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EFFECTS OF ARTIFICIAL FLOODING ON SEEDLING SURVIVAL AND GROWTH OF SIX NORTHWESTERN TREE SPECIES

by

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ABSTRACT

Seedlings of Douglas-fir, Sitka spruce, western hemlock, western redcedar, lodgepole pine, and red alder were inundated in tanks for various lengths of time in both winter and summer. Winter flooding for periods of 1 to 4 weeks severely injured Douglas-fir but had little or no effect on other species. Summer flooding for 4 and 8 weeks affected all six species--many seedlings died, and many formed adventitious roots at the waterline. Western redcedar and lodgepole pine seemed to be the most flood-tolerant species; red alder, Sitka spruce, and western hemlock seemed to be less tolerant; and Douglas-fir was extremely intolerant of flooding.

INTRODUCTION

Flood-plain forests in coastal Oregon and Washington are often inundated for short periods during the winter rainy season. Swamps are sometimes flooded for months, as are areas adjacent to water storage reservoirs throughout the Pacific Northwest. Periodically flooded areas do not involve a high percentage of total forest land area but are often extremely valuable in terms of potential productivity, esthetics, or recreational use. Maximum timber values can be realized on these areas only if they are managed for flood-tolerant species.

Surprisingly little is known about the flood tolerance of northwestern trees. Brink (1954) studied several tree species affected by the Fraser River flood of June and July 1948. He concluded that Douglas-fir and red alder were very vulnerable to floodwater. Western hemlock was somewhat less vulnerable and lodgepole pine, western redcedar, and Sitka spruce were judged most flood tolerant. Brink noted that cold, swift water seemed to be less damaging than warm, stagnant water. But his observations were qualitative; apparently, no quantitative measurements of flood tolerance are available for Pacific Northwest species.

More flood-tolerance information is available for species in other regions. Ahlgren and Hansen (1957), Green (1947), and Yeager (1949) studied flood tolerance in mixed-species forest stands in Minnesota, Iowa, and Illinois. They compared species tolerance under the natural conditions that occurred in the stands and did not control flooding depth or duration.

Flooding depth and duration have been artificially controlled to determine the relative flood tolerance of several eastern hardwoods. Hosner (1960) determined the relative tolerance of 14 hardwood species by completely inundating 1-year-old seedlings. Hosner and Boyce (1962), also, determined the relative tolerance of hardwood seedlings to a 1-inch inundation. Yelenosky (1963) used a 3-inch inundation to compare the flood tolerance of yellow-poplar, white oak, sugar maple, honey locust, and American elm. McAlpine (1961) compared yellow-poplar, sweetgum, and green ash and noted tolerance differences between the dormant and growing seasons.

Controlled artificial flooding has also been used to determine the flood tolerances of several eastern conifers. Williston (1962) submerged 1-year-old loblolly pine seedlings in northern Mississippi. They survived 32 days of total submergence during the dormant season but only 12 days during the growing season. Survival of seedlings totally submerged and seedlings submerged only to the root collar did not differ significantly. Hunt (1951) subjected seedlings of shortleaf, loblolly, and pond pine to four flooding regimes and found that all three species were flood tolerant. Walker, Green, and Daniels (1961) found that loblolly pine survived better than slash pine when both were inundated to a depth of 8 inches, but surviving slash pines grew faster after drainage. Lees (1964) flooded 1- and 2-year-old white spruce seedlings in the laboratory. The 2-year-old seedlings were more flood tolerant, but all seedlings died when totally immersed for 14 days.

Controlled, artificial flooding was used in the present study to investigate the relative flood tolerance of six northwestern species: Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), Sitka spruce (*Picea sitchensis* (Bong.) Carr.), western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), western redcedar (*Thuja plicata* Donn), lodgepole pine from the Oregon coast (*Pinus contorta* Dougl.), and red alder (*Alnus rubra* Bong.).

MATERIALS AND METHODS

Seedlings of all six species were grown from seeds collected near the Pacific coast (table 1). Seeds were stratified at 4^{o} C. for 30 days and germinated on moist filter paper. Germinated seeds were planted in April 1966 in a mixture of four parts of loam soil[1/] to one part of peat moss, which had been screened and blended before 854-gram portions were weighed into 162 1-quart plastic pots. Five germinated seeds--all of the same species--were planted in each pot, and pot locations were completely randomized, both by species and by assigned flooding treatment, on a greenhouse bench. Summer greenhouse temperatures varied from 16^{o} to 32^{o} C. All pots were equally watered daily; they were equally fertilized with 3 grams of 6-10-4 fertilizer in August 1966. In September, the seedlings were thinned to leave the two largest seedlings in each pot. Greenhouse heat was turned off in October, and all seedlings were dormant by December.

Table 1.--*Sources of seeds used in study*

Species	Location	Elevation
		Feet
Douglas-fir	Sand Lake, Oregon	300
Sitka spruce	Otis, Oregon	500
Western hemlock	Otis, Oregon	500
Western redcedar	Vancouver Island, B.C.	500
Lodgepole pine	Pacific City, Oregon	200
Red alder	Otis, Oregon	200

Two 122- by 122- by 24-centimeter wooden tanks were lined with polyethylene and placed on a bench in the unheated greenhouse (fig. 1). Pots to be flooded were randomized the same way in each tank in January 1967, and tapwater was added until all pots were flooded to a level 3 centimeters above the soil surface. Approximately 170 liters of water were added to each tank. An aquarium pump, air stone, and water pump aerated and circulated water in one tank at a rate of 3 liters per minute. Water in the second tank was left stagnant.

[1/] 44 percent sand, 39 percent silt, 17 percent clay.

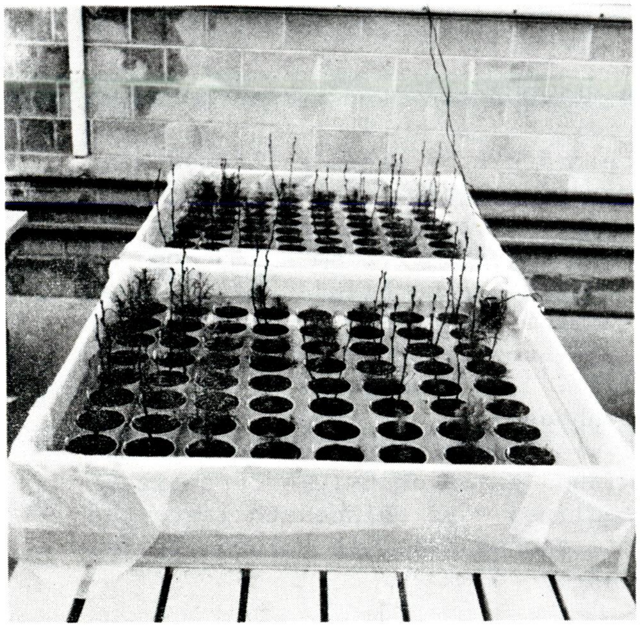

Figure 1.--*Flooding-tanks and seedlings at the beginning of the winter flooding period. The aerated tank is in the foreground.*

Each of the six species was subjected to nine treatments:

24-hour inundation, with aeration

24-hour inundation, without aeration

1-week inundation, with aeration

1-week inundation, without aeration

2-week inundation, with aeration

2-week inundation, without aeration

4-week inundation, with aeration

4-week inundation, without aeration

Control (no inundation)

Each species treatment was replicated three times with three pots (six seedlings). All inundation treatments were started at the same time. Flood-treated pots were then successively removed after 24 hours, 1 week, 2 weeks, and 4 weeks. Control pots were left on the growing bench in their original randomized positions, and the flooded pots were replaced in their original randomized order after being removed from the tanks. Average greenhouse temperatures during the treatment period were 10° C. in the daytime, 7° C. at night. All seedlings remained dormant during the treatments.

By June 1967, it was evident that the dormant flooding treatments had little effect on most of the species--only the Douglas-firs, inundated for long periods, died or showed reduced growth. Seedling shoot lengths of all species in pots from the 24-hour treatments were measured and compared with the controls in an analysis of variance. There were no significant treatment differences. Seedlings from the 24-hour winter treatments were therefore subjected to a summer flooding treatment in a single, stagnant-water tank. Pots containing these seedlings were randomized and flooded to 3 centimeters above the soil surface for periods of 4 and 8 weeks. Six pots of each species were immersed at the same time in June 1967. Three of these pots were removed after 4 weeks and placed back on the growing bench; three were removed after 8 weeks. All seedlings--winter treatment, summer treatment, and controls--were maintained in the greenhouse until the end of October 1967.

The largest surviving seedling in each pot was then washed free of soil, measured, and weighed. The following parameters were recorded:

Number of surviving seedlings per pot

Shoot weight

Root weight

Total weight

Shoot length

Root-surface area

Shoot:root ratio (by weight)

All weights were measured after drying the seedlings for 48 hours at 65° C. Root-surface areas were estimated by use of the Carley and Watson (1966) method.

RESULTS

Average survival percentages, total seedling weights, and root-surface areas are listed in tables 2 through 5. Shoot weights, root weights, and shoot:root ratios expressed essentially similar species and treatment relationships. They are not presented here.

Winter inundation did not significantly affect the survival or growth of western hemlock, red alder, Sitka spruce, lodgepole pine, and western redcedar. The five species had significantly different weights, shoot lengths, root-surface areas, and shoot:root ratios when species were compared, but an analysis of variance showed no significant treatment differences or species-treatment interactions.

Table 2.--*Average seedling survival by species and flooding treatment*

(In percent)

Treatment	Douglas-fir	Western hemlock	Red alder	Sitka spruce	Lodgepole pine	Western redceda
Control (no inundation)	100	100	100	100	100	100
Winter inundation:						
1 week--						
Aerated	65	100	100	100	100	100
Stagnant	100	100	100	100	100	100
2 weeks--						
Aerated	65	100	100	100	100	100
Stagnant	85	100	100	100	100	100
4 weeks--						
Aerated	0	100	100	100	100	100
Stagnant	50	100	100	100	100	100
Summer inundation:						
4 weeks, stagnant	0	34	50	84	100	100
8 weeks, stagnant	0	16	65	34	50	100

Table 3.--*Average total weight of largest surviving seedling per pot by species and flooding treatment*

(In grams)

Treatment	Douglas-fir	Western hemlock	Red alder	Sitka spruce	Lodgepole pine	Western redcedar
Control (no inundation)	5.80	3.71	21.49	5.54	6.26	7.88
Winter inundation:						
1 week--						
Aerated	3.00	2.58	23.18	3.97	6.52	6.73
Stagnant	3.30	2.55	24.07	3.17	6.43	4.61
2 weeks--						
Aerated	3.62	2.63	17.71	4.41	5.52	6.06
Stagnant	5.44	2.15	23.21	4.70	6.15	5.53
4 weeks--						
Aerated	--	3.24	22.95	4.16	7.95	6.73
Stagnant	2.14	2.48	19.97	5.28	8.00	5.64
Summer inundation:						
4 weeks, stagnant	--	1.42	21.45	1.89	5.84	5.43
8 weeks, stagnant	--	.89	24.37	1.90	6.14	3.06

Table 4.--*Average root-surface area of largest surviving seedling per pot, expressed as grams of calcium nitrate solution adsorbed in 10-second dip by species and flooding treatment*

Treatment	Douglas-fir	Western hemlock	Red alder	Sitka spruce	Lodgepole pine	Western redcedar
Control (no inundation)	6.6	4.8	18.7	7.2	6.9	12.9
Winter inundation:						
1 week--						
Aerated	4.1	3.5	18.1	4.9	8.4	12.2
Stagnant	4.3	3.1	17.3	4.0	6.4	6.9
2 weeks--						
Aerated	4.9	2.4	16.8	6.0	5.5	9.8
Stagnant	6.2	1.9	14.9	5.5	6.6	7.1
4 weeks--						
Aerated	--	3.4	18.5	5.7	8.7	11.7
Stagnant	2.5	2.9	15.9	6.9	12.4	8.7
Summer inundation:						
4 weeks, stagnant	--	.6	17.8	2.7	5.4	6.9
8 weeks, stagnant	--	.2	18.0	1.8	4.5	2.5

Table 5.--*Average top length of largest surviving seedling per pot, by species and flooding treatment*

(In centimeters)

Treatment	Douglas-fir	Western hemlock	Red alder	Sitka spruce	Lodgepole pine	Western redcedar
Control (no inundation)	19.3	19.0	104.7	19.0	25.7	30.7
Winter inundation:						
1 week--						
Aerated	12.0	17.7	111.3	17.7	21.7	28.7
Stagnant	17.3	18.7	112.7	17.3	25.0	25.0
2 weeks--						
Aerated	14.0	17.3	111.7	19.3	28.3	25.7
Stagnant	20.0	17.3	98.7	20.7	25.7	29.7
4 weeks--						
Aerated	--	22.0	108.3	19.0	26.7	28.7
Stagnant	9.3	15.0	107.7	23.7	27.7	27.3
Summer inundation:						
4 weeks, stagnant	--	15.0	94.5	17.0	23.7	27.3
8 weeks, stagnant	--	15.0	123.0	16.0	23.3	23.0

Winter inundation did affect the survival and growth of Douglas-fir. Even 1 week of winter inundation was detrimental. Four weeks were disastrous. Aerated floodwater was more damaging to Douglas-fir than stagnant water.

Summer flooding effects were more pronounced than the winter effects, but more difficult to interpret. The growing seedlings reacted to the summer inundation in several ways, and variation was extreme. Survival was erratic, differing from pot to pot within the same species and treatment. However, both western redcedar and lodgepole pine survived significantly better than Douglas-fir after 4 weeks of summer flooding. Total seedling weights were reduced by flooding. Root-surface areas were significantly reduced, but shoot lengths were not significantly affected by the inundation.

Much of the variation in survival and growth after summer inundation appeared to be related to waterline phenomena. All of the flooded Douglas-fir seedling stems were swollen at the waterline, as if they had been girdled (fig. 2). Roots of all inundated Douglas-fir seedlings had dead cambiums, but the shoots remained green and healthy looking until October. The flooded Douglas-firs with dead roots were judged to be dead.

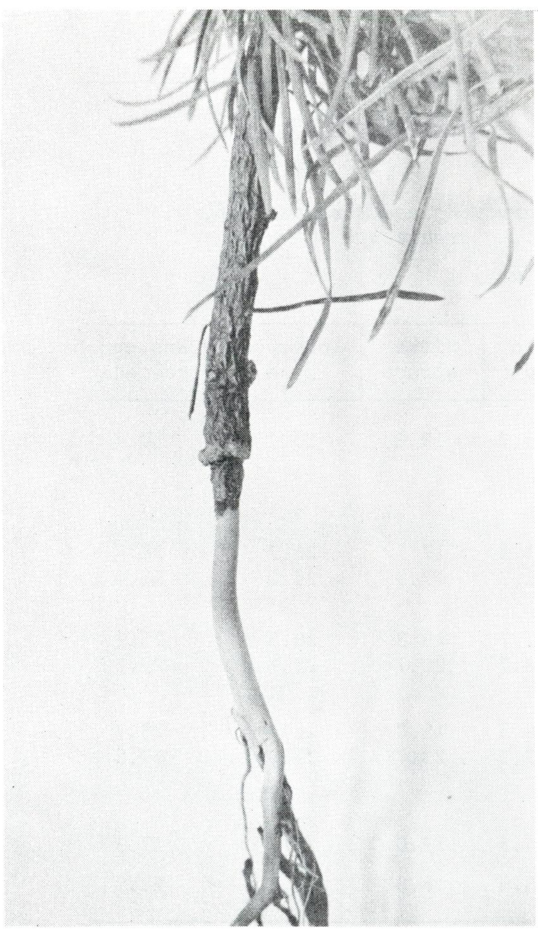

Figure 2.--*Douglas-fir seedling inundated for 8 weeks in the summer. Note dead root system and swelling at the waterline.*

Alder seedlings that formed adventitious root systems at the waterline (figs. 3 and 4) continued to live and grow even after 8 weeks of summer flooding. Those that failed to form adventitious roots died after 4 weeks of flooding.

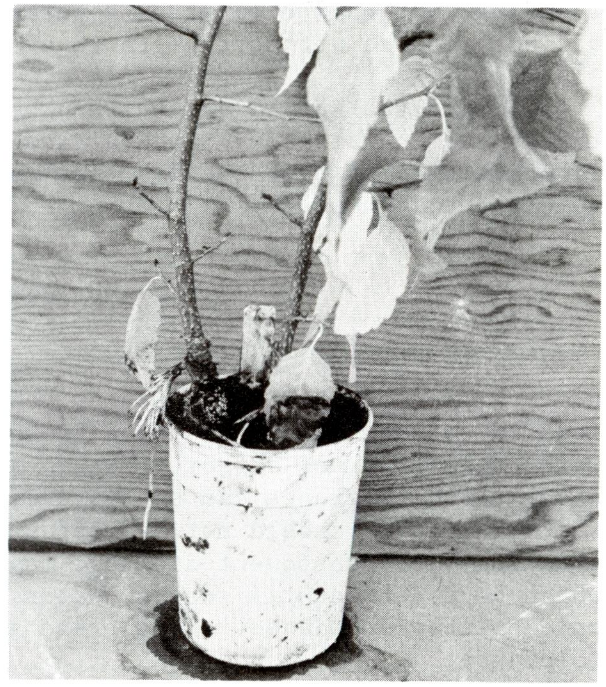

Figure 3.--*Alder seedlings after 4-week summer inundation. Note small adventitious root system on left seedling.*

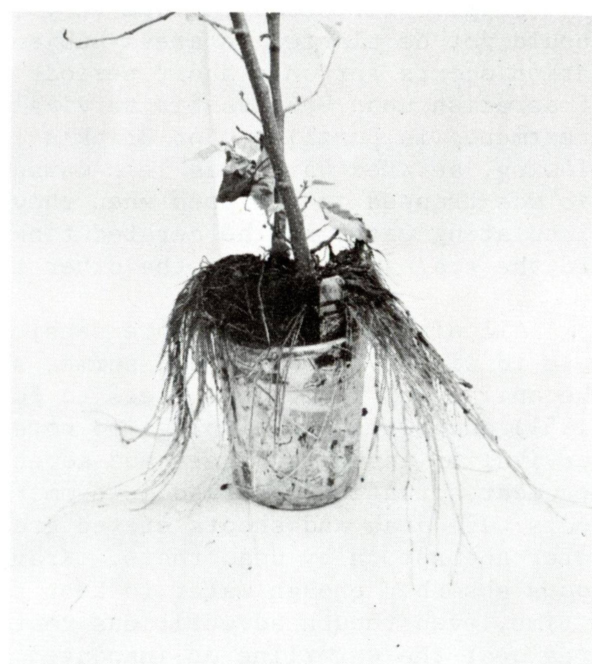

Figure 4.--*Alder seedlings after 8-week summer inundation. The adventitious roots pictured here and in figure 3 withered soon after being removed from the water.*

All summer-flooded western redcedar seedlings formed adventitious roots just below the waterline and survived. However, summer inundation decreased the growth of cedar seedlings, the effect increasing with flood duration.

All of the lodgepole pine seedlings survived 4 weeks of summer flooding, but half died after 8 weeks of flooding. Summer flooding did not seem to affect the growth of surviving lodgepole pine seedlings.

Both Sitka spruce and western hemlock were severely affected by the summer inundation. Survival and growth declined with increased flooding time in both species, but spruce seemed to be more flood tolerant than hemlock.

DISCUSSION

Short periods of winter flooding probably will not injure western hemlock, red alder, Sitka spruce, lodgepole pine, or western redcedar seedlings; these species may be grown on flood plains where shallow water tables do not affect growth. Floodwater tolerance and shallow water table tolerance can be quite different, however, and the two characteristics should not be confused. Species uninjured by temporary flooding with subsequent drainage may be unable to survive on areas which have permanently shallow water tables, even if these areas are only briefly inundated. Data presented here apply only to flood tolerance.

Douglas-fir seedlings are very intolerant of flooding. They should not be planted in areas subject to inundation even if the inundation occurs for only short periods in the winter. The adverse effect of aeration upon Douglas-fir survival and growth in the winter-flooding treatments is puzzling, for Brink's 1954 observations indicated that flowing, aerated water was less damaging than stagnant water. Perhaps air was trapped in the pots when they were inundated, and perhaps the circulating water in the aerated tank absorbed this air faster than did the stagnant water in the other tank.

All six species were more sensitive to summer flooding than they were to winter flooding, and summer survival seemed to depend upon the ability of individual trees to form adventitious roots. Kramer (1951) and Yelenosky (1963) also noted this relationship between the survival of inundated trees and adventitious root formation. The peculiar situation observed in summer-inundated Douglas-fir, where roots were dead and shoots stayed green, may have been the result of water absorption by dead roots. Kramer (1933) found that dead pine roots absorbed enough water to keep the shoots green and unwilted for a time, even though adventitious roots were not formed. The swollen area near the waterline on inundated Douglas-firs (fig. 2) probably resulted from carbohydrate accumulation when flooding interfered with downward translocation (Kramer 1951).

Statistically valid flood-tolerance ratings for each of the six species cannot be formulated from the data presented in tables 2 through 5. However, seedlings of the species may be tentatively grouped in terms of relative flood tolerance: Western redcedar and lodgepole pine seem to be the most flood tolerant; red alder, Sitka spruce, and western hemlock are intermediately tolerant; and Douglas-fir is extremely intolerant.

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