Infection of Western Hemlock and Sitka Spruce Thinning Stumps by *Fomes annosus* and *Armillaria mellea* in Southeast Alaska

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ABSTRACT

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On four young-growth forest sites where airborne inoculum of *Fomes annosus* had been detected, 182 western hemlock and 182 Sitka spruce were cut and one half of the stumps inoculated with *F. annosus*. All stumps were examined 6–15 mo later for *F. annosus* and *Armillaria mellea*. Twelve percent of the western hemlock and 16% of the Sitka spruce stumps were infected with *A. mellea*. Of the stumps inoculated with *F. annosus*, 11% of the western hemlock and 15% of the Sitka spruce were infected; of the uninoculated stumps, 3 and 12%, respectively, were infected. On 13 experimental thinning plots scattered throughout southeast Alaska, *A. mellea* occurred in 18% and *F. annosus* in 1% of 351 western hemlock and Sitka spruce stumps remaining from trees cut 23–50 mo earlier. *F. annosus* was also detected, apparently for the first time, on mountain hemlock stumps.

Western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and Sitka spruce (*Picea sitchensis* (Bong.) Carr.) are the predominant conifers in virgin forests of southeastern Alaska (8). After portions of these old forests were clear cut, dense stands of mixed western hemlock and Sitka spruce regenerated naturally (7,8). There has been little thinning in these young forest stands, but current plans call for several thousand acres to be thinned before commercial harvesting.

Fomes annosus (Fr.) Cke. and *Armillaria mellea* (Vahl. ex Fr.) Quél. are common in the old forest (10), causing 45% of the cull volume in old-growth western hemlock and 6% in Sitka spruce (9). After the old trees are cut, both fungi can continue to survive in the stumps. Stump root systems can provide both an avenue for the fungi to spread and an inoculum source for infection of surrounding young trees by either *A. mellea* or *F. annosus*. Root rot, butt rot, and mortality can thus develop in young stands.

Further, *F. annosus* often builds up after consecutive thinnings in young hemlock stands (12,17,18) because spores infect freshly cut stump surfaces, followed by fungal colonization of stump and root wood and subsequent transfer of mycelium to adjacent living trees through root contacts.

Because little is known about the incidence of *F. annosus* and *A. mellea* in young forests of southeast Alaska, this study was undertaken to determine whether spores of *F. annosus* were present in young stands at different locations; whether fresh stumps of young western hemlock, mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.), and Sitka spruce became infected naturally by either *F. annosus* or *A. mellea* or could be successfully inoculated with *F. annosus*; and whether stumps of young western hemlock and Sitka spruce cut a few years earlier contained either fungus.

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MATERIALS AND METHODS

Presence of airborne inoculum. I selected seven naturally regenerated, 10- to 20-yr-old stands of mixed spruce and hemlock (adjacent to uncut old growth) for sampling (sites A–G, Fig. 1; Table 1). At each location, 20 wire mesh platforms were placed in a cleared area of about 9 m^2. Each month from December 1977 to November 1978, a disk of shore pine (*Pinus contorta* Dougl. ex Loud. var. *contorta*) 2–4 cm thick and 6–10 cm in diameter was cut by chain saw and placed on each platform. Ten disks were collected 3 hr after placement and 10 about 30 days later; they were wrapped in paper towels, moistened slightly, and put in plastic bags.

I avoided exposing the disks during or within 6 hr after rain or snow. When disks exposed for 30 days in winter became covered with snow, the platforms were placed on top of the snow for the next exposure. The 3-hr exposure was similar to that used to obtain rough measurements of airborne inoculum in the Pacific Northwest (11,13).

All disks were transported to Juneau, AK, removed from plastic bags, and incubated in dark chambers (13) for 8–14 days at about 20 C. After incubation, the exposed face of each disk was examined microscopically for *Oedocephalum lineatum* Bakshi, the conidial stage of *F. annosus*. Because *O. lineatum* was not observed on disks periodically exposed in the laboratory or in incubation boxes, its presence on disks from the field indicated deposition of *F. annosus* spores during exposure. The percentage of disks bearing colonies of *O. lineatum* was calculated for each exposure period on each site and compared.

Natural infection and inoculation of freshly cut stumps. In April, May, and June 1978, 30 western hemlock and 30 Sitka spruce were cut on sites E, C, and A, respectively (Fig. 1). Twelve more trees of each species were cut in July 1978 on site F. The stumps, 7–15 cm in diameter, were leveled to a height of about 15 cm and numbered.

I chose 15 stumps of each tree species (six on site F) at random for inoculation with *F. annosus.* Inoculum was prepared by placing 5 ml of sterile distilled water into a 25-ml culture tube in which *F. annosus* had been growing on malt agar for 2 wk. Each tube was shaken briskly, and the resulting slurry of conidia, mycelial fragments, and agar was poured onto each stump and brushed over the surface. Isolates of *F. annosus* obtained from pine disks exposed on sites A, C, and F were used on those sites. An isolate from a pine disk from site D was used on site E.

Forty more trees of each species were felled in August 1978 on site C and in September on site A; stumps were leveled to a height of about 15 cm and numbered. Ten randomly chosen stump surfaces of each species were treated in one of four ways: (a) control, no further treatment; (b) inoculate with culture slurry as described above; (c) brush debris from the stump surface, spray surface with ethanol, and flame; (d) treatment c followed by treatment b.

In May and August 1978, 32 mountain hemlock trees were felled near site C (64 trees). Stumps were cut level at about 15 cm and numbered. Half the stumps cut in May were randomly chosen and inoculated with the *F. annosus* isolate used on site C. Mountain hemlock stumps were sampled as described below in September 1979.

Six to 15 months after trees were felled (Table 2), a disk 1–2 cm thick was cut from the top of each stump and discarded. Another disk 2–4 cm thick was cut and numbered on the underside, the bark was peeled off, and all surfaces were brushed free of debris. The disk was then sprayed with ethanol, flamed, wrapped in paper

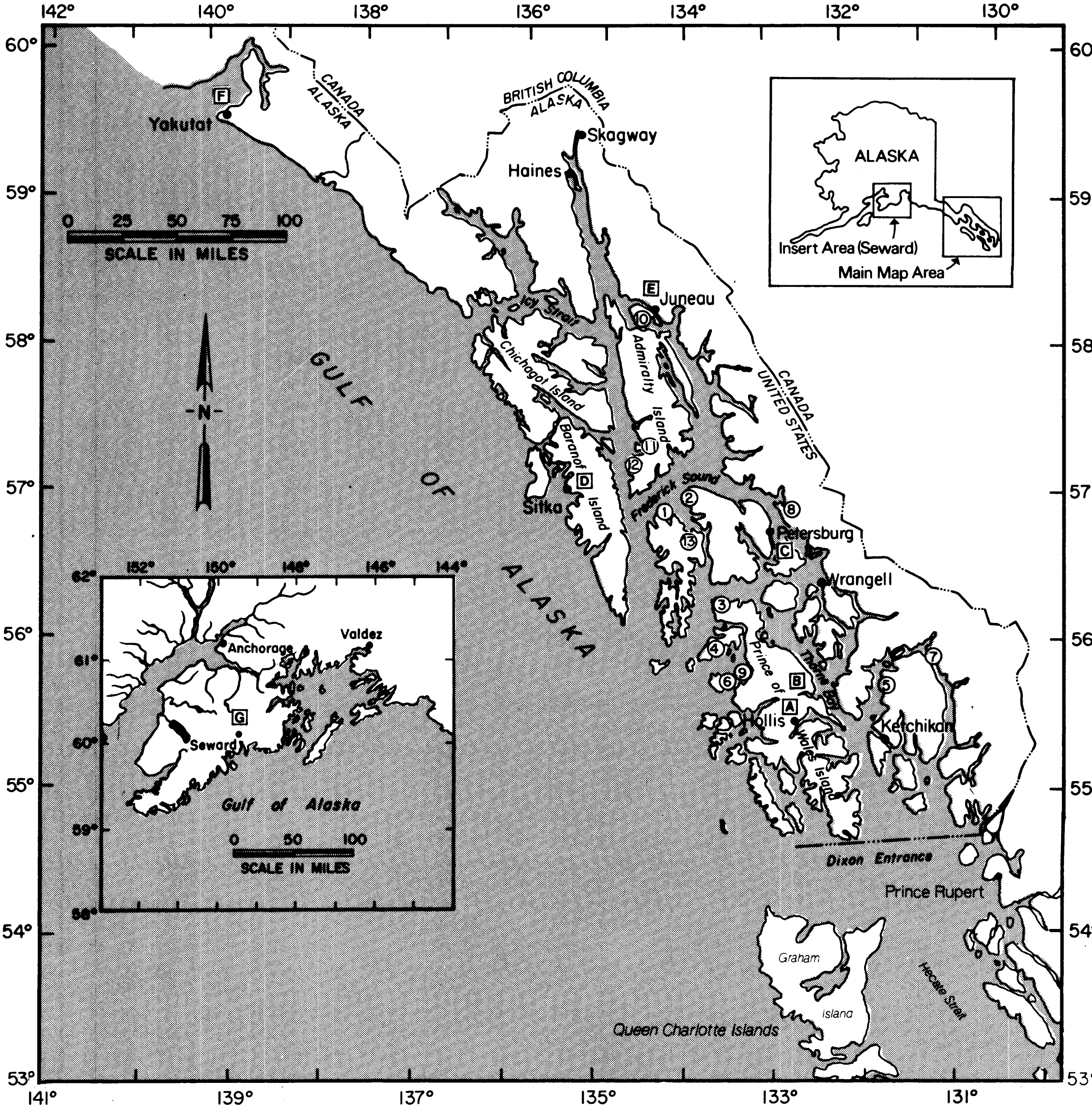

Fig. 1. Location of study areas. Letters (A–G) denote sites where airborne inoculum was sampled and disks were collected from freshly cut stumps. Numbers (1–13) are stand density plots where disks were collected from previously cut stumps.

towels, moistened slightly, put in a plastic bag, and transported to Juneau. The bark removal and surface sterilization were designed to eliminate spores of *F. annosus* present on the bark (14) that might be drawn across the stump during cutting (11). At Juneau, disks were removed from the bags, incubated in dark chambers for 10–17 days, and examined as were the pine disks for *F. annosus* on the topside.

Each stump was also examined to ground level for mycelial fans and rhizomorphs of *A. mellea*. The data for stump colonization by *F. annosus* or *A. mellea* were summarized by location and compared.

***F. annosus* and *A. mellea* in previously cut stumps.** The effect of thinning on growth and development of selected leave trees is being assessed in even-aged, second-growth stands in southeast Alaska (W. A. Farr, *unpublished*). On each of 13 stand density plots (Fig. 1, 1–13), between 18 and 30 stumps were cut level and a disk 2–4 cm thick removed from the top of each. The disks were handled and examined for *F. annosus* as above. Stumps were identified by tree species and examined to ground level for mycelial fans or rhizomorphs of *A. mellea* or both. In all, 351 stumps—178 western hemlock and 173 Sitka spruce—were sampled from trees cut 23–50 mo earlier. Data for occurrence of *F. annosus* and *A. mellea* were summarized by location.

RESULTS

Presence of airborne inoculum. Although all disks from 99 of the 144 exposures (24 sampling periods at each of six locations) gave negative results, airborne inoculum of *F. annosus* was detected at each study site in at least 2 mo (Table 1). The fungus was present on disks of both exposure periods in eight of 45 positive samplings. No *F. annosus* was detected on 30-day exposures from April through August. Data from Sitka are not included because of discrepancies in sampling procedures; however, airborne inoculum of *F. annosus* was detected during several months at Sitka.

The three most northerly sites (Juneau, Yakutat, and Seward) had low levels of airborne inoculum, which was detected during fewer months and on fewer disks than at other sites. The three most southerly sites (Hollis, Thorne Bay, and Petersburg) had the least spore deposition in April and July.

Natural infection and inoculation of freshly cut stumps. *F. annosus* and *A. mellea* were recovered from 10 and 14%, respectively, of the 364 stumps, including some stumps at all locations (Table 2). Sitka spruce stumps had a higher level of infection by *F. annosus*, through both

Table 1. Occurrence of *Fomes annosus* on pine disks exposed for 3 hr or 30 days from December 1977 through November 1978 at six forest sites in southern Alaska[a]

Site[b]	December 3[c]	December 30[d]	January 3	January 30	February 3	February 30	March 3	March 30	April 3	April 30	May 3	May 30	June 3	June 30	July 3	July 30	August 3	August 30	September 3	September 30	October 3	October 30	November 3	November 30
Hollis (Site A)	0	100[e]	100	100[e]	0	100[e]	0	100	0	0	90	0	0	0	0	0	0	0	10	30	0	100	0	0
Thorne Bay (Site B)	0	10	0	0	0	50	0	100	0	0	50	0	30	0	0	0	40	0	80	30	30	30	10	0
Petersburg (Site C)	40	10	30	60	0	90	90	20	0	0	60	0	70	0	10	0	20	0	100	0	10	90	0	50
Juneau (Site E)	0	0	0	0	0	50	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0
Yakutat (Site F)	20	0	0	0	0	0	0	10	10	0	0	0	...[f]	...	0	0	10	0	30	0	0	0	20	0
Seward (Site G)	0	0	0	10[e]	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0

[a] Percentage of 10 disks that were colonized by *F. annosus*.
[b] Data from Sitka (site D) are not included because of sampling discrepancies.
[c] Length of exposure was 3 hr.
[d] Length of exposure was 30 days.
[e] Disks removed from beneath snow.
[f] No sample collected.

Table 2. Occurrence of *Fomes annosus* and *Armillaria mellea* in freshly cut stumps

Location	Number of stumps: Western hemlock	Number of stumps: Sitka spruce	Months between tree felling and stump sampling	Stumps infected with *F. annosus*, %[a]: Western hemlock I	C	A	Sitka spruce I	C	A	Average (both species)	Stumps infected with *A. mellea*, %: Western hemlock	Sitka spruce	Average (both species)
Hollis (Site A)	30	30	14	0	13	7	20	20	20	13	43	27	35
Hollis (Site A)	40	40	12	20	5	13	25	20	23	18	0	13	6
Petersburg (Site C)	30	30	15	7	0	3	13	0	7	5	7	20	13
Petersburg (Site C)	40	40	13	10	0	5	15	20	18	11	10	15	13
Juneau (Site E)	30	30	6	20	0	10	0	0	0	5	10	10	10
Yakutat (Site F)	12	12	13	0	0	0	17	0	8	4	0	8	4
Total or average	182	182		11	3	7	15	12	14	10	12	16	14

[a] I = inoculated stumps; C = control; A = average within species. The four treatments at site A (September 1978) and site C (August 1978) were combined into two treatments, inoculated and control, because no differences occurred within methodologies.

inoculation and natural means, than did western hemlock on all sites except Juneau, where no Sitka spruce stumps were infected. Except at Hollis and Juneau, Sitka spruce stumps were also more commonly infected by *A. mellea*.

F. annosus was recovered from only 3% of all uninoculated western hemlock stumps, and these stumps were located at Hollis. Of the uninoculated Sitka spruce stumps from both trials at Hollis and from the second trial at Petersburg, 20% were infected with *F. annosus*; none were infected at Juneau or Yakutat (Table 2). Thus, no natural infection occurred on sites where relatively low levels of airborne inoculum of *F. annosus* had been detected (Table 1).

No uninoculated stumps contained both *F. annosus* and *A. mellea*. Two Sitka spruce stumps that were successfully inoculated with *F. annosus* in the first trial at Hollis also contained *A. mellea*.

A. mellea was not evident on any mountain hemlock stumps, but 13% of the inoculated stumps and 6% of the control stumps cut in May were infected with *F. annosus*. No mountain hemlock stumps were inoculated during the August cutting, but 3% contained *F. annosus*.

• ***F. annosus* and *A. mellea* in previously cut stumps.** *A. mellea* occurred in 18% of the stumps sampled, but *F. annosus* was present in only 1% (Table 3). Most stumps showed little visual evidence of decay. Several were "live stumps," indicating that their roots were grafted with selected crop trees.

DISCUSSION

The consistently low level of airborne inoculum detected at Juneau, Yakutat, and Seward, along with the absence of natural infection in stumps at Juneau and Yakutat, suggests that *F. annosus* is less common in these areas. Reevaluation of Kimmey's data (9) from Yakutat does not support this hypothesis, however. I used the same site at Yakutat to sample young-growth trees that Kimmey used 25 years earlier to sample cull in old-growth trees. Kimmey found 28% of the old-growth hemlock infected with *F. annosus*, the third highest incidence among his eight study sites in Alaska. In addition, two of only three old-growth Sitka spruce infected with *F. annosus* from all of his sites were located at Yakutat. Thus, in the old forest, *F. annosus* was at least as common at Yakutat as elsewhere in southeast Alaska.

Kimmey noted (recorded on a herbarium collection form filed at the Forestry Sciences Laboratory, Juneau) that basidiocarps of *F. annosus* were rare even though decay was common in hemlock throughout the region. T. Laurent (*personal communication*) found no basidiocarps of *F. annosus*, although its decay is common, when he dissected 1,776 trees to measure cull at 67 locations in southeast Alaska (5). Several basidiocarps previously collected in southeast Alaska and identified as *F. annosus* (1,2) have been reexamined and found to be *F. pinicola* (Schwartz ex Fr.) Cke. (R. Gilbertson, *personal communication*). During 30 months of collecting in southeast Alaska, I have gathered basidiocarps of *F. annosus* only once (15). Thus, the source of spores for the airborne inoculum remains an enigma.

Natural infection by *F. annosus* in western hemlock stumps examined 6–15 mo after felling averaged 3% (Table 2). This level was substantially lower than the 40–100% infection commonly recorded in similar trials with western hemlock stumps examined 4–7 mo after felling in coastal Oregon, Washington, and British Columbia (11,13). Morrison and Johnson (12) found a marked reduction with time in survival of *F. annosus* within western hemlock stumps. More than 48% of their stumps were infected 6 mo after felling, whereas only 7.5% remained infected 5 yr later.

Dimitri et al (3) graphically showed a similar reduction in infection of Norway spruce (*Picea abies* (L.) Karst.) stumps in Germany from 70% 30 min after cutting to less than 10% 500 days later. This reduction in fungal presence with time probably reflects differences between fungal penetration and successful colonization of stump wood by *F. annosus*. The much lower incidence of *F. annosus* in stumps sampled 2–4½ yr after cutting (1%; Table 3) than in those sampled 6–15 mo after cutting (7.5% average natural infection in both tree species; Table 2) may reflect this reduction in fungal survival with time. Determining subsequent development of *F. annosus* in mountain hemlock stumps will be especially interesting as this appears to be the first record of the fungus on this host.

Our knowledge about *F. annosus* and *A. mellea* on young Sitka spruce growing within its natural range is limited. Wallis and Reynolds (18) had examined only 10 Sitka spruce stumps when they reported a natural infection level of 10% by *F. annosus*. This sampling contrasts with the 19% infection they recorded after examining 705 western hemlock stumps. Morrison and Johnson (11) did not find enough Sitka spruce on their study sites to sample for natural infection; however, 65–100% of the Sitka spruce stumps they inoculated with *F. annosus* became infected.

These data on stump infection, through both natural means and inoculation, suggest that young Sitka spruce are at least as susceptible to infection by *F. annosus* as western hemlock. The results contrast with observations of natural occurrence of *F. annosus* on old-growth trees in southeast Alaska. Kimmey (9) found *F. annosus* in only 3 of the 352 mature Sitka spruce he examined, whereas the fungus was present in 51 of the 230 mature western hemlock. The pattern was similar with *A.*

Table 3. Occurrence of *Fomes annosus* and *Armillaria mellea* in previously cut stumps

Location (Plot no.)	Months between thinning and sampling	Number of stumps: Western hemlock	Sitka spruce	Total	Percentage infected with *F. annosus*: Western hemlock	Sitka spruce	Average	Percentage infected with *A. mellea*: Western hemlock	Sitka spruce	Average
Saginaw Bay (1)	44	15	15	30	7	0	3	7	13	10
Pt. White (2)	23	15	15	30	0	0	0	0	0	0
Alder Creek (3)	24	15	15	30	0	7	3	0	7	3
Edna Bay (4)	39	15	15	30	0	0	0	20	33	27
Traitors Cove (5)	36	14	13	27	0	0	0	...[a]	...	7
Warmchuck (6)	30	13	9	22	0	0	0	15	0	9
Saks Cove (7)	35	15	3	18	0	0	0	0	0	0
Thomas Bay (8)	50	15	15	30	0	0	0	...[b]	...	...
Tuxekan (9)	30	11	13	24	0	0	0	64	62	63
Douglas (10)	34	15	15	30	0	0	0	13	27	20
Hood Bay (11)	48	15	15	30	0	0	0	67	53	60
Whitewater Bay (12)	35	5	15	20	0	0	0	40	33	37
Port Camden (13)	33	15	15	30	0	0	0	0	0	0
Total or average		178	173	351	1	1	1	16	19	18

[a] Tree species not determined during collection.
[b] Not examined for *A. mellea*.

mellea; again, my data suggest that this fungus is at least as common in stumps of young-growth Sitka spruce as in western hemlock. Kimmey (9) found *A. mellea* in 12 Sitka spruce and 47 western hemlock. Englerth (4) did not record either fungus on old-growth Sitka spruce logged from the region in the early 1940s.

A. mellea was present in a higher proportion of stumps of both species than was *F. annosus*, especially in the stumps 2–4½ yr old. D. Morrison (*personal communication*) recently found a similarly higher incidence of *A. mellea* than of *F. annosus* in previously cut young-growth stumps of Sitka spruce and western hemlock on the Queen Charlotte Islands, about 125 miles south of site A in Figure 1.

Although no stumps were excavated in this study, *F. annosus* and *A. mellea* were found together on the aboveground portions of only two stumps: both were Sitka spruce that had been inoculated with *F. annosus*. In young Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) plantations attacked by Armillaria root rot, Filip (6) consistently found that aboveground portions of old-growth western hemlock stumps are colonized by *F. annosus*, whereas roots are colonized by *A. mellea*. This condition apparently prevents contact between *F. annosus* in central tissues of the old stumps and roots of the second-growth Douglas-fir.

Characteristic infection centers of Armillaria root rot have not been observed in southeast Alaska, and only two instances of noticeable mortality in young-growth stands have been attributed to *A. mellea* (10,16). In both situations, mortality was concentrated in western hemlock and did not have an overall negative effect on stocking density or distribution (T. Laurent, *personal communication*). Because *A. mellea* apparently causes little damage in young stands, its relatively common occupancy of stump and root wood may provide a valuable biological limitation to the spread of *F. annosus* from infected stumps to adjacent standing trees (12,17).

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