Root Disease Threat Minimal in Young Stands of Western Hemlock and Sitka Spruce in Southeastern Alaska

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ABSTRACT

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The development of root diseases in young, managed stands of western hemlock and Sitka spruce in southeastern Alaska has been a concern because organisms that incite root disease are known to occur, and the same root disease organisms cause problems in similar stands in British Columbia, Oregon, and Washington. In this study, however, colonization by *Heterobasidion annosum* was rare in standing live trees and their survival was poor in inoculated and noninoculated trees and stumps of young-growth Sitka spruce and western hemlock at several locations in southeastern Alaska. Furthermore, *H. annosum* survived less than 5 yr in naturally infected stumps of either species. The high rainfall and associated high water content of stumps (generally well over 100% moisture content) and low temperatures common to the region appear to limit colonization by *H. annosum*. In contrast, stump colonization by *Resinicium bicolor* and presumably saprophytic *Armillaria* spp. was common, but mortality in adjacent trees was rare. These data suggest there is little likelihood that root disease fungi will damage young, managed stands of Sitka spruce and western hemlock within the current 90- to 120-yr rotation.

Additional keywords: biological species, environmental conditions, wood moisture content

Butt and stem decay are common in old-growth trees in southeastern Alaska (15). Gross timber volumes in affected stands often have been reduced by one-third or more (8) through rot caused primarily by hymenomycetes, including *Heterobasidion annosum* (Fr.) Bref. (*Fomes annosus* (Fr.) Cke.), *Armillaria* spp., and *Phaseolus schweinitzii* (Fr.) Pat. (*Polyporus schweinitzii* Fr.) (13). These same fungi frequently cause root disease in young trees. For example, *H. annosum* is of particular concern in management of young stands of western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) in coastal British Columbia, Washington, and Oregon (3,17,35) and plantations of Sitka spruce (*Picea stichensis* (Bong.) Carr.) in the British Isles (22–24).

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Over 120,000 ha of old-growth Sitka spruce/western hemlock forest (SS/WH) have been harvested through clearcutting on the mainland and islands of southeastern Alaska. This harvest continues on 4,000-8,000 ha annually (12). Young stands of SS/WH have regenerated naturally into these cut units, generally with adequate stocking and vigorous growth (11). At age 15–20, these stands are of a size suitable for precommercial thinning. Such operations are being conducted, creating numerous stumps that may serve as infection courts for root disease fungi.

Spores of *H. annosum* and *Armillaria* spp. are relatively common in these young stands (27,28), even though basidiocarps of *H. annosum* are rare (27,28) and infection of small stumps by *H. annosum* is infrequent (27,33). Stump colonization by *Armillaria* spp., probably by contact of its roots with rhizomorphs or infected roots rather than by spores (36), is considerably more frequent (27,33), but death of trees near infected stumps is rare.

Even though data from young stands of SS/WH in southeastern Alaska indicate that stump colonization by *H. annosum* is limited and that damage from *Armillaria* spp. is minor (27,28,33), there still is concern with the potential for root disease to develop. This concern arises from the prevalence of decay by these fungi in old trees harvested from sites now occupied by young SS/WH, from the overall abundance of inoculum, and from the frequent colonization of thinning stumps by *H. annosum* in nearby British Columbia (18,34). In addition, stumps previously sampled for *H. annosum* in southeastern Alaska (27,33) were small (< 15 cm in diameter) and thus were excluded from sampling a possible infection court of larger stumps with heartwood.

This paper reports on several studies designed to further clarify whether root diseases pose a threat to the productivity of young stands of SS/WH in southeastern Alaska.

MATERIALS AND METHODS

Study locations. The island topography of southeastern Alaska precludes accurately locating small study sites on a map with a scale suitable for publication. Approximate locations for most sites mentioned here are mapped elsewhere (4,27,33). In addition, all sites are named for the nearest geographic entity, as denoted by Orth (20).

Reexamination of thinning stumps. In 1978, young Sitka spruce, western hemlock, and mountain hemlock (*T. mertensiana* (Bong.) Carr.) trees were cut at various locations in southeastern Alaska (27). Half of the stumps were inoculated with cultures of *H. annosum*, and all stumps were sampled 6–14 mo later for *H. annosum* and *Armillaria* spp.

(27). These stumps were reexamined 5–6 yr later (during 1983–1984) for decay, mycelial fans, and rhizomorphs of *Armillaria* spp. They were measured for moisture content (MC) and sampled for *H. annosum*.

To measure MC and to sample for *H. annosum*, a disk (1–2 cm thick) was cut from the top of each stump and discarded. Another disk (2–4 cm thick) was cut, numbered on the underside, transported to Juneau, cleaned of bark and debris, and weighed. After weighing, disks were individually wrapped in moist toweling and incubated in dark chambers at about 20 C (27). After incubation for 2–3 wk, the upper surface of each disk was examined microscopically for *Spiniger meineckellus* (Olson) Staplers (*Oedocephalum lineatum* Bakshi), the conidial stage of *H. annosum*. Other fungi also were noted and attempts were made to culture and identify common ones. Disks were then oven-dried at about 40 C for 72 hr and weighed again. The MC of each disk was calculated on a percent dry weight basis.

Except for those at Yakutat, stumps with *H. annosum* in 1979 were removed from the soil by digging and pulling with a block and tackle and their roots were examined for decay characteristic of *H. annosum*. Symptomatic tissues were incubated and examined for *S. meineckellus*, as described above.

Data were summarized by location and tree species for MC and occurrence of *H. annosum*, *Armillaria* spp., and *Resinicium bicolor* (Fr.) Parm. (*Odontia bicolor* (Fr.) Bres.), a fungus common on the disks.

Inoculation of young trees with *H. annosum*. Crop trees in young stands of SS/WH near those where stumps were sampled at Juneau, Hollis, and Petersburg were inoculated with *H. annosum*. Thirty western hemlock and 30 Sitka spruce at Hollis and Juneau, and 40 of each species at Petersburg, were inoculated in 1980; 12 more trees of each species were inoculated at Juneau in 1981. Two roots that emerged from the root collar at an angle of >40° from one another were selected on each tree. An inoculation point 1.25–5 cm in diameter and within 25–50 cm of the tree base was located on each root. Roots on half of the trees in each stand were damaged by exposing sapwood along the face of the root at the inoculation point. One root on each tree received an inoculum segment colonized by *H. annosum*, the other received an uncolonized, control segment. Inoculum segments were tied to roots at the selected point and covered with soil.

To generate inoculum, red alder (*Alnus rubra* Bong.) branch pieces (10–12 cm long, 3–6 cm in diameter) were placed into jars filled about one-third full of water. They were sterilized in an autoclave for 2–3 hr, seeded with agar plugs containing *H. annosum*, and incubated for at least 6 mo before use. This method was used because it worked well for preparing woody inocula of *Armillaria* spp. (32) and *Phellinus weirii* (Murr.) Gilb. (10).

Isolates obtained from airborne inocula at Hollis and Petersburg were used, respectively, at these locations, and an isolate obtained from airborne inocula at Sitka was used in the 1980 trial at Juneau. The 1981 trial at Juneau used an isolate obtained from an infected stump at Saginaw Bay (27).

A few inoculated roots at each location were examined in 1981 or 1982; the rest were examined in 1984. Segments were collected and examined for colonization by *Armillaria* spp. They were split longitudinally, incubated like the stump disks, and examined microscopically on all surfaces for *S. meineckellus*. Roots were examined for indications of infection. Those with stain or incipient decay were collected, incubated, and examined for *S. meineckellus*. Data were summarized by location and tree species for occurrence of *H. annosum* on inoculum segments and roots. Similar data were collected for occurrence of *Armillaria* spp. at Juneau and Hollis. Along with these inoculations, various inoculum segments colonized by different isolates of *H. annosum*, including the one from Saginaw Bay, and noncolonized control segments were buried at the Juneau site in 1981 and 1982 and were examined periodically thereafter by the above procedures for viability of *H. annosum* and colonization by *Armillaria* spp.

Examination of large-diameter thinning stumps and trees. The U.S. Forest Service has established a series of stand density plots in southeastern Alaska to evaluate tree growth responses to various intensities of thinning (4). Several of these plots are located in the most mature stands of young-growth SS/WH in southeastern Alaska and contain thinning stumps that are considerably larger than those previously sampled (27). In seven of these plots that had been thinned from 5 to 8 yr earlier, stumps ranging from 5 to 50 cm in diameter were measured and sampled for decay fungi and MC, as described above. Over 650 stumps, including 90 or more from six plots and many over 35 cm in diameter from all plots, were sampled. Data were summarized by location and tree species for MC and occurrence of *H. annosum*, *Armillaria* spp., and *R. bicolor*.

Few stands of SS/WH in southeastern Alaska were thinned 30 or more years ago. However, records are available for one stand on an island in Karta Bay that was thinned in 1950 (6). The stand is now about 130 yr old. On this site, 15 western hemlock and 15 Sitka spruce trees were drilled at the base with a portable gas-powered drill with a 2-cm-diameter ship's auger. One hole was drilled at a 45-degree angle down from the base of each tree about 15 cm into the interior of the root collar region. Wood chips obtained from the drillings were collected and incubated to determine frequencies of live-tree infection by *H. annosum* (1).

Inoculation of large stumps. In six of the more mature stands of young-growth SS/WH in southeastern Alaska (near Douglas, Eagle River, Tuxekan, Shaheen Creek, Edna Bay, and Warmchuck Inlet), 40 Sitka spruce and 40 western hemlock trees from 20 to 50 cm in diameter at breast height were selected. These trees were selected in pairs of the same species and comparable size so that the neighbors were within 1 m of each other, and one member of each pair had a major lateral root growing towards the other. The latter trees were felled to leave a stump about 20 cm above the ground.

At each site, 15 stumps of each species were scribed down the middle and, immediately after felling in 1984, each half of the surface was inoculated with one of two isolates of *H. annosum*. Inoculum was prepared by placing 5 ml of sterile distilled water into a 25-ml culture tube in which *H. annosum* had been growing on malt agar for 2 wk. Each tube was shaken briskly, and the slurry of conidia, mycelial fragments, and agar was poured and brushed onto each stump half (27). On larger stumps, two or three tubes were used for thorough coverage. One isolate came from a colonized stump at Saginaw Bay and the other from airborne inoculum. The other five stumps of each species on each site received only a water slurry from malt agar. This method was used instead of basidiospores because the scarcity of *H. annosum* sporocarps in southeastern Alaska (27) precluded collection of sufficient basidiospore inoculum. Asexual spores and mycelium of *H. annosum* are adequate sources of inoculum (14).

Two years after inoculation, all stumps were sampled for *H. annosum* and other decay fungi, as described above.

Inoculation of stumps with two isolates was an attempt to enhance establishment of *H. annosum* because the relative ability of the isolates to infect, survive, and decay stump wood was not known. The trees were paired because we planned to wait several more years and then fell trees paired with stumps found to be infected with *H. annosum* to determine whether the fungus had grown from colonized stumps to adjacent live trees (22).

For these data, contingency tables were used to analyze the statistical significance of differences associated with time, MC, or host species. Unless otherwise noted, results discussed were significant ($P \leq 0.05$).

RESULTS

Reexamination of thinning stumps. Excluding Yakutat, *H. annosum* was found in 36 of the 340 stumps in 1979: 12 of 170 hemlock and 24 of 170 spruce (27). In 1983, 330 of these stumps were reexamined and *H. annosum* was found in only one hemlock stump from Hollis; it also had been infected in 1979. In addition, *H. annosum* was not found in any excavated root systems.

In contrast, *Armillaria* spp. were common on stumps and root systems in 1983. At Juneau and Hollis, their occurrence increased substantially from the levels recorded in 1979 (Table 1). No trees near infected stumps were, however, attacked by *Armillaria* spp. *R. bicolor* also was common; it occurred in 36% of the stumps, including some of both species on all sites. *Armillaria* spp. and *R. bicolor* cooccupied seven spruce and five hemlock stumps. To our knowledge, this is the first recovery of *R. bicolor* in Alaska (29).

Neither *Armillaria* spp. nor *H. annosum* were found in mountain hemlock stumps; *R. bicolor* was recovered from two of these stumps. In 1979, seven of these 64 stumps had *H. annosum*, but none had *Armillaria* spp. There was a significant difference between the MC of mountain hemlock stumps and either western hemlock or Sitka spruce (Table 2). Of the mountain hemlock stumps, 73% had an MC <100%. Of the Sitka spruce and western hemlock stumps, 96% had an MC >100%; 22% of these stumps had an MC >200%. The MC of Sitka spruce and western hemlock stumps also differed significantly, with spruce stumps being wetter. However, development of *Armillaria* spp. in stumps of either species was not inhibited by a high MC (Table 2). Colonization by *Armillaria* spp. was more common on spruce stumps than on hemlock. However, on western hemlock stumps with an MC >150%, colonization by *Armillaria* spp. was significantly more frequent than on those stumps with a lower MC (Table 2).

Inoculation of young trees with *H. annosum*. No inoculated trees became infected with *H. annosum*, and only three of the 183 inoculum segments collected in 1984 (2 or 3 yr after placement) still contained *H. annosum*. Whereas *H. annosum* could have died out in the inoculum before use, segments inoculated with two different isolates and left incubating in the jars did form viable sporophores. In contrast, *Armillaria* spp. occurred in 50% of the segments inoculated with *H. annosum* at both Juneau and Hollis and in 75 and 45% of the control segments at these respective locations.

Inoculum segments buried at Juneau in 1981 and 1982 were periodically sampled through November 1983. In this 1983 sampling, *H. annosum* was no longer detected, but *Armillaria* spp. occurred in all of the control segments and in half of those inoculated with *H. annosum* and buried in 1982. Because *H. annosum* was not recovered in 1983, sampling was suspended.

Examination of large-diameter thinning stumps and trees. Colonies of *H. annosum* were found on disks from only three of the 658 stumps, one from each of three different locations. Two of these disks were from "live" stumps (cambium still viable and callus forming over stump surface, indicative of a graft with roots of a nearby live tree), and the nature of the colony suggested that it originated from surface contamination during cutting (27). These two stumps were not considered to be colonized by *H. annosum*. Thus, only one 12-cm-diameter western hemlock stump from Old Frank's Creek appeared to be naturally colonized by *H. annosum*. In addition, *H. annosum* was not detected in the live trees sampled by drilling in the thinned stand at Karta Bay.

In contrast, many stumps from all sites contained *Armillaria* spp. and some were colonized by *R. bicolor*; a few had both fungi (Table 3). However, none of these fungi sporulated on these or any other sampled stumps. The MC of disks cut from these stumps was typically between 100 and 200%, with Sitka spruce showing greater variation than western hemlock (Table 4). In contrast to the small stumps from younger stands (Table 2), few of these larger stumps had moisture contents over 200%. Again, colonization by *Armillaria* spp. was common, particularly in stumps with a high MC (Table 4).

Inoculation of larger stumps. After 2 yr, only 5% of the 240 stumps contained *H. annosum*. Of these, there were three western hemlock and one Sitka spruce at Edna Bay, two spruce and one hemlock at Tuxekan, three hemlock at Shaheen, and one hemlock at Eagle River; all had been inoculated. *Armillaria* spp. also were scarce, occurring on only one stump at each location. At all locations except Shaheen, *R. bicolor* occurred on a few stumps of both species.

DISCUSSION

Natural colonization of stumps by *H. annosum*, regardless of species, location, age, or size, was rare in southeastern Alaska. Even inoculation of stumps only led to occasional establishment of the fungus. In stumps where *H. annosum* was known to have been present, it was unable to persist over 5 yr. Attempts to inoculate standing live trees failed, and the trees sampled in stands thinned over 35 yr ago were not infected. Together, these data suggest that *H. annosum* is not a problem to management of young stands of western hemlock and Sitka spruce in southeastern Alaska even though spores of the fungus occur in young stands (27), as does decay in old-growth trees (13).

These data, and other reports (17,18,27,33), indicate that *H. annosum* becomes a less-common inhabitant of thinning stumps with time and increasing

Table 1. Occurrence of *Armillaria* spp. (percent of stumps colonized) in thinning stumps[a]

Location	Sitka spruce		Western hemlock		Average	
	1979	1983	1979	1983	1979	1983
Juneau	10	69	10	44	10	57
Petersburg	17	12	9	9	13	10
Hollis	19	57	19	44	19	51

[a] Based on 340 stumps in 1979 and 330 in 1983. Stumps created in 1978 (27).

Table 2. Moisture content (MC) and occurrence of *Armillaria* spp. in disks collected in 1983 from 1978 thinning stumps

Location[a] and species	Number of disks by percent of MC[b]				
	0–50%	51–100%	101–150%	151–200%	>200%
Juneau					
Sitka spruce	0	0	2 (0)	10 (50)	17 (88)
Western hemlock	0	0	18 (33)	8 (75)	1 (100)
Hollis					
Sitka spruce	0	3 (33)	16 (56)	33 (45)	18 (78)
Western hemlock	0	12 (17)	51 (25)	5 (100)	2 (100)
Petersburg					
Sitka spruce	0	0	4 (0)	28 (21)	35 (6)
Western hemlock	0	0	53 (11)	13 (15)	1 (0)
Petersburg					
Mountain hemlock	5 (0)	42 (0)	17 (0)	0	0
All Sitka spruce	0	3 (33)	22 (41)	71 (37)	70 (44)
All western hemlock	0	12 (17)	122 (20)	26 (50)	4 (75)

[a] Data for stumps at Hollis and Petersburg are pooled because month of thinning in 1978 did not affect moisture content in 1983 (27).
[b] Number of disks in each category for each species, followed in parentheses by the percentage of those disks containing an *Armillaria* sp.

Table 3. Occurrence of *Armillaria* spp. and *Resinicium bicolor* in stumps sampled on various stand density plots

Location	Number of stumps sampled[a]			Number infected with: *Armillaria* spp.			*R. bicolor*			Both fungi		
	WH	SS	Total	WH	SS	Total	WH	SS	Total	WH	SS	Total
Edna Bay I	40	50	90	31	38	69	8	6	14	3	3	6
Edna Bay II	53	52	105	37	30	67	7	9	16	3	6	9
Warmchuck	55	57	112	43	33	76	5	12	17	5	9	14
Heceta	45	65	110	21	17	38	7	12	19	2	4	6
Old Frank's Creek	68	48	116	52	40	92	11	12	23	8	4	12
Sand Pt.	8	3	11	8	3	11	1	1	2	0	1	1
Thorne River	68	46	114	36	28	64	10	4	14	4	3	7
Total	337	321	658	228	189	417	49	56	105	25	30	55

[a]WH = western hemlock, SS = Sitka spruce. Sizes and moisture contents for these stumps appear in Table 4.

Table 4. Moisture content (MC) and occurrence of *Armillaria* spp. in disks collected from stand density plots[a]

Stump diameter and species	Number of disks by percent of MC[b] 0–50%	51–100%	101–150%	151–200%	>200%
5–15 cm					
Sitka spruce	7 (14)	27 (37)	45 (60)	11 (82)	1 (100)
Western hemlock	0	9 (11)	75 (57)	17 (71)	0
16–25 cm					
Sitka spruce	2 (0)	14 (64)	59 (59)	26 (73)	6 (100)
Western hemlock	0	10 (20)	73 (68)	38 (87)	0
26–35 cm					
Sitka spruce	0	11 (36)	37 (62)	12 (83)	3 (67)
Western hemlock	0	5 (60)	47 (89)	19 (89)	1 (0)
>36 cm					
Sitka spruce	1 (100)	1 (0)	25 (64)	12 (83)	3 (67)
Western hemlock	0	2 (100)	12 (83)	3 (33)	0
Total					
Sitka spruce	10 (20)	53 (43)	166 (61)	61 (79)	13 (85)
Western hemlock	0 (0)	26 (27)	207 (70)	77 (82)	1 (0)

[a]Pooled across locations; see Table 3.
[b]Number of disks in each category for each species, followed in parentheses by the percentage of those disks containing an *Armillaria* sp.

latitude along the West Coast of North America. For example, 62% of the western hemlock stumps sampled in southern British Columbia were infected with *H. annosum*, but only 9% remained infected 5 yr later (17). Farther north along the coast of British Columbia, including the Queen Charlotte Islands, initial levels of infection in stumps from young, thinned stands were much lower: 11.7% for western hemlock, 23.6% for Sitka spruce, and 4% or less for both species for stumps with >10% of their surface area colonized (18). Although Morrison et al (18) were not able to resample stumps in these northern stands at a later date, they did find a substantial reduction in survival of *H. annosum* in 3-yr-old vs. 1-yr-old stumps in the same thinned stands. This reduction in fungal presence with time may reflect differences between fungal penetration and colonization of stump wood by *H. annosum* (27), or it may indicate that only a small stump area was colonized (<10%) and *H. annosum* was not able to persist (18).

With increasing latitude, lower temperatures (7) and higher rainfall (5) probably reduce the aerial population of *H. annosum* spores (25). Also, Redfern (22,24) suggests that in Britain infection of Sitka spruce stumps may be limited by high rainfall, an event that can occur on any date in southeastern Alaska (5,19), and that on sites with high rainfall, *H. annosum* is absent from stumps with a high MC, a result similar to that reported here.

Perhaps the high MC of these stumps reduces availability of oxygen to a level that inhibits growth of *H. annosum*, as indicated for white fir wetwood (37). The low temperatures common to southeastern Alaska could also affect fungal use of the limited oxygen available, as they would lower overall metabolic rates and inhibit evaporation of water from stump surfaces. The reduced ability of *H. annosum* to incite disease in such cool, wet, and oxygen-poor environments is discussed elsewhere (23,24,30). Interestingly, these same conditions may allow for ready colonization of stumps by *Armillaria* spp. (30).

The frequent occurrence of *Armillaria* spp. in thinning stumps agrees with data from northern British Columbia (18), where 32% of the nonpine stumps were infected with an *Armillaria* sp. identified as North American Biological Species (NABS) V. The NABS of *Armillaria* spp. in stumps from southeastern Alaska are not well documented, but NABS V and IX are common in the region (31,32). NABS V has been identified from two thinning stumps from Hollis (G. McDonald, *personal communication*). Curiously, colonization of stumps by *Armillaria* spp. was much lower in the stand near Petersburg than in stands at Juneau, Hollis, or any location where larger stumps were sampled (Tables 2 and 3). Spores of NABS V and IX were, however, present in the stand at Petersburg (28,32). Because these two species have limited pathogenic capabilities on coastal species and sites (16,32,36), their common occupancy of stump wood should be viewed not with alarm, but as a probable deterrent to spread of the limited *H. annosum* that may inhabit these stumps.

The limited colonization by *Armillaria* spp. on the larger stumps inoculated with *H. annosum* is attributed to the short time between cutting and sampling. Many of these stumps were "live," a characteristic that my observations suggest retards colonization by *Armillaria* spp. Interestingly, Redfern (22) suggested that "live" stumps of Sitka spruce are infected more readily by *H. annosum* than those that die rapidly after tree felling. The limited levels of colonization by *H. annosum* in southeastern Alaska do not allow for assessment of such stump conditions on colonization by this fungus.

Even though *R. bicolor* is a known root and stem-wound pathogen of Sitka spruce, its occurrence in these stumps is not viewed with alarm because it is rarely damaging (2). If commercial thinning operations are conducted, then logging wounds might become an exception because *R. bicolor*, as well as *H. annosum*, can enter such wounds in Sitka spruce and cause decay (21). Whether or not such decay will develop following injury to the boles of young trees in southeastern Alaska is currently under investigation (P. Hennon, *personal communication*).

R. bicolor also has been recovered from stumps of young Sitka spruce in the United Kingdom (22; B. Greig, *personal communication*), from stumps of western hemlock in southern British Columbia (17), and from decayed western hemlock trees in Washington state (9). Apparently, *R. bicolor* does not compete effectively with *H. annosum* for occupancy of stump wood in western hemlock and Sitka spruce (B. Greig, *personal communication*), as *Peniophora gigantea* (Fr.) Massee does in pine (26), and thus it is not an effective biocontrol agent for *H. annosum*.

In marked contrast with the conclusion of Wallis and Reynolds (35) that root and butt rot caused by *H. annosum* does pose a threat in managed stands in coastal British Columbia, my opposing conclusion agrees with a report for *H. annosum* on western hemlock in Oregon and Washington (9). To summarize, environmental conditions, the biological species of *Armillaria* that are present, and plans for relatively short (90–120 yr) rotations limit the likelihood that root disease fungi, particularly *H. annosum*, will cause problems in young, managed stands of Sitka spruce and western hemlock in southeastern Alaska.

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