination of its effectiveness are needed according to the target plant species.

However, the reason for the sudden decrease in *Carex oxyandra* in 2015, which simultaneously occurred in both experiments 1 and 2, was not explainable in the present study. It might have been caused by some extraordinary meteorological event, such as an extremely heavy snow or a long period of when snow remained that is unusual in this area, because this sedge is an evergreen species. It might also have been caused by the innate life span of the community: some sedge species have been reported to decline spontaneously after forming dominant communities, without any treatment to suppress them [12]. Monitoring *Carex oxyandra* communities is also desirable, since it not known whether the community is transient or more permanent.

4.1 Suppression of *Carex oxyandra*

Seedlings of Japanese cypress were not successfully established after herbicide treatment of *Carex oxyandra* communities. At the early stage of establishment, neither germination of seeds nor survival for half a year past germination were satisfactory. Half a year after sowing 400 seeds per m^2, at most 22.2 individuals per m^2 (5.6%) could be counted in fall 2010 (Table 1). This percentage is inferior to the commonly expected germination percentage (from 10 to 40%) of Japanese cypress seeds [9].

One of the causes of inferior establishment is considered to be the thick mat of withered sedge leaves, which occupied the soil surface for about 3 years in the present study. Removing such a thick obstacle that interferes with root elongation into the soil is critical. Japanese cypress seeds are viable for a short period [9], so they cannot survive until the mat decomposes. It is probable that more seeds had germinated initially, but most died and had disappeared before our survey, which also shows the severity of the growth environment. A gradual decrease in the number of individuals and elongation in height after 2011 indicates a phenomenon like self-thinning, which could be caused by an inferior environment in the area of the withered sedge, rather than by competition among Japanese cypress seedlings. Therefore, withering of a *Carex oxyandra* community is insufficient to promote the establishment of seedlings.

Considering the inferior early growth of the tree seedlings, some additional treatment is needed to improve the growth environment. The most characteristic *Carex oxyandra* community after herbicide treatment is a thick, carpet-like mat of withered leaves. It has been reported that soil disturbance plays an important role in increasing the survival rate of viable seeds of Japanese cypress [10], and soil scarification to remove dwarf bamboo is effective in promoting regeneration of a forest (though the effect depends on the physiochemical features of the soil) [13].

5. CONCLUSION

In the present study, the effect of herbicide was examined at various dilution levels on suppressing the community of *Carex oxyandra* in the Miure Experimental Forest within the Kiso National Forest. Coverage and plant height of *Carex oxyandra* decreased obviously after a half year in all dilution levels, and the suppressing effect continued during 2 years in the lower dilution from ×25 to ×400. However, the influence of suppressing the sedge on the establishment of Japanese cypress seedlings is also confirmed: withered leaves formed a carpet-like thick mat, which remained several years and was suspected to restrict the germination and growth of tree seedlings.

Our results suggest this method to promote the establishment of trees if an established community of *Carex oxyandra* can be suppressed:

(a) Scratching treatment (to breaking up mats) should be done after the community of *Carex oxyandra* has been suppressed. Based on our observations, a small cutting tool like a hand dredge or sickle is sufficient to break up or remove the mat. Though the mat is thick just after withering (maximum thickness was 2.5 cm in the present study), it is not so hard as to be difficult to break, unlike dwarf bamboo.

(b) If the establishment of tree seedlings is not sufficient, herbicide should be reapplied to prevent the sedge from recolonizing.

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