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FACTORS INFLUENCING SEEDLING EMERGENCE AND SURVIVAL IN *CERCIDIPHYLLUM JAPONICUM*

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Abstract: *Cercidiphyllum japonicum* SIEB. et ZUCC. is found in riparian forests in Japan, but the seedlings rarely regenerate more than coexisting tree species. We investigated *C. japonicum* emergence and seedling survival in a nursery for 21 months. Bare soil, soil-with-litter, and gravel treatments and 3.0%, 10.9%, 22.7%, 60.1%, and 100% relative photosynthetic photon flux density (RPPFD) light conditions were tested. Seedling emergence depended on soil type and light conditions. Owing to *C. japonicum*'s small seed size, germinated seedlings could not penetrate the litter layer and became desiccated in gravel, but most seedlings emerged and survived in bare soil. These surviving seedlings needed quite bright light to germinate but not extreme light conditions. Initial mortality was high, but most of the seedlings that survived the first three months survived for the duration of the study, even under quite dark 10% RPPFD conditions. Current-year seedlings grew poorly under bright light conditions and rarely survived under the brightest light condition, when survival was probably negatively affected by desiccation. After one year, seedlings were able to use the higher light conditions more efficiently for growth. Such seedlings probably have a high chance of survival. Under low light conditions, both current- and second-year seedlings grew poorly. However, even small seedlings are likely to survive under low light conditions in a nursery, because the seedbed is level and nursery seedlings do not face all of the threats that are present in an actual forest.

Keywords: Germination test, Riparian forest, Seedling emergence, Seedling survivorship, Seedling size

INTRODUCTION

Cercidiphyllum japonicum SIEB. et ZUCC. is a common species in riparian forests in Japan, but saplings rarely outnumber coexisting *Fraxinus platypoda* OLIV. and *Pterocarya rhoifolia* SIEB. et ZUCC. (KUBO et al. 2000, 2001a,b, SAKIO et al. 2002). Forest disturbances of various types, magnitudes, and frequencies alter topographical and soil conditions in riparian forests (KOVALCHIK & CHITWOOD 1990, ITO & NAKAMURA 1994). Adaptive strategies in response to these environmental disturbances have been reported in tree species in Europe (KALLIOLA & PUHAKKA 1988), the United States (JOHNSON et al. 1976, WHITE 1979), New Zealand (DUNCAN 1993), and Japan (ANN & OSHIMA 1996, SAKIO 1997, SAKIO et al. 2002). KUBO et al. (2000) reported that many *C. japonicum* seedlings emerged from bare soil in riparian forests, but the presence of litter and gravel reduced emergence, and seedlings required relatively high light conditions to survive. Moreover, SEIWA & KIKUZAWA (1996) reported that litter cover inhibited the emergence of *C. japonicum*, because the small seedlings that developed from small seeds could not penetrate the litter layer.

These studies examined *C. japonicum* seedling germination in forests, where microsites feature unique combinations of influences. By examining germination under nursery conditions, where growing conditions can be controlled, we were able to clarify the factors that affect germination. In this study, we examined *C. japonicum* seed germination and survivorship under various soil and light conditions in a nursery in order to study the factors that limit the emergence and survival of *C. japonicum*. Furthermore, we discuss how seed size affects seedling survival and differences in *C. japonicum* seedling establishment in nursery and natural riparian forest settings.

MATERIAL, STUDY SITE AND METHODS

Material

Cercidiphyllum japonicum grows in riparian forests in Japan. Many *C. japonicum* are found in V-shaped valleys with steep slopes and various riparian disturbances (KUBO et al. 2001a). Individual stand density is usually low, and colonies are not distinct; saplings are seldom found within forests. Seedlings are most likely to regenerate in large-disturbance areas (SAKIO et al. 2002), but not where there is litter and gravel. Many seedlings emerge from bare soil on steep slopes, rocky ground, and fallen logs, but almost all seedlings die within a year (KUBO et al. 2000). *C. japonicum* maintains itself by producing numerous sprouts (KUBO et al. 2001b, SAKIO et al. 2002). The seeds are small; most are approximately 3 mm long and 2 mm wide, and they are only about 6 mm long including the wing. Current-year seedlings are also small (approximately 1.5 cm in height). It has been reported that some *C. japonicum* seeds retain germination ability for two years (TAKEUCHI 1975).

Seedbed conditions

Germination tests were conducted at the Forestry Research Branch Nursery, in the Saitama Prefecture Agriculture and Forestry Research Center (elevation 100 m), in Yorii, Saitama Prefecture, central Japan. On 7 May 1998, seedbeds for 15 different treatments were prepared; five light conditions were tested on three soil treatments. Three soil treatments were arranged randomly for each light condition in three replicates to reduce eventuality (Fig. 1). Light densities of 3%, 10.9%, 22.7%, 60.1%, and 100% RPPFD were created using muslin screens and assumed to represent various forest light conditions. The three soil treatments (bare soil, soil with litter, and gravel) represent forest soil conditions and optimal and/or inhibiting germination conditions for some species. Each seedbed was 1×1 m, but only the core 0.7× 0.7-m quadrat was used for the test. Five hundred *C. japonicum* seeds that had been harvested in the previous year were sown in each bed. Fine mineral soil was used to represent the bare-soil treatment. For the soil-with-litter treatment, natural forest litter (about 200 g/m^2 dry weight) collected from the Nakatsugawa riparian forest near Ohtaki Village was layered to a depth of about 5 cm on the bare soil; this equaled the amount of leaf litter that fell the previous year in the forest. For the gravel treatment, a 3-cm-deep layer of gravel 5–25 mm in diameter was laid on 10 cm of river sand. The gravel size was the average of that around

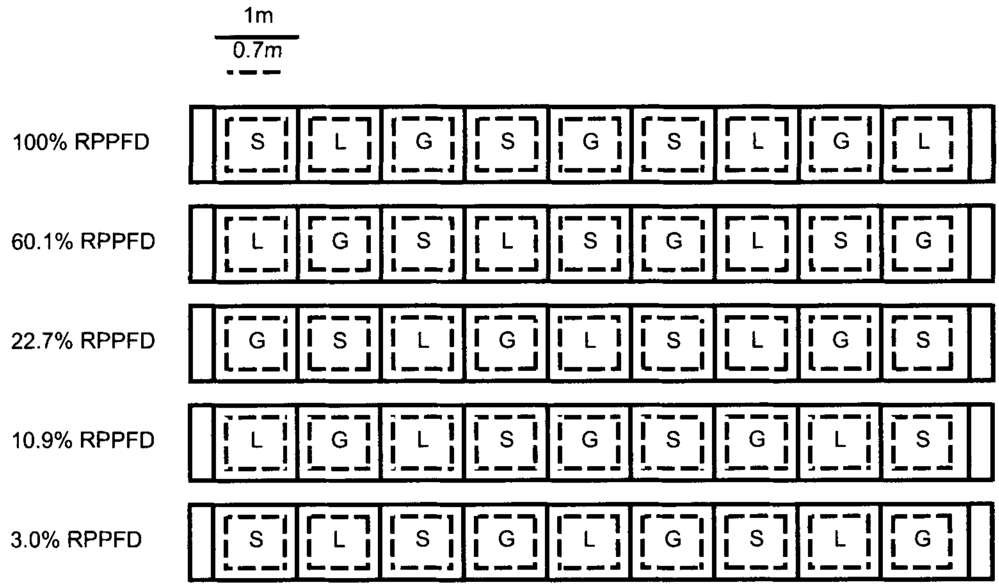

Fig. 1. Treatment layout within seedbeds in the nursery. Seedbeds of three soil treatments were arranged randomly in each light condition in three replicates. Each seedbed, illustrated by a solid line, was 1 × 1 m, but only the core 0.7 × 0.7-m quadrat, illustrated by the dashed line, was used for the test. RPPFD – relative photosynthetic photon flux density, S – bare soil, L – soil with litter, and G – gravel.

channel sites in a nearby forest. After sowing, each seedbed was covered with 24-mm-mesh netting to avoid litter loss. The seedbeds were then watered.

To test seed soundness, laboratory tests of *C. japonicum* germination were conducted on wet filter papers in laboratory dishes. One hundred *C. japonicum* seeds were sown on each dish in four replicates. The germination rate was 16.2% on average.

Measurement of seedling emergence and survivorship

Emerging and surviving *C. japonicum* seedlings were counted from 7 May 1998 to 25 January 2000. Seedlings were numbered and recorded within each seedbed upon emergence and death. In the spring following sowing (25 May 1999), surviving seedlings and newly emerged seedlings were counted. Final survival was determined on 25 January 2000. We did not measure the water conditions in the seedbeds.

Measurement of seedling height

The height of surviving seedlings, recorded on 20 November 1998, was used as an indicator of treatment effect. Seedlings were harvested on 25 January 2000, and the height and total dry weight of individual seedlings were recorded after drying them to a constant weight at 80 °C for 24 hours. Only seedlings that had emerged in 1998 were included in the dry-weight measurements.

RESULTS

Seedling emergence

The mean germination of *C. japonicum* seedlings for each light and soil treatment is shown in Table 1. Mean seedling emergence over all treatments was 0.92%, but emergence from the three soil treatments varied greatly. Emergence was greatest from the bare-soil treatment (2.6%) and minimal from the soils with litter (0.013%) and gravel (0.16%). Seedlings emerged under all light conditions, though at different rates. The significance of differences was tested by two-factor factorial analysis of variance (two-factor factorial ANOVA) and Fisher's protected least significant difference (PLSD). Significantly more seedlings emerged from bare soil with 10.9%, 22.7%, and 60.1% RPPFD than from soil-with-litter or gravel treatments, under all light intensities (two-factor factorial ANOVA, PLSD, $P < 0.05$). Moreover, for bare soil, emergence was significantly greater under moderate light conditions (22.7% and 60.1% RPPFD) than in the brighter or darker treatments (3.0%, 10.9%, and 100% RPPFD, two-factor factorial ANOVA, PLSD, $P < 0.05$).

Seedling survivorship

Most seedlings (98%) emerged within about one month of sowing (17 June 1998; Fig. 2). Many seedlings died within the first three months following emergence (20 August 1998). Subsequent losses were minimal; numbers barely changed from August 1998 until the trial ended on 25 January 2000. The greatest number of seedlings survived under moderate light conditions of 22.7% and 60.1% RPPFD. Although fewer seedlings survived under 10.9% RPPFD conditions, some did survive for the duration of the study. In contrast, all of the seedlings in the 3.0% RPPFD treatment died within three months of emergence. In the 100% RPPFD treatment, only three seedlings survived the first year, and only one survived through the end of the trial. All seedlings that emerged from the gravel treatment died within two months of emergence (14 July 1998), and only one seedling that emerged from soil with litter survived until the final harvest.

In the spring following initial sowing (25 May 1999), an additional four *C. japonicum* seedlings emerged from two replicates of bare soil: three seedlings under 10.9% RPPFD and one under 22.7% RPPFD (Fig. 2).

Seedling growth

Figure 3 shows the height of current-year *C. japonicum* seedlings on 20 November 1998 by light treatment, together with height and total dry weight of second-year seedlings harvested on 25 January 2000. Current-year seedlings grown under 22.7% RPPFD were significantly taller than seedlings grown under 60.1% RPPFD when measured at the end of the first growing season (ANOVA, PLSD $P < 0.05$). At the termination of the trial, second-year seedlings grown under 22.7% and 60.1% RPPFD were significantly taller than those grown under 10.9% RPPFD, but did not differ significantly from each other (ANOVA, PLSD $P < 0.05$). The Kruskal-Wallis test showed significant differences ($P < 0.05$) in the total dry weight of seedlings among the light conditions. The Scheffé test did not detect a significant

Table 1. Mean germination rate (%) of *Cercidiphyllum japonicum* seedling with data mean ± standard deviation. There are significant differences between a and b, c and d.

Relative photosynthetic photon flux density	3.0%	10.9%	22.7%	60.1%	100%	Average
The bare soil	0.67 ± 0.31^{d}	$1.73 \pm 0.50^{a,d}$	$4.67 \pm 0.42^{a,c}$	$4.87 \pm 2.50^{a,c}$	0.93 ± 0.23^{d}	2.57 ± 2.13
Soil with litter	0^{b}	0^{b}	0^{b}	0.07 ± 0.12^{b}	0^{b}	0.01 ± 0.05
Gravel	0.53 ± 0.76^{b}	0.27 ± 0.46^{b}	0^{b}	0^{b}	0^{b}	0.16 ± 0.40
Average	0.4 ± 0.51	0.67 ± 0.88	1.56 ± 2.34	1.64 ± 2.72	0.31 ± 0.48	0.92 ± 1.71

difference ($P < 0.05$), probably due to a lack of data, but the seedlings grown under higher light conditions weighed more.

DISCUSSION

Seedling emergence

Mean emergence was substantially lower in our nursery experiment (0.92%) than in the laboratory test (16.2%), probably because of restricting factors such as light or soil conditions (Table 1). Researchers have reported that *C. japonicum* seedlings emerge from bare soil even under low-light forest understories, but that few emerge from soil with litter or gravel in natural forests (SEIWA & KIKUZAWA 1996, KUBO et al. 2000). The small size of *C. japonicum* seeds probably accounts for these findings.

Research has also shown both negative and positive effects of litter on seedling emergence (GRIFFIN 1971, SYDES & GRIME 1981a,b). Litter has a negative effect on *C. japonicum* seedling emergence, because seedlings from such small seeds cannot penetrate the litter layer (SEIWA & KIKUZAWA 1996, FARMER 1997). Furthermore, small seeds may be less able to send deep roots into the soil, because their roots support minimal nutrient storage (FENNER 1985, YAMAMOTO 1987).

In our nursery study, seedlings in bare soil emerged under all light conditions, but moderate light densities appeared to be optimal (Table 1). Light is an important factor for seedling germination from dormancy. Moreover, germination depends on the light quality (PONS 1992, BEWLEY & BLACK 1994, FARMER 1997). Although light quality was not surveyed in our nursery, *C. japonicum* needed quite bright light to germinate. Fewer seedlings emerged, however, in the brightest light treatment of 100% RPPFD. We observed that the soil surface dried and hardened under this condition, suggesting that high light intensities may cause greater desiccation, which may inhibit seedling emergence. Bare soil was thus better for germination of the small seeds, but not when the light was too bright.

Furthermore, severe evaporation is more evident in gravel than in soil (KAYANE 1980). In our nursery, we observed that the more covered seedbeds had a higher water content. The reason that seedlings preferentially emerged under the two lowest light conditions from gravel (Fig. 2) may be because it was relatively easy for them to maintain moisture levels under these light conditions.

TAKEUCHI (1975) reported that some *C. japonicum* seeds retained germination ability for two years. Interestingly, in our study, only four seedlings emerged in the year following

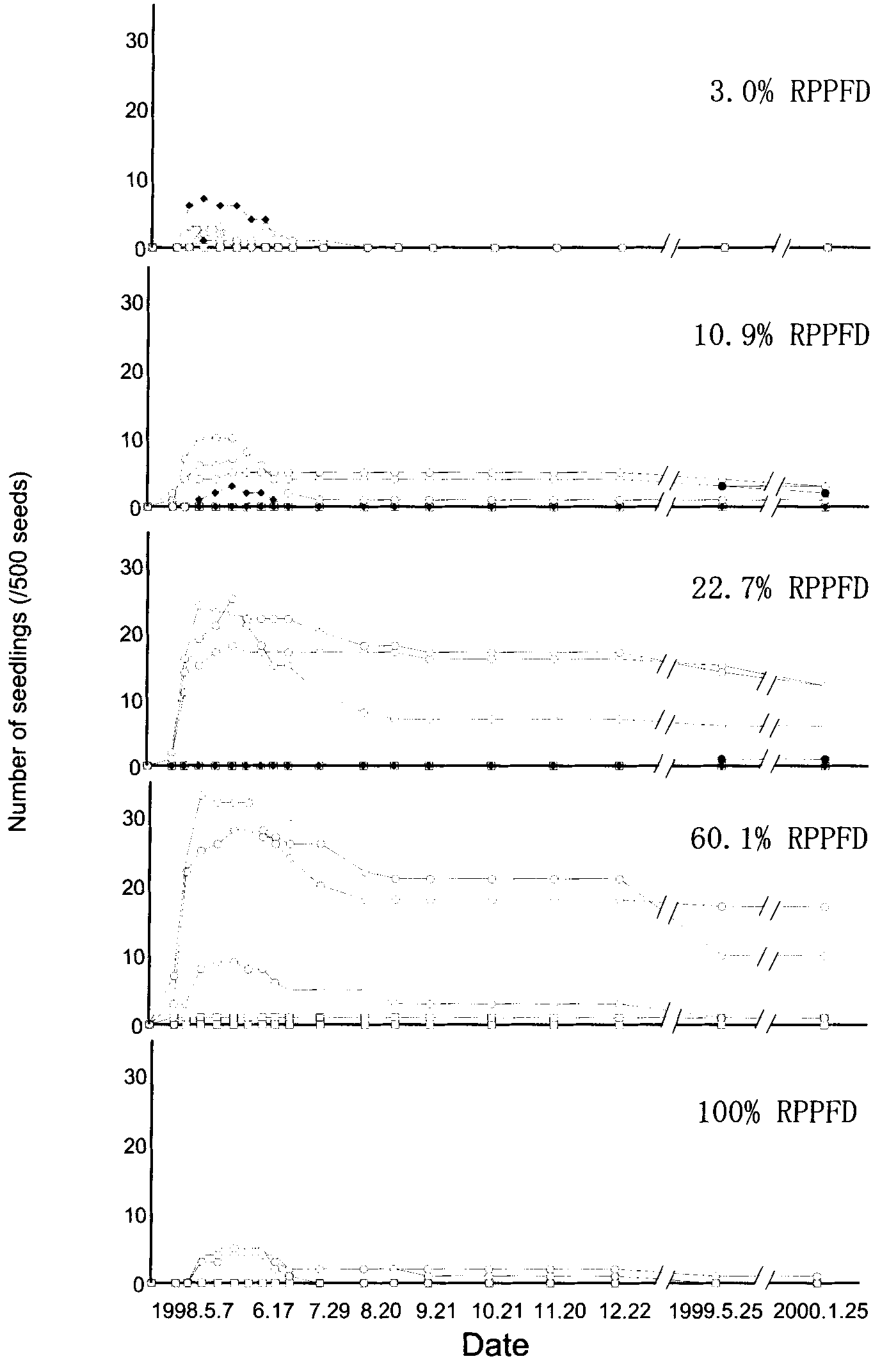

Fig. 2. Seedling germination and survival under experimental soil and light treatments over the seasons. ○ – seedlings from bare soil in 1998, □ – seedlings from soil with litter in 1998, ◆ – seedlings from gravel in 1998, ● – seedlings from bare soil that were new in 1999.

sowing (Fig. 2), suggesting that seed survival in soil beyond one season is uncommon. Moreover, SAKIO et al. (2002) pointed out that *C. japonicum* produces seeds annually and thus has consistent seed production.

In this study, many *C. japonicum* seedlings emerged from the bare-soil treatment. As litter is a limiting factor for small seeds and moisture evaporates readily from gravel, in natural riparian forests many *C. japonicum* seedlings emerge from bare soil but not from litter-covered soil and gravel. In contrast, the seedlings and saplings of coexisting tree species such as *Fraxinus platypoda* and *Pterocarya rhoifolia* are able to grow in litter-covered soil and gravel, because these species have much larger seeds (SATO 1988, KISANUKI et al. 1995, SAKIO 1997, KUBO et al. 2000). To minimize conflicts with major species, selection may have favored mineral soil conditions lacking litter as a suitable niche for *C. japonicum*.

Seedling survival

Many *C. japonicum* seedlings died within three months after emergence, but thereafter, few seedlings died, even under 10.9% RPPFD (Fig. 2). Many seedlings survived under moderate to high light conditions (22.7% and 60.1% RPPFD). Seedlings likely died due to lack of light under low light intensity or by desiccation under high light intensity. In the latter instance, all surviving seedlings were in bare soil, except one seedling in soil with litter. Previous research found that water deficiency caused by the absence of litter deters seedling survival (SEIWA & KIKUZAWA 1996). In our nursery tests, we also observed that seedlings appeared to shrivel and die under the brightest light condition (100% RPPFD).

Current-year seedlings grew poorly under moderately bright light (60.1% RPPFD), although many survived; second-year seedlings, however, made better use of the brighter light (Fig. 3). Under low light conditions, seedlings grew poorly throughout the study. Other studies have reported that whereas only a few current-year *C. japonicum* seedlings survived in large forest gaps (SEIWA & KIKUZAWA 1996), saplings were able to withstand substantial desiccation as well as shade stress (FUJIMOTO & MATANO 1994). Seedlings that survive their first year appear to be better able to tolerate bright light conditions in subsequent years.

In contrast to our nursery study, a study of natural riparian forests (KUBO et al. 2000) found that almost all seedlings died under all light conditions and in all seasons. Seedling death was especially high under dark conditions beneath canopy trees, where the relative light intensity was less than 10% (KUBO et al. 2000). Otherwise, factors controlling seedling survival seemed to differ by site. In natural riparian forests, *C. japonicum* seedlings sometimes occur on steep slopes that have been left bare by landslides or by surface-soil and litter erosion induced by heavy-rainfall. Under such conditions, *C. japonicum* seedlings might also be washed away by further rain and soil movement, and the lack of litter cover may result in the desiccation of young seedlings. Moreover, falling litter may damage young seedlings, especially in autumn. In contrast, our nursery seedbed was level, and there was no soil, water, or litter movement to impact seedling survival negatively. Although seedlings of some species die from damping off, this disease has not been found in *C. japonicum*.

A good place for a seed may not be a good place for seedling survival (FARMER 1997); forest emergence sites of *C. japonicum* seedlings may be too severe for seedling survival, especially when they are young. Tolerance of limiting factors in the forest, moreover, may

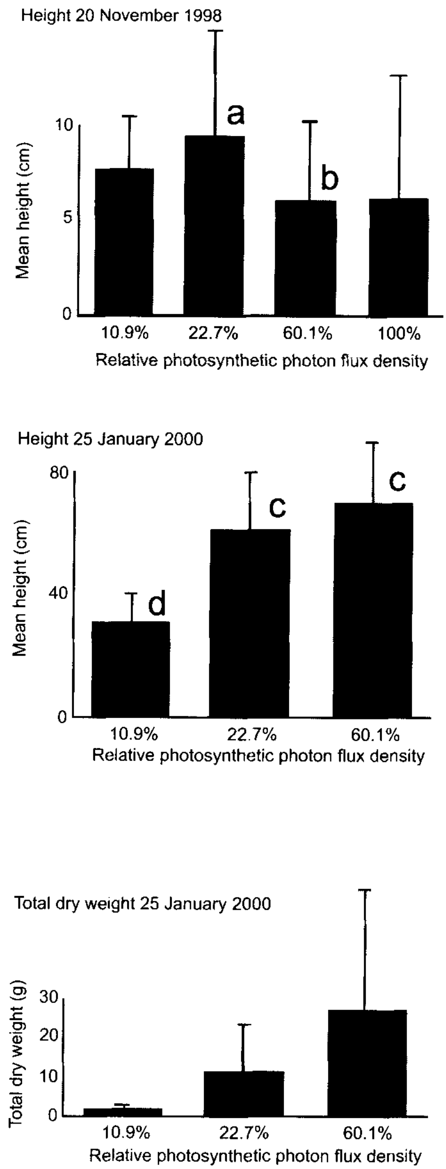

Fig. 3. Seedling height as influenced by light density. The upper and middle figures show the mean seedling height on 20 November 1998 and 25 January 2000, respectively; the lower figure shows total dry weight as determined on 25 January 2000. There were no seedlings in the 3.0% RPPFD treatment on 20 November 1998 or 25 January 2000 and only one seedling in the 100% RPPFD treatment on 25 January 2000. Vertical bars indicate standard deviation from the mean. Measurements were based only on seedlings that emerged in 1998, as new seedlings in 25 May 1999 were affected by factors other than the light conditions. Data on seedling height in the upper and middle figures were analyzed by ANOVA and PLSD techniques. Dry-weight data in the lower figure were analyzed by Kruskal-Wallis and Scheffé test techniques. The different letters (a to d) show significant differences in each figure.

thus be dependent on seedling size. Since the test seedbeds in our nursery were level and did not have limiting factors like those in actual forests, even small seedlings under low light conditions were able to survive.

We concluded from our nursery germination tests that *C. japonicum* seedlings have some shade tolerance, as seedlings survived light conditions of 10% RPPFD. However, *C. japonicum* seedling regeneration requires large soil disturbance (KUBO et al. 2001a, SAKIO et al. 2002). Large disturbances provide the bare-soil conditions that favor initial seedling emergence and the high light conditions that lead to efficient seedling growth. We also found that the few seedlings that survived their first year exhibited high survivability.

CONCLUSIONS

Seedling emergence of *C. japonicum* depended on soil and light conditions. Germinated seedlings could not penetrate a thick litter layer because of their small seed size, and they became desiccated in gravel. Most of the seedlings that emerged and survived were in bare soil. Moderate light was optimal for germination. Seedlings that survived the first three months after germination generally survived subsequently, even under somewhat dark conditions (10% RPPFD). The survival and growth of current-year seedlings under bright light conditions were limited, suggesting desiccation, although seedlings grew more efficiently under these conditions after one year. Under low light conditions, both current- and second-year seedlings grew poorly.

In natural riparian forests, many factors limit seedling survival, such as litter and the seedlings being washed away by rain or moving soil, in addition to extremes of light intensity, the primary factor that affected seedling survival in our nursery. Although small seedlings under low light conditions were able to survive in our nursery because of the level seedbed and the absence of disturbance factors, in forests almost all current-year seedlings die from low light conditions. Therefore, even though our seedlings exhibited some shade tolerance, larger seedlings under bright light conditions have a survival advantage. Because large disturbances in forests result in bare areas and bright light conditions, *C. japonicum* seedlings are well suited to these environments in a natural riparian forest.

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