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Effect of forest floor disturbance on seedling establishment of *Chamaecyparis lawsoniana*

DONALD B. ZOBEL
Department of Botany and Plant Pathology, Oregon State University, Corvallis, OR, U.S.A. 97331

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Native seeds of *Chamaecyparis lawsoniana* (A. Murr.) Parl. (Port-Orford-cedar) were sown on treated 1-m² plots in four natural stands in southwestern Oregon, U.S.A. Treatments, replicated four times per stand, were (1) control, with natural litter undisturbed, (2) litter removed, (3) litter removed and burned with ash replaced on plot, and (4) spaded after litter removal. Eighty-nine percent of germination occurred in early to mid-June. The spading treatment had the most germinants and the most survivors. Litter removal and burning treatments supported many fewer germinants, had the smallest seedlings, and had no survival after two growing seasons. Percentage survival of the few germinants in the control was as good as for the spading treatment, 5-6% after three summers. Although much natural seedling establishment may occur on natural litter, soil disturbance appears to greatly increase the rate of establishment. Litter removal alone does not increase establishment.

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Des graines à provenance indigène de *Chamaecyparis lawsoniana* (A. Murr.) Parl. ont été semées sur des places-échantillons de 1 m² dans quatre peuplements naturels dans le sud-ouest de l'Orégon, U.S.A. Les traitements, reproduits à quatre reprises au sein de chaque peuplement, étaient: (1) témoin, avec litière naturelle sans modification, (2) litière enlevée, brûlée et remise sous forme de cendres dans la place-échantillon et (4) sol labouré après enlèvement de la litière. La germination s'est effectuée à un taux de 89% du début à la mi-juin. Le bêchage du sol s'est avéré le traitement qui a donné les meilleurs résultats quant à la germination et au nombre de plants qui ont survécu. Les traitements effectués par enlèvement de la litière et réduction de celle-ci en cendres ont généré beaucoup moins de plantules; ceux-ci ont aussi donné les plus petits semis en plus d'aboutir à une survivance nulle après deux saisons de croissance. Le pourcentage de survie des quelques plantules chez les places-échantillons témoins était aussi bon que celui des traitements par sol labouré, c'est-à-dire 5 à 6% après trois étés. Quoique l'implantation des semis puisse s'effectuer sur litière naturelle, la modification physique du sol paraît grandement augmenter le taux d'implantation. L'enlèvement de la litière seule n'augmente pas cette capacité d'implantation.

[Traduit par le journal]

Introduction

Chamaecyparis lawsoniana (A. Murr.) Parl. (Port-Orford-cedar) has a limited range in Oregon and California, U.S.A. Within that range, it occupies sites from coastal sand dunes to subalpine forest, growing on a variety of soils and with many different tree species. It is also versatile in a seral sense: in most communities it acts as a pioneer, although somewhat slow growing (Hawk 1977), and regenerates well from seed in both clearcuts and partial cuts (James and Hayes 1954). It reproduces sufficiently in closed forest to remain a part, if not a dominant, of second or later generations (Hawk 1977). Its shade tolerance (Baker 1945; Zobel and Hawk 1980) and fire tolerance apparently have allowed it to increase with a regime of periodic fires which killed young trees but not the majority of the overstory.

Age-size analysis indicates that reproduction of *C. lawsoniana* is continuing without fire. A consid-

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TABLE 1. Site characteristics

Site name	Abbreviation	Elevation (m)	Vegetation zone	Stand age (years)	Stand basal area (m^2/ha)	Mean temperature (°C)				Total natural germinable seedfall 1975–1976 (no. m^{-2})
						Air		Soil		
						Warmest month	Coldest month	Warmest month	Coldest month	
Coos Co. Forest	CCF	70	Pisi	65	59	13.3	5.4	13.2	6.8	63
Coquille River Falls	CRF	520	Tshe	450+	69	14.6	3.6	12.2	4.0	14
Agness Pass	AGN	850	ME	110	29	14.5	2.0	13.5	3.6	<5
Game Lake	GAL	1280	Abco	170	78	14.2	1.1	12.3	N.A.	16

NOTE: Vegetation zones (Franklin and Dyrness 1973) are Pisi, *Picea sitchensis*; Tshe, *Tsuga heterophylla*; ME, mixed evergreen; and Abco, *Abies concolor*. Temperature data are for September 1974 to September 1976.

erable spread in age occurs among the many seedlings and saplings present in most stands (G. M. Hawk and D. B. Zobel, unpublished data). The type of seedbed sometimes controls success of regeneration for other species of *Chamaecyparis*; for at least two species, litter removal will increase establishment (Little 1950; Sato 1974).

An experimental approach was used to help clarify whether forest floor disturbance aids reproduction of *C. lawsoniana*. Native seeds were sown on four different substrates in natural forest: the undisturbed forest floor; litter removed (as might occur by erosion by water); litter burned; and ground cultivated after litter removal (to simulate a windthrow mound, a landslide, or deposition from erosion). This paper describes seedling establishment, survival, and growth for the first three growing seasons in these conditions.

Methods

Study sites

Four contrasting sites were chosen in southwestern Oregon, U.S.A. (Table 1, Fig. 1): (1) a dense young coastal forest in the *Picea-Chamaecyparis*/Sandstone Community (communities are described by Hawk (1977)), Coos County Forest (CCF); (2) an old-growth forest at low elevations in the southern coast range, *Tsuga-Chamaecyparis/Polystichum-Oxalis* community, Coquille River Falls Research Natural Area (CRF); (3) a relatively young mid-elevation forest in the *Chamaecyparis/Lithocarpus* community, Agness Pass (AGN); and (4) a high elevation *Abies concolor-Chamaecyparis*/herb forest of mod-

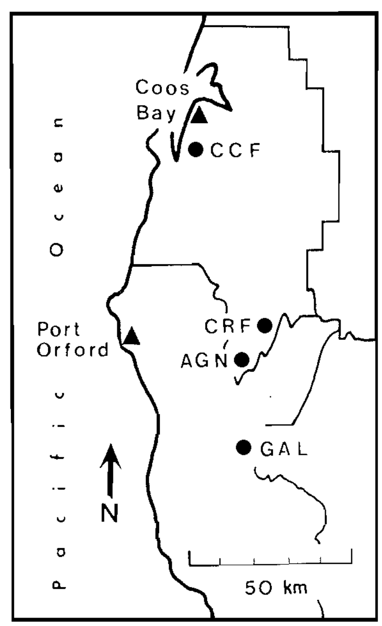

FIG. 1. The study sites in southwestern Oregon, U.S.A. (circles). Solid lines outline Coos (north) and Curry County. Latitude of Port Orford is 42°45′ N. Site characteristics are presented in Table 1. CCF, Coos County Forest; CRF, Coquille River Falls; AGN, Agness Pass; GAL, Game Lake.

TABLE 2. Periodic germination, survival of early June germinants, and rainfall at nearby weather stations

	Rainfall (cm)			% of total germinations occurring	% of June germinants surviving at end of period
Period	North Bend	Powers	Illahe		
Early May to late May	1.9	2.0	2.9	0	—
Late May to mid-June	0.6	0.4	0.4	89	100
Mid-June to mid-July	2.2	0.6	1.6	9	56
Mid-July to mid-August	4.4	5.5	6.3	1	38
Mid-August to mid-September	2.5	3.0	2.6	1	33

erate age, Game Lake (GAL). The latter three sites have considerable natural reproduction of *Chamaecyparis*; Coos County Forest has none. Coos County Forest, Coquille River Falls and Game Lake are on productive soils, the former two on Eocene sediments and the latter on dioritic material with a mixture of serpentine washed from a nearby ridge. Agness Pass is on serpentine, where trees are smaller and the canopy more open. Understory light was low in the stands at Coos County Forest and Coquille River Falls (<1% full sun); it was 2% at Game Lake and 8% at Agness Pass. Light measurements were made in areas surrounding the plots but not the plots themselves (Zobel and Hawk 1980). At all sites, simultaneously with this study, air and soil temperature, plant moisture stress (Zobel and Hawk 1980), and seedfall (Zobel 1979) were monitored.

At each site, four areas were chosen for replication of the study. Each area was relatively homogeneous with respect to microtopography, soil, and vegetation, with conditions which appeared to be feasible for establishment of conifer seedlings, given an appropriate substrate. Although the four areas in each site differed somewhat, all represented typical aspects of the local forest community. In each area, four 1-m^2 plots were established, with at least a 30-cm buffer between, avoiding trees, logs, and large rocks. Treatments were assigned randomly to plots within each replication and carried out in August, 1975: (1) "control" (C) was left untouched; (2) "litter removal" (R) had all organic matter of identifiable origin ("L" and "F" layers) removed from the plot; (3) "litter removal and burn" (B) was like R, but all the litter was burned in incinerators away from the site and the ash from each plot then spread evenly over it; (4) "litter removal and spade" (S) was like R, but with the soil thoroughly cultivated to 20 cm deep. All living plants rooted in the plots (except C) were removed at ground level, and all roots, rhizomes, and large stones were removed from S plots.

Seed collection and planting

Seeds were collected from trees or squirrel-cut branches in September, from populations coextensive with the study sites and growing under similar conditions, for placement on the native site. All collections were within 1.5 km of the site except Coquille River Falls, where about half the seed was from several kilometres away in the same river valley. Seed was extracted in the laboratory, weighed, and germination tests run. A weighed seed lot, calculated to give 50 germinations per plot, was evenly spread over the middle 90 cm × 90 cm of each plot on 18-19 October, 1975. Sowing occurred after the fall rains began and was during the major peak of seedfall (Zobel 1979). This natural seedfall (Table 1) supplemented the seed applied, doubling the supply at Coos County Forest.

Observations

Plots were observed monthly from February to late September, 1976. As they appeared, all conifer seedlings were mapped and their condition indicated. Height above the cotyledons was measured to the nearest millimetre. Apparent cause of death was recorded when dead seedlings were located, but most simply disappeared. Survivors were measured again in late August, 1977, and October, 1978, along with any new 1977-1978 seedlings.

Results and discussion

No germinations were observed through early June. Between then and 18 - 20 June, 89% of total germinations occurred (Table 2), from 71% at Game Lake to 95% at Coos County Forest. A few seeds germinated after 18 August (Table 2) at Agness Pass and Game Lake, the higher elevation sites. Late germinants survived relatively well; in September, 49% of June germinants were alive in the spaded plots compared with 67% of those from July and 33% of those from August. A wet August (Table 2) with 3.5 times the normal precipitation probably aided survival of the late germinants.

Other conifer seed from natural seedfall germinated as late as did that of *Chamaecyparis*. Eighty-five percent of *Tsuga heterophylla* (Raf.) Sarg. (western hemlock) at Coquille River Falls and Coos County Forest germinated during the first 3 weeks of June. In contrast, in clearcuts at 600-900 m in the Oregon Cascades, germination of *Tsuga* reaches 85% before mid-May (Gashwiler 1971). Although the dates may vary from year to year, it seems likely that late germination is characteristic of the coastal region where this study was done. Temperature seems the most probable trigger for the burst of germination in June. Mean temperatures did not suggest any particular level of temperature being reached simultaneously in early to mid-June. However, from 6 to 21 June, minimum air temperatures at 1 m usually exceeded 5°C at all sites, the first period with minima this high which lasted

TABLE 3. Total number of germinations and percent survival in September 1976, August 1977, and October 1978, by sites within treatments

			Survival (%)		
Treatment	Site	Total germinants 1976	September 1976	August 1977	October 1978
Control (C)	CCF	7	0	0	0
	CRF	5	60	40	20
	AGN	2	50	0	0
	GAL	3	0	0	0
	Total	17	24	12	6
Burned litter (B)	CCF	66	8	0	—
	CRF	1	0	0	
	AGN	12	17	0	
	GAL	10	30	0	
	Total	89	11	0	
Removed litter (R)	CCF	95	13	0	—
	CRF	4	25	0	
	AGN	6	17	0	
	GAL	13	31	0	
	Total	118	15	0	
Spaded (S)	CCF	116	37	6	0
	CRF	22	50	10	5
	AGN	78	68	26	13
	GAL	54	61	22	6
	Total	270	52	15	5

longer than 2-3 days. This apparently was the first warm period long enough to support seedling emergence, although a possible requirement for long photoperiod cannot be ruled out.

Overall germination was very poor, from 34% of the expected 50 per square metre in treatment S to 2% in the control. Despite the reported dislike of rodents for *C. lawsoniana* seed (Moore 1940), animals do harvest cones in the forests studied and may have eaten seed from the plots. Some of the

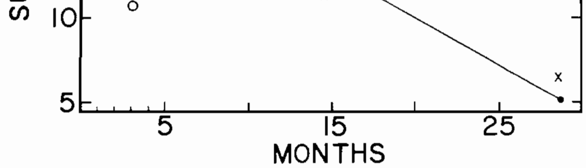

FIG. 2. Decline of percent survival of 1976 germinants with time since mid-June based on data from all sites. Note the log scale for survival. Treatments are S, spading after litter removal; C, control; B, litter burned; R, litter removal.

poor response to R and B treatments may be due to seeds washing off the steeper plots. C and S provided a rougher surface to retain and hide them. Plots at Game Lake had a hard surface which was probably difficult for root penetration. At Coquille River Falls, elk tracks harbored two-thirds of the germinants in one plot of treatment S, although they occupied only 15% of its area.

Treatments and sites differed in germination and survival. At all sites, treatment S had the most total germinations (Table 3), including 69% of those after mid-June, and the most survivors for the three seasons (Table 3, Fig. 2). Differences among treatments were statistically significant at Coos County Forest and Game Lake (Table 4). The initial rate of mortality in S was lower than for treatments R and B, and declined further after August (Fig. 2). Although treatments B and R had many more germinants than the control, most were at Coos County Forest and none survived their second summer (Table 3). Mortality in the control was slow during the last two seasons; however, seedling numbers were extremely small, making interpretation of the data difficult.

A linear relationship of log of survivorship to time existed for the rapid decline of seedling numbers in treatments B and R. In contrast, the concave curves for treatments C and S indicate that risk of death declines with age of the seedling (Harper 1977).

TABLE 4. Probability that the difference among treatments is due to chance, as determined by analysis of variance within each site

Site	Total no. germinants	Germinants after June	Survivors 1976	Survivors 1977
CCF	$p<0.005$	$0.025<p<0.05$	$0.005<p<0.01$	$0.10<p$
CRF	$0.10<p$	$0.10<p$	$0.10<p$	$0.10<p$
AGN	$0.05<p<0.10$	$0.10<p$	$0.05<p<0.10$	$0.05<p<0.10$
GAL	$0.005<p<0.01$	$0.025<p<0.05$	$0.01<p<0.025$	$p<0.005$

Coos County Forest, with no native seedlings, had the greatest number of germinants (Table 3). However survival to September 1976 was only 21%, compared with about 50% at other sites, and there were no survivors at Coos County Forest by October 1978 (Table 3). The dense shade probably was responsible for the complete mortality. Agness Pass, with the most open canopy, had the best survival. Success of germination was least in the old growth at Coquille River Falls (Table 3).

Most of the 70 first-season seedlings located after death were at Coos County Forest. Fifteen succumbed to a basal fungus, 15 were buried under litter, 7 appeared to die from desiccation, and 25 were simply snapped off above the soil surface while the stem was still succulent. During rainstorms, throughfall from the dense Coos County Forest canopy falls as very large drops which probably caused most of the "broken stem" deaths. Seedlings developed in the dense shade here may have been more delicate than elsewhere.

Following germination, seedlings grew little in height in 1976, those from treatments B and R averaging 2.2 mm above the cotyledons compared with 3.8 mm for the control and 4.3 mm for treatment S. Seedlings in treatment S grew significantly more than those in B and R. Differences among sites were smaller than those among treatments. By August 1977, seedlings averaged 13.6 mm above the cotyledons, with no significant differences among treatments or sites.

By October 1978, only one 1976 seedling remained in the control plots and fourteen in treatment S. They averaged 27 mm above the cotyledons, the largest being 52 mm. Only three post-1976 germinants were present in 1977 and four in 1978.

The ratio of viable seeds sowed per established seedling (in October 1978) was 1:800 in the control and 1:57 in treatment S. The actual seedling production per available seed was even lower because of the addition of natural seedfall.

Little previous work has been done on seedling survival of *C. lawsoniana*. James and Hayes (1954) report no effect of organic matter depth on stocking several years after clear-cutting, parallel to failure of our R treatment to increase establishment. Our first year survival was somewhat less than a previous seed-spot study (Moore 1940) in a clearcut. Our seedlings were only about a third as tall as Fowells (1965) reports; his data are probably for open-grown plants. Experimental seedling establishment of *Chamaecyparis thyoides* (L.) B.S.P. (Atlantic white cedar) and *C. obtusa* (Sieb. and Zucc.) Endl. (hinoki cypress) is increased by litter removal; however, both species naturally reproduce well on at least some kinds of organic matter (Little 1950; Sato 1974).

Germination in natural litter occurred in this study; in September 1976 at Coquille River Falls, three of five germinants were alive and C seedlings were taller than all but S seedlings. One seedling was still alive in a control plot in October 1978. Information about seed-crop size (Zobel 1979), seedling-sapling density (Hawk 1977) and age, and the data given here suggest that establishment in natural litter in older stands could perhaps account for the existing reproduction of *C. lawsoniana*. It seems obvious, though, that disturbance of the mineral soil would greatly increase the establishment rate, and such incidents may account for the majority of the native saplings. Simple litter removal is not sufficient to increase establishment of *C. lawsoniana*. The effect of seedbed condition on later survival would also be important. After three seasons, however, the percentage of germinants surviving was no better in S plots than in the control (Table 3).

Seedlings can arise from recent seedfall or from dormant seed stored in the soil (Harper 1977). For example, up to half the seed of *Chamaecyparis thyoides* germinates after the first season (Little 1950). However, available data (Isaac 1943) and the few germinations after 1976 in this study indicate *C. lawsoniana* to be more like *C. obtusa*, most seeds of which lose their viability over winter (Sato 1974).

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