1824

Emergence and Mortality of Douglas-Fir, Western Hemlock, and Western Redcedar Seedlings

JAY S. GASHWILER

Abstract. Emergence of natural seedlings on the H. J. Andrews Experimental Forest in west-central Oregon between 1956 and 1967 was irregular from year to year; but most seedlings appeared between April 15 and May 15. Average percentage of first-year mortality was: Douglas-fir 82, western hemlock 97, and western redcedar 95. Major causes of first-year mortality, in percent, were: Douglas-fir—animal 58, weather 27, and disease 6; hemlock—weather 58, disease 21, and animal 11; redcedar—weather 80, animal 8, and disease 2. Cumulative losses of Douglas-fir seedlings, in percent, were: 1 year 83, 2 years 86, 3 years 86, 4 years 88, 5 years 88, and 6 years 89. Seedling protection might be most productive if directed toward animals for Douglas-fir and toward weather for hemlock and redcedar. ***Forest Sci. 17:230–237.***

Additional key words. *Pseudotsuga menziesii, Tsuga heterophylla, Thuja plicata,* animal damage, mortality, natural regeneration.

RELATIONSHIPS between wildlife and tree regeneration from natural seed fall were investigated on the H. J. Andrews Experimental Forest from 1954–67. As by-products, these studies yielded information on the emergence and mortality of seedlings of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), and western redcedar (*Thuja plicata* Donn).

The Andrews Forest is on western slopes of the Cascade Mountains within the Willamette National Forest near Blue River, Oregon. The study areas, originally in old-growth timber, are two similar clearcuts (3G and 9A) of 41 and 25 acres, which were slash-burned in the fall of 1953 and 1959, respectively. Soil is mostly a clay loam of volcanic origin on southerly slopes of about 13 percent. Elevations range from 1,975 to 2,750 ft. Interpolation of the Berntsen and Rothacher (1959) data, on the basis of elevation, indicates that annual precipitation averages roughly 100 inches.

Methods

Field Layout. In the 3G clearcut an annual emergence and mortality of seedlings were observed from 1956–60 on to 12 randomized replications. Each replication consisted of four 3 × 3-ft plots; three of the plots were enclosed (exclosures) and the other was open (unprotected) (Gashwiler 1967). In the 9A clearcut area similar data were obtained from 1961–67 on three replications

The author is Wildlife Research Biolo[gist], Denver Wildlife Research Center, U. S. Bu[reau] of Sport Fisheries and Wildlife, and is statio[ned] at the U. S. Forest Service Silviculture Labo[ra]tory in Bend, Oregon 97701. He apprecia[tes] the assistance by personnel of the Willam[ette] National Forest, especially Charles M. L[...] and individuals of the Blue River Ranger D[is]trict; the cooperation of members of the Pac[ific] Northwest Forest and Range Experiment S[ta]tion; and manuscript review by William I. S[...] of the Station and Curtis H. Halvorson of [the] Bureau; and assistance in all phases of the [in]vestigation by his wife, Melva. Manuscript [re]ceived Dec. 17, 1970.

sampling areas, each randomized replication consisting of three exclosures and one open quadrat, each 35 ft square; nine 3 x 3-ft sample plots were located in each exclosure and in the open quadrat. In 1962 and 1963, some seedlings found adjacent to the open quadrats were also marked and observed. Cumulative Douglas-fir seedling mortality was also determined on two line transects in 3G and four in the 9A clearcuts.

Emergence and mortality of seedlings were checked twice weekly during the germination period and weekly thereafter until the start of fall rains. Each new seedling was marked with a wire stake. When a seedling died, cause of mortality was recorded.

Some vegetation was clipped to keep it from growing into or spreading out beneath the exclosure tops. Tall plants that would have provided animal access routes into the exclosures were topped at about 3 ft on all quadrats. This disturbance was not considered serious. Living seedlings were removed annually from all quadrats just prior to emergence of the new crop; those on the line transects were left undisturbed.

Identification of Seedling Mortality. Criteria used to identify the cause of seedling damage or mortality were similar to those used by Shearer and Halvorson (1967), Fowells and Stark (1965), Isaac (1938, 1943), and Toumey and Korstian (1931). However, a few additional categories and characteristics were employed.

Animal.—Seedling cut off, nibbled on, eaten, or undermined.

Small mammal.—Seedling cut off either cleanly or raggedly in early spring before or after seed coat is shed. Cut is usually made through the upper stem, sometimes through the cotyledons or lower stem, and is often angled. Burrowing beneath seedling may cause death.

Bird.—Seedling cut, sometimes cleanly, in early spring while seed coat is on the cotyledons. Cut may be either horizontal or angled near the crown; often stubs of cotyledons are left. Sometimes the entire seedling is pulled from the soil and left lying. This damage is sometimes difficult to differentiate from that of small mammals.

Cutworm (Noctuidae).—Succulent seedling cut smoothly and usually horizontally, near ground line. Occurrence most likely in early spring. Feeding often done beneath cover, and tips of cotyledons sometimes not consumed. Presence of cutworms, or their sign, confirms cause.

Other insect.—Cotyledons, needles, or stem nibbled or eaten. Damaged area often ragged. Skeletonization, if present, is similar to that made by tiny slugs.

Tan slug (*Limax* spp.).—Seedling stem cut off raggedly near ground level, often with a slime trail to or from stub. Tiny slugs, probably tan ones, sometimes skeletonize cotyledons or needles. Presence of slugs, or their sign, confirms cause.

Weather.—Seedling intact, but off-color and damaged.

Heat.—Young seedling upright or prostrate, with stem lesions above the ground line, after surface temperatures have exceeded 125°F. Damage most common on dark, exposed surfaces. Temperature pellets were used to monitor surface temperatures (Silen 1956).

Drought.—Seedling gradually desiccates while erect; needles may turn yellowish, or remain a dull medium green. Mortality usually occurs during or after dry periods. Heat and drought injury frequently occur together, and it is difficult to determine which causes death.

Frost heave.—Seedling lifted partly or completely from the ground; root or stem bark sometimes stripped. Damage generally occurs in spring during periods of freezing and thawing.

Frost injury.—Watery lesions on succulent stems near ground level, or reddish-brown new growth. Dried frost lesions are almost identical to heat lesions. Both types of damage may occur in early spring. When the damaged parts break from larger seedlings, the stub remaining may look as though it had been browsed.

Erosion.—Seedling washed out.

Disease (chiefly damping-off).—Stem constricted at ground level, along the roots, or at the root cap; seedling wilts and may fall over. When dry, its roots become dark brown or black. Damage occurs mainly in early spring during periods of cool, damp weather.

Mechanical.—Seedling stepped on by deer or other animals, or otherwise destroyed by mechanical means.

Missing.—Seedling gone; no cause apparent.

Causes of mortality cannot be assigned with certainty to every dead seedling. For example, young, healthy seedlings are brittle, snap with a clean break, and bear little evidence on cause of break. Injured parts of young seedlings dry out quickly, thereby masking evidence of the causal agent. Two or more mortality agents may also affect a seedling simultaneously, making positive identification of the main agent difficult. For these and other reasons, one sometimes leans heavily on judgment in assigning cause of death. Misjudgments may occur, but such errors probably compensate. By frequent examinations, looking closely at available signs and considering the seedling's local environment, one may evaluate mortality factors with reasonable accuracy. A hand lens was used routinely, since seedlings are small and signs of damaging agents difficult to see.

Compilation of Data. Data were compiled separately for four nearly equal periods per month, hereafter termed "weeks." Since data from the two clearcuts did not differ, they were combined for analysis. Comparisons also revealed little, if any, difference in emergence dates for seedlings from the various exclosures and open quadrats. Consequently, emergence data from all plots were also combined. In the mortality compilations only the unprotected (open quadrat and line transect) seedlings were used, because on protected plots the wooden exclosure frames and wire covering may have influenced seedling mortality (Gashwiler 1967, Schubert 1955, Fowells and Arnold 1939).

Time of Seedling Emergence

There were many yearly variations in seedling emergence. In 1959, freshly emerged Douglas-fir and redcedar seedlings were found November 17 in a clearcut near the 9A study area. The Douglas-firs had bright-winged seed coats attached to the cotyledons and were considered seeds of the year. In some years emergence started the last third of March and was complete by the latter part of May. Generally, the emergence period covered 2 months, from about the middle of April to about the middle of June. Most seedlings emerged during a month-long period spanning the last half of April and the first half of May (Fig. 1). Under field conditions, emergence of seedlings appears to be closely associated with site and prevailing weather. Seedlings emerged earliest in small protected areas which generally had a dark surface, a moderate to steep slope, and southerly exposure. Dry or cold weather retarded emergence. Soon after rain fell or temperatures rose, the number of emerging seedlings increased, if other factors remained favorable.

Some Douglas-fir seedlings appeared during the last half of March (Fig. 1). Emergence reached a high level by the third week of April, remained high until the second week of May, then declined rapidly, and ended by the last of June.

Hemlock seedlings also started emerging during the third week of March. Emergence increased slowly until the last of April, and then rose until the second week of May. It then declined rapidly and ended the second week in July.

Data on emergence of redcedar seedlings are relatively few, mostly from the

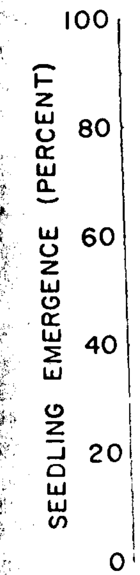

FIGURE 1. P

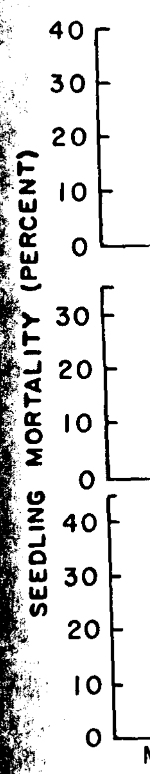

FIGURE 2.
1956–66.

ıures and open
ımergence data
ıbined. In the
y the unpro-
line transect)
e on protected
e frames and
ıfluenced seed-
967, Schubert
1939).

ce

variations in
1959, freshly
edcedar seed-
er 17 in a
ly area. The
ed seed coats
nd were con-
n some years
ird of March
latter part of
gence period
ut the middle
ddle of June.
ing a month-
half of April
g. 1). Under
of seedlings
ited with site
lings emerged
areas which
a moderate
ly exposure.
l emergence.
temperatures
ng seedlings
s remained

gs appeared
h (Fig. 1).
level by the
d high until
ıen declined
of June.
ırted emerg-
of March.
ıntil the last
the second
ıned rapidly
July.
edar seed-
ly from the

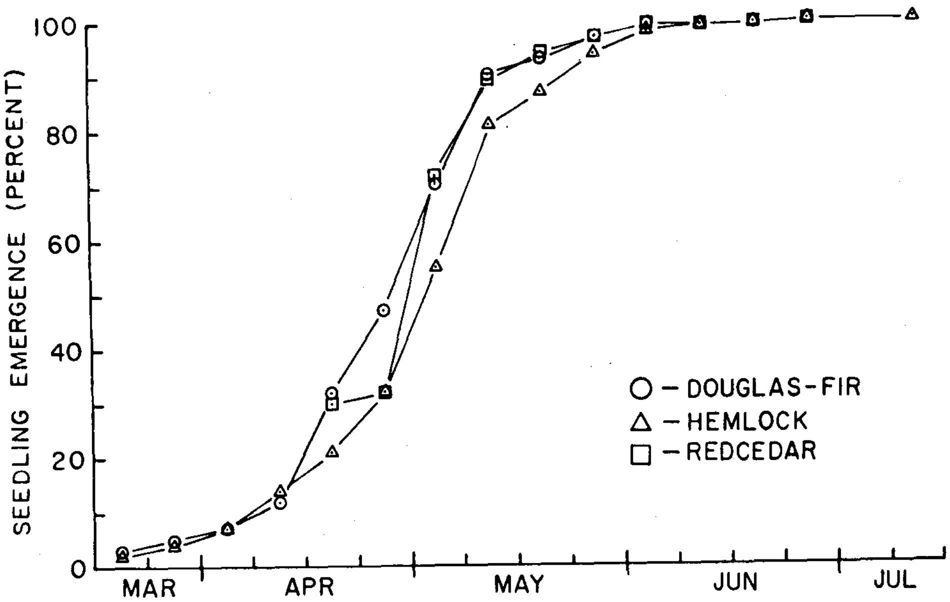

FIGURE 1. *Periodic seedling emergence—cumulative average based on 4,796 seedlings from 1956–66.*

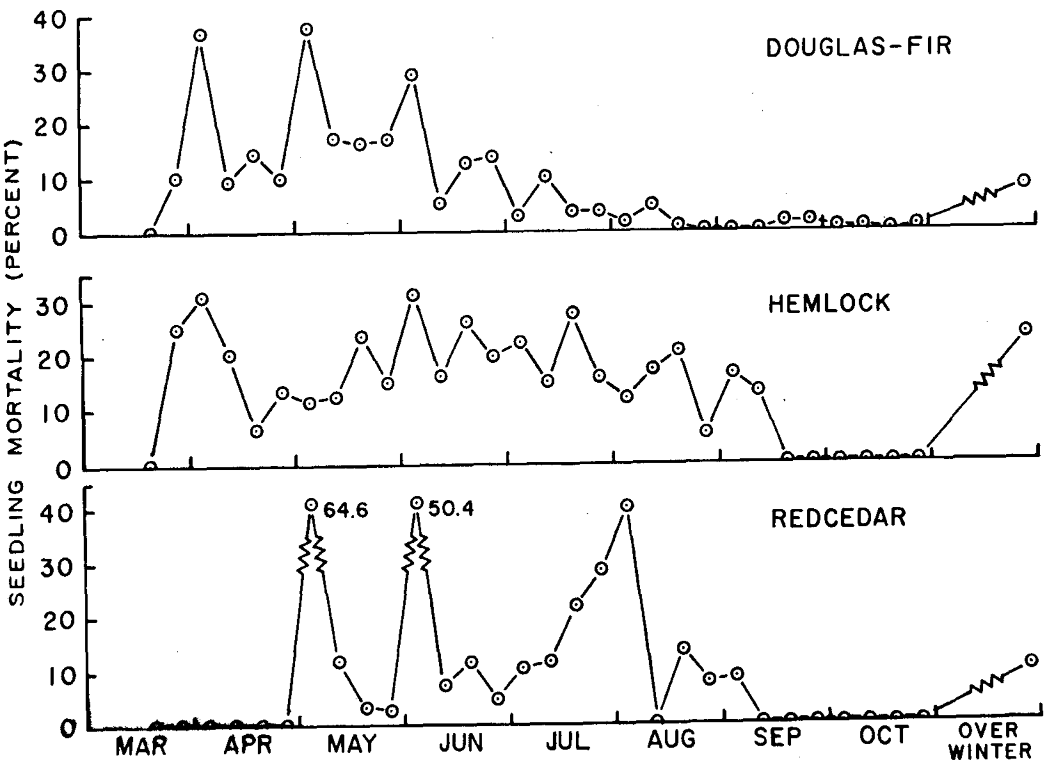

FIGURE 2. *Periodic seedling mortality (based on the number alive at start of period) averaged for 1956–66.*

1956 seed year, and are not considered representative. However, redcedar appeared to follow roughly the same emergence pattern as the other two species.

Seedling Mortality

First-Year Mortality. Seasonal mortality differed markedly between species (Fig. 2). Many of the exposed, "high-risk" Douglas-fir seedlings succumbed during emergence or shortly thereafter; hardier ones on better sites survived. Later in the growing season, losses among the survivors dropped to low levels. Overwinter seedling losses averaged about 9 percent of those surviving at the start of winter.

Hemlock also suffered relatively heavy early-season mortality. However, unlike Douglas-fir, hemlock losses continued at a relatively high level until early September. By that time most were dead, and the survivors apparently were confined to favorable sites. The loss overwinter averaged 23 percent of those present at the start of winter, or more than 2.5 times greater than the equivalent loss of Douglas-fir. Total first-year losses of hemlock seedlings averaged 97 percent, nearly 15 percent greater than for Douglas-fir.

Heavy redcedar mortality occurred irregularly. Many seedlings died soon after peak emergence periods. But by September, loss among survivors was slight. Overwinter losses of those present at start of winter averaged 10 percent, similar to those of Douglas-fir. Total first-year loss averaged about 95 percent.

Cumulative Mortality of Douglas-fir. The average cumulative loss of Douglas-fir seedlings on line transects was observed over a 6-year period. These seedlings grew on many microsites, and were exposed to all mortality agents. Seedling mortality was high during the early part of the first season: 47 percent by late May, 75 by late June, and 80 percent by late July. During the first year, 83 percent of the seedlings succumbed; this was only 1% greater than occurred in the larger sample from the exclosures and quadrats. Total cumulative mortality percentage at the end of the second year was 86, third year—86, fourth year—88, fifth year—88, and sixth year—89. This suggests that after the first year, mortality is low and reasonably uniform.

Causes of Seedling Mortality

Douglas-Fir. Animal activity accounted for 58 percent of the first-year losses of Douglas-fir seedlings (Table 1). Small mammals and cutworms were mainly responsible. Douglas-fir seedlings start appearing in early spring, often when other vegetation such as fireweed (*Epilobium* spp.) is making a slow start. Seedlings are thus available to animals when other succulent food is scarce. Both preference and availability are thought to be important in destruction by animals.

Weather factors, primarily heat and drought, caused 27 percent of the Douglas-fir mortality. Another 6 percent was due to disease, and about 8 percent involved missing seedlings. The latter may have been eaten or carried away by animals.

Western Hemlock. Animals, mostly cutworms and other insects, caused a minor part of hemlock mortality (11 percent). Weather factors accounted for 58 percent, more than double that for Douglas-fir. Exposure to full sunlight on dry, southerly exposures was detrimental to many seedlings. Drought killed 38 percent, and heat 18 percent. Hemlock seedlings are vulnerable to disease; over a fifth died from this cause—three times as many as for Douglas-fir.

Western Redcedar. Limited data show that only 8 percent of the redcedar seedlings were lost to animals, mostly cutworms. Weather factors caused nearly 80 percent of the losses; heat was more important than drought (Table 1). Nearly 10 percent of the marked seedlings disappeared, but only a few succumbed to disease. Most of the seedlings emerged in 1957, and data from this year dominated results. Since the spring of 1957 was hot and dry, leading to many heat and drought losses, a more representative sample might show somewhat different loss percentages.

TABLE 1. First-year seedling mortality by species and cause. Based on 389 Douglas-fir, 331 hemlock, and 176 redcedar seedlings from open quadrats and line transects. (In percent)

Cause	Douglas-fir	Western hemlock	Western redcedar	Average
Animal	58	11	8	31
Small mammal	28	1	0	13
Bird	6	1	0	3
Bird or small mammal	1	1	0	1
Tan slug	4	1	0	2
Cutworm	17	3	7	10
Other insect	2	4	1	2
Weather	27	58	80	48
Heat	14	18	45	21
Drought	10	38	34	25
Frost heave	1	1	1	1
Frost injury	2	1	0	1
Disease	6	21	2	11
Mechanical	1	1	0	1
Missing	8	9	10	9

Changes in Cause of Mortality with Time. The causes of first-year mortality in Douglas-fir seedlings changed as the clearcuts revegetated (Table 2). Revegetation following slash burning was studied on the 9A clearcut, and used as indicative of the cover on both areas. During the first season after burning, the clearcut was a black, barren area with only a light vegetative cover (9 percent). Newly germinated seedlings were readily visible and animals seemed to have little trouble locating them as evidenced by the 72-percent mortality caused by animals. Much of this (45 percent) was the result of small mammal activity. Weather factors accounted for an additional 18 percent loss, with drought and heat the chief causes. First-year seedling losses on the fresh burn were 91 percent.

Four years after burning 41 percent of the clearcut surface was covered with vegetation. On both areas, first-year seedling mortality caused by animals averaged 61 percent, mostly from cutworms. Their populations apparently had increased with the plants that provided their food. Losses due to small mammals were only a third as great as on the fresh burn, but weather-caused losses were slightly greater. Even though more live shade was available, mortality caused by heat was much greater; consequently, drought losses declined. Ten percent of the seedlings died of disease. First-year seedling mortality on the 4-year-old burns averaged 73 percent.

Seven years after burning, plant cover on 9A still averaged only 41 percent. Loss of first-year seedlings to animals dropped to 54 percent on both areas, and most of this was attributable to small mammals. Cutworm damage was about an eighth of that suffered during the fourth season. Other plants, such as fireweed, may have served as buffers for the Douglas-fir seedlings, thereby reducing cutworm-caused mortality. Nearly a third of the seedling losses were attributed to weather, with heat and drought being equally important. First-year seedling mortality in the seventh year averaged 89 percent.

Literature Cited

BERNTSEN, C. M. 1958. Silvical characteristics of western hemlock. USDA Forest Serv Silv Ser 3, 16 p. Pacific Northwest Forest Range Exp Sta, Portland, Oreg.

——, and J. ROTHACHER. 1959. A guide to the H. J. Andrews Experimental Forest. USDA Forest Serv, 21 p. Pacific Northwest Forest Range Exp Sta, Portland, Oreg.

FOWELLS, H. A., and R. K. ARNOLD. 1939. Hardware cloth seed spot screens reduce high surface soil temperatures. J Forest 37:821–822.

——, and N. B. STARK. 1965. Natural regeneration in relation to environment in the mixed conifer forest type of California. USDA Forest Serv Res Pap PSW-24, 14 p. Pacific Southwest Forest Range Exp Sta, Berkeley, Calif.

GASHWILER, J. S. 1967. Conifer seed survival in a western Oregon clearcut. Ecology 48: 431–438.

HAIG, I. T., K. P. DAVIS, and R. H. WEIDMAN. 1941. Natural regeneration in the western white pine type. USDA Forest Serv Tech Bull 767, 99 p. Northern Rocky Mountain Forest Range Exp Sta, Missoula, Mont.

ISAAC, L. A. 1938. Factors affecting establishment of Douglas-fir seedlings. USDA Forest Serv Circ 486, 45 p. Pacific Northwest Forest Range Exp Sta, Portland, Oreg.

———. 1943. Reproductive habits of Douglas-fir. 107 p. Charles Lathrop Pack Found, Washington, D. C.

SCHUBERT, G. H. 1955. Freezing injury to young sugar pine. J Forest 53:732.

SHEARER, R. C., and C. H. HALVORSON. 1967. Establishment of western larch by spring spot seeding. J Forest 65:188–193.

SILEN, R. R. 1956. Use of temperature pellets in regeneration research. J Forest 54: 311–312.

TOUMEY, J. W., and C. F. KORSTIAN. 1931. Seeding and planting in the practice of forestry. 507 p. John Wiley and Sons, Inc, New York.

How to Increase Forest Productivity; Present International Findings

M. Vyskot and G. Vincent, eds. Statni zemedelske nakladatelstvi, Prague, 1968. 422 pp. Price Kcs 54.–.

Review by Richard K. Hermann
Forest Research Laboratory, Oregon State University, Corvallis

HOW TO meet the rising demand for wood as a raw material, as populations increase while the areas available to grow wood continue to shrink, is becoming a matter of great concern in the highly industrialized countries of Europe. Mobilization of all scientific and technological resources to increase both yield and utilization of wood is considered the most promising approach to a solution of the problem. This book, with contributions by twelve foresters from both sides of the Iron Curtain, is intended as a step in that direction, according to the introduction by M. Vyskot. Papers are in English, German, Russian, or French with summaries in another of these languages. The material deals with forests and management practices in the temperate zone of Europe and is directed mainly toward a European audience. Many of the issues discussed are of more than regional importance, however, and will also be of interest to foresters outside of Europe.

Papers on silviculture predominate. Van Miegrot's (Belgium) "The Function of Silviculture, Means and Possibilities" (G.f. (= German, French summary)) evaluates silvi-

TABLE 2. Cause of mortality for first-year Douglas-fir seedlings emerging 1, 4, and 7 years after slash burning.
(In percent)

Cause	Years since burning 1[a]	4	7
Animal	72	61	54
Small mammal	45	15	34
Bird	13	1	7
Bird or small mammal	3	0	0
Tan slug	6	1	8
Cutworm	4	42	5
Other insect	1	2	0
Weather	18	22	31
Heat	6	14	15
Drought	10	5	14
Frost heave	0	2	0
Frost injury	1	1	2
Erosion, water	1	0	0
Disease	0	10	6
Mechanical	2	1	1
Missing	8	6	8
Average first-year mortality	91	73	89

[a] 9A area only.

Discussion

The time of seedling emergence was variable and apparently subject to many factors; this agrees with Isaac (1943) who found that the start of Douglas-fir germination in a clearcut varied in different years from the last week in April to the second week in June. First-year loss of Douglas-fir seedlings for the entire study period averaged 82 percent, practically identical to the 83 percent reported by Isaac for areas near Carson, Washington. Computations from the percentages of smaller samples given by Isaac (1938) for all degrees of shade, show an average cumulative mortality, in percent, of: first year, 85; second year, 91; third year, 92, and fourth year, 91. This is very similar to that found in the present study. Several factors probably contributed to the greater resistance of Douglas-fir seedlings, compared to hemlock and redcedar, to weather-caused mortality. Earlier emergence favors Douglas-fir seedlings by giving them time to develop root systems and harden their stems during the cooler period. For instance, by the first week of May, 70 percent of the Douglas-fir seedlings had emerged compared to 55 percent for hemlock (Fig. 1). In addition, the larger size of the Douglas-fir seedlings seems to increase endurance of adverse conditions. Haig *et al.* (1941) considered deep initial root penetration of Douglas-fir seedlings responsible for their better drought resistance.

Small size, more limited availability in early spring, and possibly low palatability are thought responsible for the minor use of hemlock seedlings by animals. Berntsen (1958) also reported that animal damage to hemlock seedlings was usually a minor problem. Many hemlock seedlings did not have as much time as Douglas-fir seedlings to develop an adequate root system and to harden before dry weather began. Haig *et al.* (1941) found that hemlock seedlings initially had shallow root penetration and were thus not adequately established to withstand drought. Also because of their small size, they may be less able to resist adversities.

Redcedar seedlings were not eaten extensively by animals, possibly because of their small size and a repulsive flavor. They were apparently unable to cope with clearcut conditions. Like hemlock, redcedar seedlings initially have shallow root penetration (Haig *et al.* 1941); this leaves them especially vulnerable to drought.

Cause of first-year seedling losses for the three species averaged about one-half weather, one-third animal, one-tenth disease, and one-tenth missing. Type of loss is largely dependent on which mortality agent gets first chance at the seedling. Efforts to alleviate seedling losses might be most productive if they could be directed toward animals for Douglas-fir and toward weather for hemlock and redcedar.