Decline and Mortality of *Chamaecyparis nootkatensis* in Southeastern Alaska, a Problem of Long Duration but Unknown Cause

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ABSTRACT

Shaw, C. G., III, Eglitis, A., Laurent, T. H., and Hennon, P. E. 1985. Decline and mortality of *Chamaecyparis nootkatensis* in southeastern Alaska, a problem of long duration but unknown cause. Plant Disease 69:13-17.

Alaska-cedar (*Chamaecyparis nootkatensis*) trees have been dying of an unknown cause in large numbers at several locations in southeastern Alaska for more than 75 yr. At least 9,700 ha of cedar forest have been affected. Diseased stands often have 50% or more of their total volume in Alaska-cedar, of which 25% or more is dead or dying. Decline and mortality of small understory cedar trees have occurred either along with or after decline and mortality of larger overstory trees. Affected trees either die quickly and turn brown after a few growing seasons or decline and die slowly with their crowns gradually changing color and decreasing in fullness for 5 yr or more. Diameter growth decreases with crown deterioration. Some trees respond to foliage loss by producing bushy, epicormic branches. The cedar bark beetle (*Phloeosinus cupressi*), previously suggested as a cause of mortality, was found to be a secondary agent that only attacked trees in advanced decline. *Armillaria* sp. occurred frequently on dead and dying trees but not consistently on recently killed trees, suggesting that it is not the primary cause. No other known pathogens were isolated from affected trees. The patterns of tree death and decline are consistent with a hypothesis that environmental stress is the primary cause of the problem.

Alaska-cedar (*Chamaecyparis nootkatensis* (D. Don) Spach) occurs along the Pacific coast from Prince William Sound in Alaska, south through British Columbia, Washington, and Oregon, and into the mountains of northern California (10). The wood is quite valuable, with individual logs often commanding hundreds to thousands of dollars on the export market (2,9). Although making up less than 5% of the timber volume in southeastern Alaska (11), the 1.1 million cubic meters of Alaska-cedar growing stock (8) are thus an important segment of the forest resource.

At several locations in southeastern Alaska, trees of *C. nootkatensis* have been dying in large numbers for more than 75 yr (Figs. 1–3). Mortality was first documented in 1909, when Sheldon (16) commented about forests around Pybus Bay on south Admiralty Island: "Vast areas are rolling swamps with yellow cedar, mostly dead." Dead cedar were reported again in 1927 on Kupreanof Island (*unpublished*, on file at Forestry Sciences Laboratory, Juneau, AK) and 27 yr later, when McCambridge (13) found that bark beetles (*Phloeosinus* sp.) commonly infested dying Alaska-cedars, especially those growing on muskegs and other low-quality sites. Since 1954, mortality has been reported (8,12) throughout the Alexander Archipelago (Fig. 1); at least 9,700 ha of forest land have been affected (18).

Decline and mortality in Alaska-cedar have been attributed to *Phloeosinus* bark beetles (4,12,13), root disease (12,17), and environmental influences (1). The objectives of this paper are to describe the decline and death of cedar trees and stands and to collate and interpret available information on the disease.

Accepted for publication 25 June 1984.

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MATERIALS AND METHODS

Decline and death of individual trees. Several hundred dead and dying Alaska-cedar trees throughout southeast Alaska were examined during a 5-yr period. In 1981, 27 trees near Slocum Arm (Chichagof Island, Fig. 1) were felled, excavated, and examined in detail along their crowns, stems, and roots for symptoms and signs of biotic agents possibly involved with decline. We attempted to isolate fungi from symptomatic tissues, using malt-extract agar, potato-dextrose agar (PDA), and two media selective for *Phytophthora* spp. (P. Hamm, *personal communication*).

Trees selected for excavation expressed an array of crown symptoms, with 10–95% crown fullness and color variations from yellow-brown to dark green. The estimates of percent foliage retention or crown fullness were based on the amount of foliage we considered would have been present if all twigs had contained a normal contingent of foliage.

Because of uncertainty concerning the role of *Phloeosinus* beetles in decline of Alaska-cedar (3,4), several hundred dead and dying cedars around Slocum Arm were examined specifically for attack by *Phloeosinus* sp.

Decline and death of cedar stands. A composite map based on observations made over the past 15 yr during annual aerial surveys for forest pests was made of the distribution of cedar mortality in southeastern Alaska.

To characterize cedar decline and mortality on a stand basis, we surveyed forested lands around Slocum Arm (Fig. 1), where large populations of Alaska-cedar occur within an array of stand types. Thirteen stands were selected for ground survey. Selection was not random or based on the relative occurrence of each stand type, thus data were not statistically analyzed but were tabulated for comparative purposes.

Within each stand, a randomly chosen point marked the center of a 0.08-ha circular plot. Two similar plots were

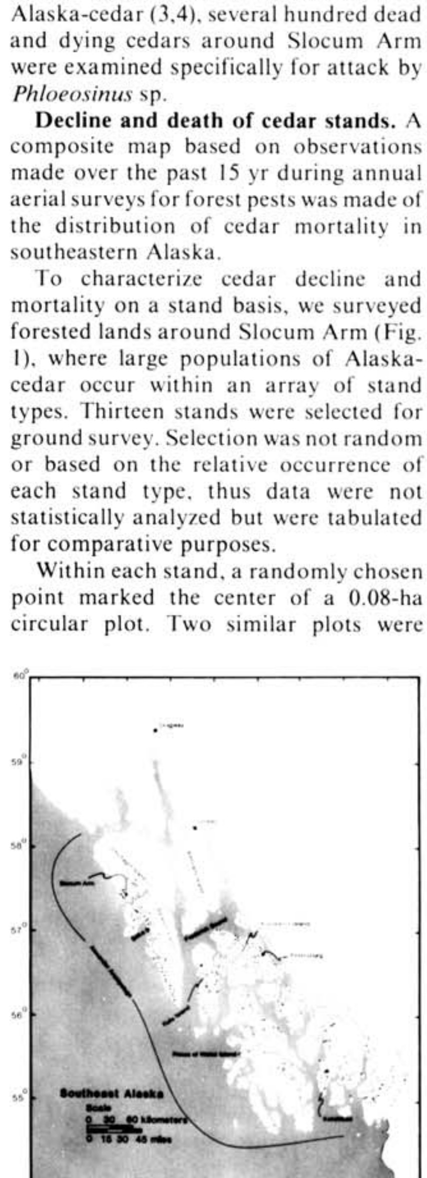

Fig. 1. Locations of cedar mortality (•) recorded during aerial surveys from 1968 to 1982.

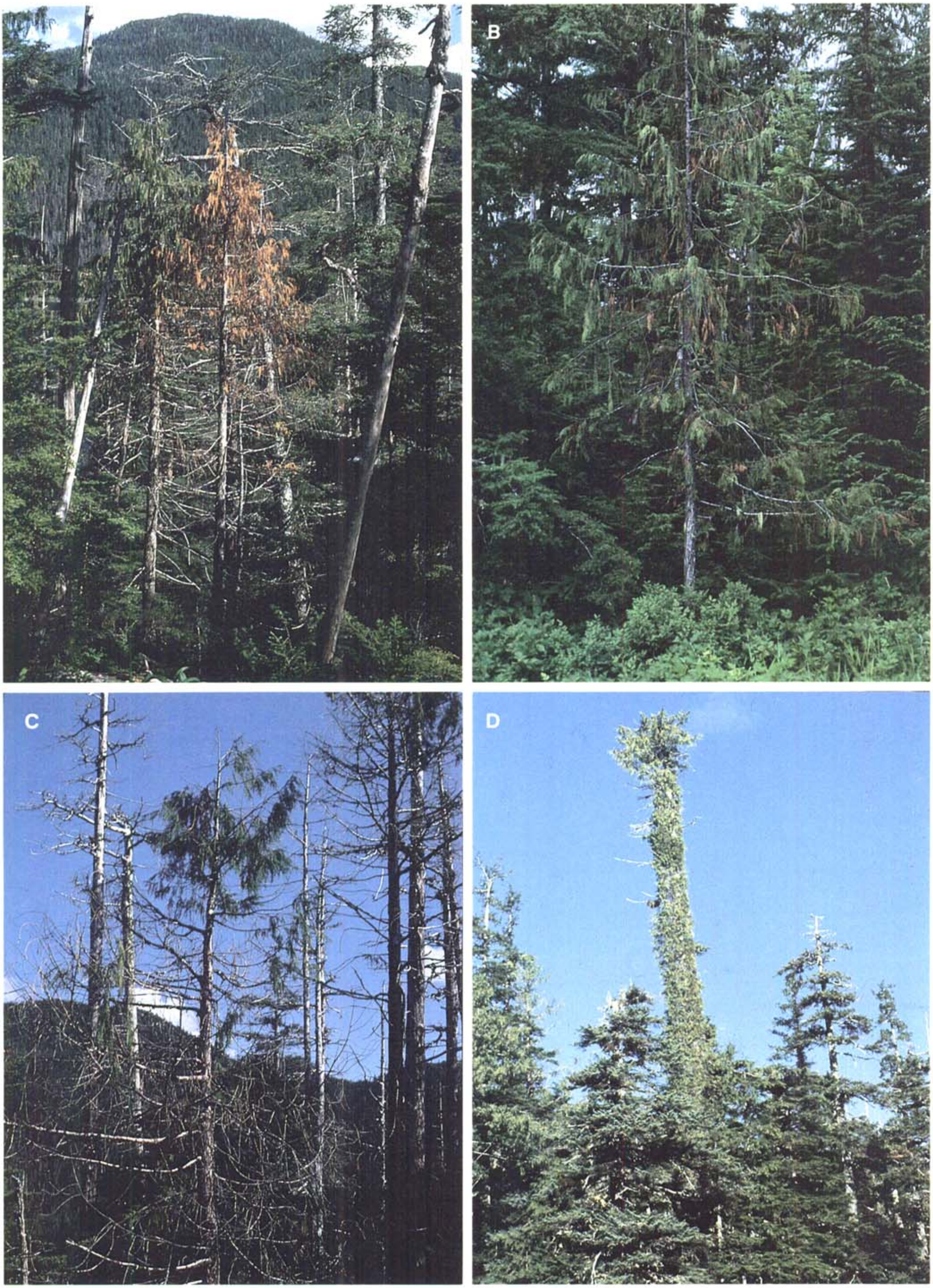

Fig. 2. Crown conditions of declining and recently killed Alaska-cedar trees. **(A)** Tree with relatively full crown that died rapidly and recently. **(B)** Live tree with crown in early stages of gradual decline. Note wilted appearance and variously colored foliage. **(C)** Declining tree with green but sparse crown. **(D)** Tree with extensive epicormic branching along stem.

established 61 m from the first at bearings of 30 and 330 degrees. This pattern occasionally required on-site modifications because of access, boundary locations, and terrain. For all trees greater than 15 cm dbh, we recorded species, dead or alive, dbh, and total height. For cedar trees, we estimated retention of foliage to the nearest 10%. Foliar colors were also categorized in 10% increments as dark green, green, light green, yellow-green, yellow, yellow-brown, and brown. Declining cedars, as indicated by off-color or thin crowns, were examined for insects or disease organisms by inspecting foliage, bark, and cambium. For dead trees, time since death was estimated by judging the degree of needle, twig, branch, and bark retention (5). Trees were grouped as having died within the last 5, 6–10, 11–20, or more than 20 yr.

Fig. 3. Stand showing extensive mortality and decline of Alaska-cedar.

Cedars with at least 50% live foliage and an overall color of yellow-green or darker green were classified as healthy for purposes of this survey; all others were classified as declining. This procedure allowed us to compare decline in different stands.

RESULTS

Decline and death of individual trees. Trees of all sizes, ages, and crown classes have been affected. Some trees appear to die within a few years; their crowns lose little foliage while changing from green to shades of yellow and finally to brown (Fig. 2A). Other trees appear to decline over a longer period; their crowns gradually decrease in fullness as they change color. Crowns of such trees often contain varying proportions and shades

Fig. 4. Discoloration of inner phloem and cambium at the base of a dying Alaska-cedar. This symptom was common, but not omnipresent, on dying trees. Other than *Armillaria* sp., no known pathogenic fungi were isolated from such tissues.

Fig. 5. Elongated scars common on Alaska-cedar but not considered indicators or causes of decline.

of green, yellow, and brown foliage (Fig. 2B). Crown fullness in trees showing gradual decline may slowly drop to as low as 10% live foliage before death (Fig. 2C). Some affected trees respond to loss of foliage by producing short, bushy, epicormic branches along the bole (Fig. 2D). We interpret this as a form of recovery from earlier decline, although the longevity of such trees is unknown.

Diameters (at breast height), heights, and ages of the 27 excavated trees ranged from 8.6 to 17.3 cm, 5.5 to 14 m, and 118 to 225 yr, respectively. Eight trees had 85% or more foliage retention and were considered healthy from crown appearances; the remaining 19 were considered declining. Diameter growth of 17 declining trees had been reduced during the previous 5 yr, but only two of the eight healthy trees showed this trend. This prolonged growth reduction indicated that the trees had been under stress for several years.

On most excavated trees, many fine roots were dead and water-soaked and bark was easily removed from wood. Soil around most excavated trees was moist with a perched water table often present within the rooting zone. This condition was not unexpected because annual precipitation in the area averages 210 cm (6).

Mycelial fans of *Armillaria* sp. occurred in 11 trees. Infected trees ranged in crown condition from light green and 90% full to yellow-brown and only 10% full. Therefore, there was no obvious relationship between the presence of *Armillaria* sp. and the condition of a tree's crown. *Armillaria* was common, but not omnipresent, on recently killed cedar trees throughout the area.

Thirteen trees, including seven infected with *Armillaria* sp., had discolored inner bark extending in a roughly triangular shape several centimeters up the stem from the roots (Fig. 4). Two additional trees had a similar symptom on the main root distal to the root collar. We isolated fungi from the leading edge of this stained region on 14 trees. Although this symptom is similar to that caused by *Phytophthora lateralis* Tucker & Milbrath on *C. lawsoniana* (Murr.) Parl. (14), no pythiacious fungi were isolated. The only known pathogen obtained was *Armillaria* sp.; however, four unidentified fungi that were distinguished from one another by cultural characteristics apparent on PDA medium occurred in, respectively, 8, 5, 4, and 3 of these 14 trees. Identification and pathogenicity testing of these fungi are in progress.

Regardless of crown condition, cedar trees frequently displayed dead decorticated strips that extended upward from the base from one to several meters (Fig. 5). Twelve of the 27 excavated trees, including three with relatively green and full crowns, were scarred. These scars were of unknown origin, although damage by bears has been suggested as a possible cause (15). Some scars were only a few years old as indicated by recently stripped bark (probably the activity of bears). Other scars were estimated to be decades old as evidenced by extensive callus along the margins and thoroughly decayed sapwood within the scar. Some scars girdled more than 50% of the stem's basal circumference; others girdled less than 5%. Because scars occurred on healthy trees as well as those in all stages of decline, we do not consider their presence to be an indicator or cause of the problem.

Four of the 19 declining trees, but none of the healthy ones, were attacked by *Phloeosinus cupressi* Hopkins—the only *Phloeosinus* sp. that has been confirmed on *C. nootkatensis* in southeastern Alaska. Two of the trees attacked by beetles had primarily yellow-brown foliage and 10–20% foliage retention; the other two had some off-green foliage mixed with the yellow-brown and 60 and 65% foliage retention. Three of the trees attacked by beetles were also infected with *Armillaria*.

Evidence of *P. cupressi* was found in only 14 of the several hundred Alaska-cedar trees examined; of these, seven were currently under attack. These trees were growing either on a muskeg fringe or on gentle slopes near muskegs and ranged from 6.8 to 25 cm dbh. Some dead trees with evidence of past attack by *P. cupressi* were larger, indicating no real preference by beetles for hosts of a certain stem size.

Retention of foliage on cedars freshly attacked by beetles ranged from 5 to 70%. This remaining foliage was typically half brown and half either gold or yellow-green. Subsequent observations of other trees freshly attacked by *P. cupressi* indicated a consistently similar crown coloration.

Decline and death of cedar stands. Figure 1 shows known locations of cedar mortality in southeastern Alaska. South of Frederick Sound (Fig. 1), Alaska-cedar and western redcedar (*Thuja plicata* Donn ex D. Don) often occur on the same site. From aerial observations, it is difficult to distinguish species of dead trees. Thus, locations south of Frederick Sound can be identified from the air only as dead cedar. On the ground, dead stems of each species can be readily distinguished, and examinations in several stands south of Frederick Sound have shown mortality to be occurring in Alaska-cedar.

Characteristics of decline and mortality vary considerably among stands of Alaska-cedar (Fig. 3). Some stands show recent and acute mortality, with most dead trees having red-brown foliage and intact bark. In other stands, most dead cedars appear as barkfree, white snags. Many stands contain a mixture of long-dead snags, recently killed stems, and chronically declining trees. Regardless of overstory characteristics, regeneration is sparse or absent in many affected stands.

Timber volumes and characteristics of cedar within the stands surveyed at Slocum Arm showed considerable diversity (Table 1). Gross volumes were

Table 1. Species composition, timber volumes, and characteristics of Alaska-cedar in 13 stands sampled near Slocum Arm, AK

Stand	Species composition[a]			Total stand volume[b]	Cedar volume[b] (m^3/ha)			Total no. of cedars[c] (live and dead)	Percentage of cedars dead			Time since death (yr) (% of all dead cedar)				Percentage live cedars showing decline		
no.	C	H	S	(m^3/ha)	Live	Dead	Total		Total	<15 cm dbh	≥15 cm dbh	≤5	6–10	11–20	>20	Total	<15 cm dbh	≥15 cm dbh
1	10	80	10	163	2	0	2	2	0	0	0	0	0	0	0	...[d]	...	...
2	2	50	30	152	35	0	35	83	4	5	4	3	25	50	25	11	12	11
3	50	40	10	124	57	31	88	22	9	0	11	0	0	50	50	10	0	12
4	70	20	10	213	147	10	157	124	10	13	8	22	0	33	45	21	34	16
5	50	50	10	223	53	6	59	94	10	12	9	7	0	33	60	28	41	24
6	60	30	10	163	79	11	90	70	6	17	28	0	12	4	84	4	14	0
7	80	20	10	177	55	79	134	279	37	21	57	16	38	35	11	47	37	70
8	80	20	10	253	112	77	189	124	40	23	45	52	12	10	25	40	43	38
9	80	20	10	144	72	43	115	94	43	25	44	26	5	53	16	50	50	50
10	80	10	10	161	29	106	135	393	44	32	79	39	26	26	9	47	43	90
11	60	30	20	162	56	31	87	62	39	25	43	26	26	26	22	61	67	58
12	50	50	10	272	97	33	130	45	49	67	42	0	0	4	96	9	0	11
13	80	20	0	199	36	114	150	317	79	82	77	5	9	30	56	29	28	31

[a] Live and dead trees ≥15 cm dbh; C = Alaska-cedar, H = western hemlock and mountain hemlock, and S = Sitka spruce. Because 10% was the smallest occurrence category used, some stands totaled 110%.

[b] Gross volumes including dead trees for all stems greater than 15 cm dbh. Net volumes would average about 40% less. Conversion factor: 1,000 board ft = 3.96 m^3.

[c] Actual numbers examined, not trees per hectare.

[d] Too few cedar trees to calculate.

reasonably high considering Alaska-cedar's reputation for predominating on muskeg and other low-quality sites (7,15). Stands 4, 8, 12, and 13 had particularly high volumes, with cedar as a major species (Table 1). In three of these commercially attractive stands, more than 25% of the cedar volume was dead, as it was in five of the other nine stands.

In six of the eight stands with more than 25% of the cedar volume dead, 29% or more of the live cedar were also declining (Table 1). Furthermore, only stands containing a low volume of dead cedar (stands 4, 5, and 6) had substantially more small trees declining than large ones. Only stand 12 had markedly greater mortality among small cedars than large ones. All cedar mortality in stand 12, except for one large tree, occurred more than 20 yr ago.

Only three stands had enough small (< 15 cm dbh) and large (≥ 15 cm dbh) cedars to compare mortality by tree size and time since death (Table 2). Stand 13 had the greatest cedar mortality (79%, Table 1). More than 80% of all dead cedars, regardless of size, were dead for at least 10 yr and more than 50% were dead for at least 20 yr (Table 2). In addition, nearly one-third of the live cedar trees, both large and small, were declining (Table 1). In contrast, most large overstory trees and small understory trees in stands 7 and 10 that died had been dead for 5–20 yr; only a few small trees died more than 20 yr ago (Table 2). Within the past 5 yr, mortality among small trees in these stands has been nearly twice that of large trees (Table 2); however, nearly twice as many large live trees as small ones are declining (Table 1).

Many declining and dead trees were infected with *Armillaria* sp.; however, few were attacked by *P. cupressi*. There was no apparent relationship in the occurrence of either organism to tree size. Evidence of these organisms was difficult to detect in trees dead a long time. Other than elongated scars, there was little other visual evidence of direct attack by organisms that could be related to tree death.

Table 2. Mortality of Alaska-cedar by tree size and time since death in stands 7, 10, and 13

Stand no.	Time since death (yr) for cedars < 15 cm dbh (% of dead cedar)				Time since death (yr) for cedars ≥ 15 cm dbh (% of dead cedar)			
	≤5	6–10	11–20	>20	≤5	6–10	11–20	>20
7	25	50	22	2	13	34	39	14
10	49	26	22	3	27	25	32	16
13	6	11	31	51	4	8	29	59

DISCUSSION

Extensive mortality of Alaska-cedar has been recorded at many locations in southeastern Alaska; however, when or where it first occurred is unknown. Also unknown is whether mortality and decline started in different locations at about the same time, whether they have occurred since initiation at any one place in a continuous or sporadic manner, or whether areas currently showing decline and mortality are expanding in size.

Stand survey data indicate that decline and mortality in smaller understory trees occurred either along with or after decline and mortality in larger overstory trees. In stands with more than 25% dead cedar, small trees do not appear to die and decline sooner or in a greater proportion than large trees.

Declining trees express an array of crown symptoms. We consider yellow, gold, and brown to be the last shades in the progression of crown color changes that take place as cedars die. Because fresh beetle attacks were only found on trees with these crown colors, a host tree must be substantially debilitated before it can be attacked successfully by an endemic population of *P. cupressi*.

Even though decline and mortality of Alaska-cedar are prevalent at Slocum Arm, current and past occurrences of *P. cupressi* have been limited. Few cedar snags have old beetle galleries, which suggests that extensive cedar mortality occurred primarily in the absence of *P. cupressi*. In recently killed and currently dying cedars, the pattern was the same—only a few trees showed signs of beetle activity. Thus, we do not consider the cedar bark beetle to be a primary cause of Alaska-cedar decline, but rather, a secondary agent associated with trees already under severe and recognizable stress.

Armillaria sp. frequently occurred on dead and dying cedars but not consistently on recently killed trees, suggesting that it is not the primary cause of decline and mortality. Attempts to isolate other known pathogens, including *Phytophthora* spp., were unsuccessful. Other than the relatively rare occurrence of *Phloeosinus cupressi* and common occurrence of elongated scars, there was little evidence of attack by organisms on declining trees. The absence of a recognizable biotic cause of mortality and decline, coupled with the temporal pattern of cedar death and decline by tree size, are consistent with the pattern of mortality and decline that might be expected from an environmental stress such as winter drying—a cause suggested by Anderson (1).

Future harvesting within old-growth forests of southeastern Alaska will include areas that support stands of Alaska-cedar (8). Decisions concerning harvesting techniques, salvage operations, reforestation plans, thinning regimes, etc., in such stands require data on the cause and consequences of the extensive decline and mortality that is occurring. Because cedar regeneration is sparse or absent in many affected stands, the commercial future of the species on sites expressing decline is questionable. The information in this report does not provide the details necessary for making prudent management decisions but does provide the manager with an awareness of the problem and the scientist with a basis for planning future work.

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