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Managing Heart Rot in Live Trees for Wildlife Habitat in Young-Growth Forests of Coastal Alaska

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Abstract

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Stem decays of living trees, known also as heart rots, are essential elements of wildlife habitat, especially for cavity-nesting birds and mammals. Stem decays are common features of old-growth forests of coastal Alaska, but are generally absent in young, managed forests. We offer several strategies for maintaining or restoring fungal stem decay in these managed forests that can be used to enhance specific types of wildlife habitat.

Keywords: Stem decay, heart rot, cavity nest, wildlife habitat.

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Introduction

Stem decays (also known as heart rots) are specialized fungi that cause internal decay of living trees. These fungi are ubiquitous and important elements of the old-growth coastal rain forests in Alaska. Herein, we summarize some important contributions of stem decays in creating wildlife habitat and providing other ecological services. We then offer silvicultural techniques that can be used to retain or restore desirable amounts of stem decay in coastal Alaskan forests. These treatments could be prioritized where wildlife habitat or late-successional characteristics are primary resource goals in managed forests. Over time, measures taken to actively manage wood decay in young stands will facilitate predictable types of wildlife habitat and other desired features and processes of old-growth forests.

Stem decay is especially prevalent in old-growth forests with infrequent fire, where long-lived trees are invaded by fungi that slowly consume wood.

Background

In coastal Alaska, stem decays cause about 30 percent loss of merchantable wood volume in mature forests (fig. 1) (Farr et al. 1976, Kimmey 1956). Timber cull studies are often the best or only source of information about the incidence and quantity of decay in live forest trees, and report results in terms of impacts on merchantable volume. Stem decay is especially prevalent in old-growth forests with infrequent fire, where long-lived trees are invaded by fungi that slowly consume wood. Beyond the considerable commercial losses to timber value, stem decay fungi also influence a number of important ecological processes. Carbon and nutrient cycles and forest structure are continually altered by these fungi in every old-growth forest in coastal Alaska. Stem decay fungi are important drivers of stand structure and dynamics by causing tree death and canopy gap formation through bole breakage (Hennon 1995, Hennon and McClellan 2003). In contrast, stem decays are generally absent or far less abundant in young, managed coastal forests (Tait et al. 1985). In southeast Alaska, there are 440,000 acres of young-growth on the Tongass National

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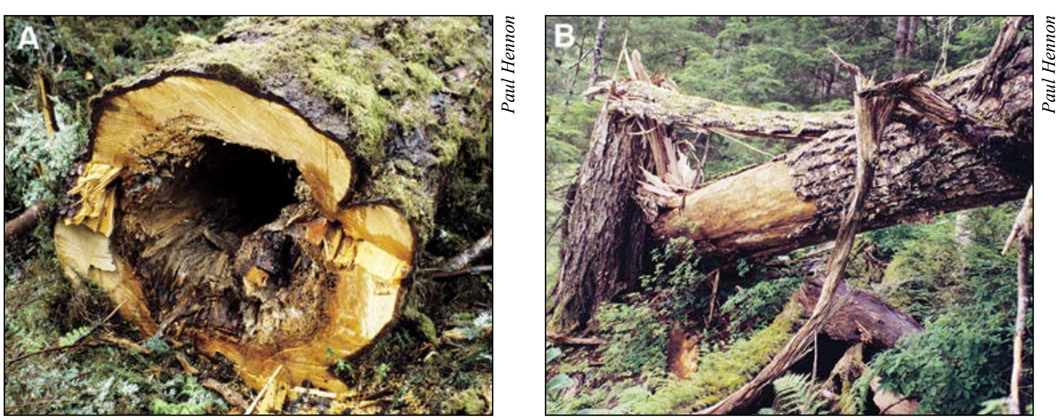

Figure 1—Stem decay fungi cause substantial losses to commercial timber resources (A) and drive a range of ecological functions, including canopy gaps caused by tree death, that maintain old-growth functions (B).

Forest, 245,000 ac on Alaska Native Corporation lands, and 45,000 ac on Alaska's state lands. Some of these lands currently designated to be managed primarily for non-timber objectives offer opportunities for active management that promotes or accelerates characteristics of old-growth forests. The Tongass National Forest Land and Resource Management Plan emphasizes that management should consider wildlife and vegetation diversity implications on all land use designations. We recommend considering treatments to restore stem decay for wildlife habitat in stands or portions of stands that will persist over time (i.e., will not be harvested in the foreseeable future) to provide longer term habitat. This report focuses on the role of stem decays in providing habitat, and on management approaches that can be used to promote desired amounts of stem decay in managed stands of any age.

Wildlife habitat—

In Pacific Northwest forests, 25 to 30 percent of bird and mammal species are dependent on decayed wood in trees to provide habitat for nests, dens, and roosts (Bunnell et al. 1999, Harestad and Keisker 1989, Li and Martin 1991, McClelland and Frissell 1975, Raphael and White 1984). In Alaska, it is estimated that 27 species are obligate cavity users. Birds, bats, and squirrels tend to use cavities obligatorily, while many mammals use cavities opportunistically (Bunnell et al. 1999). Lack of sufficient cavities for habitat is often considered a key threat to at-risk forest species, especially woodpeckers (Bunnell et al. 1999). Among cavity-nesters, primary cavity excavators are particularly important because the cavities that they create become legacy structures used by other wildlife in the decades that follow. In North America, up to 77 percent of nesting cavities used by nonexcavators are produced by primary excavator birds (rather than decay without excavation) and the majority of cavities persist for more than a decade (Cockle et al. 2011).

In southeast Alaska, densities of cavity-nesting bird species were found to be significantly lower in young stands (35 years old) compared to old-growth stands in the two decades following thinning treatments (Matsuoka et al. 2012). This effect occurred regardless of thinning treatment density, probably because of the lack of large trees and snags with adequate decay for cavity-nesting habitat in the previously clearcut stands. Future monitoring of these stands may show that injuries caused by different logging treatment intensities may accelerate the rate of stem decay development and the return of cavity nesters.

Most research has evaluated the use of dead trees (snags) and snag cavities by bird species compared to the use of live trees with decay. Standing snags offer valuable habitat in old forests to cavity dwellers. In coastal Oregon and Washington, northern flying squirrels preferred den sites (cavities and other structures) in live trees to dead trees at a ratio of 2:1 (Carey et al. 1997), but use of cavities in live and dead trees was nearly equal on Prince of Wales Island in Alaska (Pyare et al. 2010). In southeast Alaska, at least 12 species of birds relied on tree cavities for roosting or nesting in old forests (table 1; Kessler 1979), where usage was typically in the upper third of the tree bole (Hughes 1985). Wagner (2011) found that red-breasted sapsuckers on Kupreanof Island in southeast Alaska created nesting cavities in large-diameter spruce and hemlock snags, with an average cavity height and tree height of 58 ft and 90 ft, respectively. In a study that measured the number of dead trees in unmanaged old-growth stands in southeast Alaska, Hennon and McClellan (2003) reported a density of 17 to 22 large dead trees (diameter at breast height ≥ 18 in) per acre; 20 to 35 percent of these were standing snags, while the rest were on the forest floor, having been uprooted or bole-snapped. These densities of dead tree structures in old-growth forests can be used as a reference condition to contrast with young-growth stands.

In contrast to a live tree that develops stem decay, a sound tree that is killed outright by cutting or that dies standing will decay from the outside in, and will not develop a distinctly decayed or hollow interior.

Table 1—Cavity-dependent bird species on Kosciusko Island in southeast Alaska (Kessler 1979) and bird species considered to be old-growth-dependent in southeast Alaska (Noble 1978)

Cavity-dependent	Old-growth-dependent
Boreal chickadee	Sooty grouse
Boreal owl	Brown creeper*
Brown creeper*	Chestnut-backed chickadee*
Chestnut-backed chickadee*	Downy woodpecker*
Downy woodpecker*	Golden-crowned kinglet
Hairy woodpecker*	Hairy woodpecker*
Northern hawk-owl	Audubon's warbler
Northern saw-whet owl	Red-breasted sapsucker
Red-breasted nuthatch	Red-tailed hawk
Red-breasted sapsucker	Ruby-crowned kinglet
Three-toed woodpecker*	Sharp-shinned-hawk
Western screech-owl	Three-toed woodpecker*

*= Indicates that species appear in both lists. Common names of birds have been updated.

Live trees with internal wood decay offer wildlife habitat similar to snags and downed trees, but there are a few important distinctions. First, live trees with stem decay generally remain standing longer than snags, providing longer-term habitat for species that use standing structures. Second, large hollows with a solid exterior are produced in live trees only when white rot stem decay fungi create a softened or hollow interior while the tree continues radial growth to provide sound outer wood. In contrast to a live tree that develops stem decay, a sound tree that is killed outright by cutting or that dies standing will decay from the outside in, and will not develop a distinctly decayed or hollow interior. Black bears prefer large hollows for hibernation, seeking out such structures in old-growth forests of southeast Alaska (DeGayner et al. 2005). Some of these hollow structures used by bears are present in dead trees, but were originally formed or initiated through the action of stem decay fungi while trees were still alive. These unique structures created in living trees can provide important habitat features that persist long after tree death.

Stem decay fungi—

Stem decay is caused by fungi that invade and colonize the wood of living trees and decompose wood before the tree is dead. These fungi vary in appearance, specialization, infection biology, and type of decay produced (table 2; fig. 2). Some species require the exposed wood of wounds for entry, continue their decay after the tree dies, and are also general decomposers of dead trees (e.g., *Fomitopsis pinicola*). Other wood decay fungi initiate in the roots and spread to decay the tree's lower bole as a butt rot (e.g., *Phaeolus schweintizii*). Several highly specialized fungi invade through small branches and are generally restricted to live or recently killed trees (e.g., *Phellinus pini* and *Echinodontium tinctorium*). In addition to the stem decay fungi that are adapted to infect live trees, others are particularly important for softening wood of dead trees for excavation in coastal Alaska (fig. 3).

Table 2—Stem decay fungi on live conifer trees in southeast Alaska

Heart and butt rot fungi[a]	Western hemlock	Mountain hemlock	Western redcedar	Sitka spruce	Lodgepole pine	Type of Rot/decay
Armillaria spp.	X	X	X	X	X	White
Ceriporiopsis rivulosa			X			White
Coniophora sp.		X				Brown
Echinodontium tinctorium	R	X				Brown
Fomitopsis pinicola	X	X		X		Brown
Fomitopsis officinalis					X	Brown
Ganoderma spp.	X			X		White
Heterobasidion annosum	X			X		White
Laetiporus sulphureus	X	X	R	X		Brown
Phaeolus schweinitzii	X			X		Brown
Phellinus hartigii	X	R				White
Phellinus pini	X	X		X	X	White
Phellinus weirii			X			White

[a] Some root rot fungi are included because they are capable of causing both root and butt rot of conifers.
R indicates that the fungus is rare on this host.

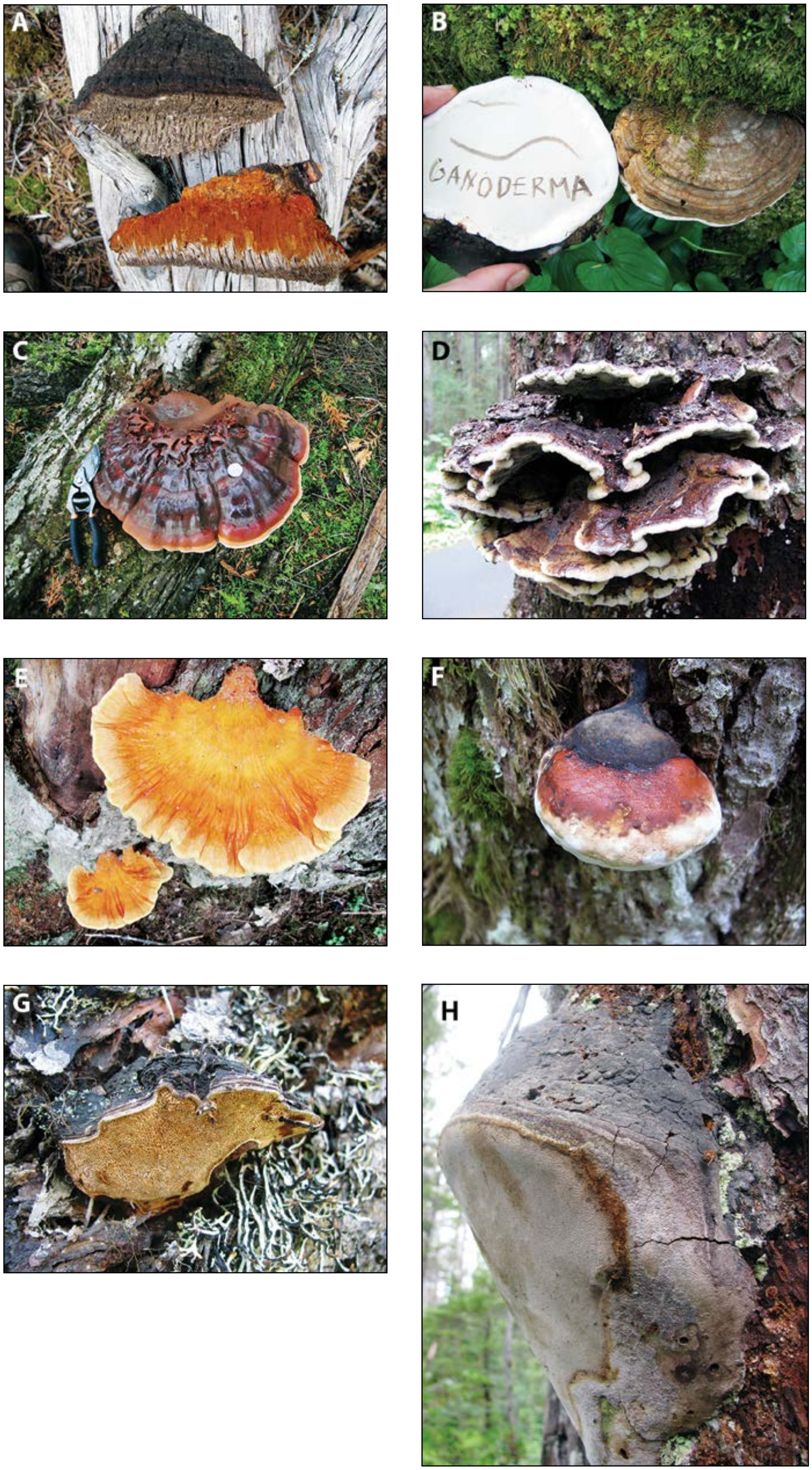

Figure 2—Conks (fruiting bodies) of several stem decay fungi of conifers in coastal Alaska. (A): *Echinodontium tinctorium* (paint fungus), (B) *Ganoderma applanatum* (artist's conk), (C) *Ganoderma tsugae* (lacquer or varnish conk), (D) *Phaeolus schweinitzii* (velvet-top fungus), (E) *Laetiporus sulphureus* (sulphur fungus), (F) *Fomitopsis pinicola* (red belt conk), (G) *Phellinus pini* (pini conk or red ring rot), and (H) *Phellinus hartigii* (Hartig's conk). Photos by Robin Mulvey.

Figure 3—*Fomitopsis pinicola* (A) decays dead woody tissue of live or dead trees, softening snags for excavation and decomposing downed woody debris. *Laetiporus sulphureus* (B) and *Ganoderma applanatum* (C) also serve to prepare snags for excavation. Photos by Robin Mulvey.

Most of the internal wood decay of Sitka spruce is brown rot while most of the wood decay of western hemlock is white rot. These striking differences in decay between tree species likely influence their use as habitat.

The fruiting bodies of stem decay fungi (usually conks or mushrooms) disperse airborne spores, but the actual degradation of wood is by the threadlike vegetative part of the fungus (hyphae) inside trees. Two groups of stem decay fungi (brown and white rots) can be distinguished by their chemical degradation of wood cells, although both soften wood by breaking down cell walls. Brown rot fungi degrade only cellulose, leaving the other primary constituent of wood (lignin) as a considerably less dense but fairly stable residual structure that is suitable for excavation by woodpeckers. White rot fungi digest both cellulose and lignin, which can create hollows in trees that are considered to be a key habitat feature for some birds and mammals. Most of the internal wood decay of Sitka spruce is brown rot (84 percent), while most of the wood decay of western hemlock is white rot (63 percent) (Kimmey 1956; fig. 4). These striking differences in decay between tree species likely influence their use as habitat.

Some fungi have preferences for different parts of the tree, most likely because of their manner of infection. The fungus *Phaoelus schweinitizii* resides in the lower stem and major roots. *Fomitopsis pinicola* can occur anywhere on roots or the stem, but it is most common low on the bole, where frequent wounds promote infection. *Fomitopsis officinalis*, a fairly rare brown rot fungus that produces large conks

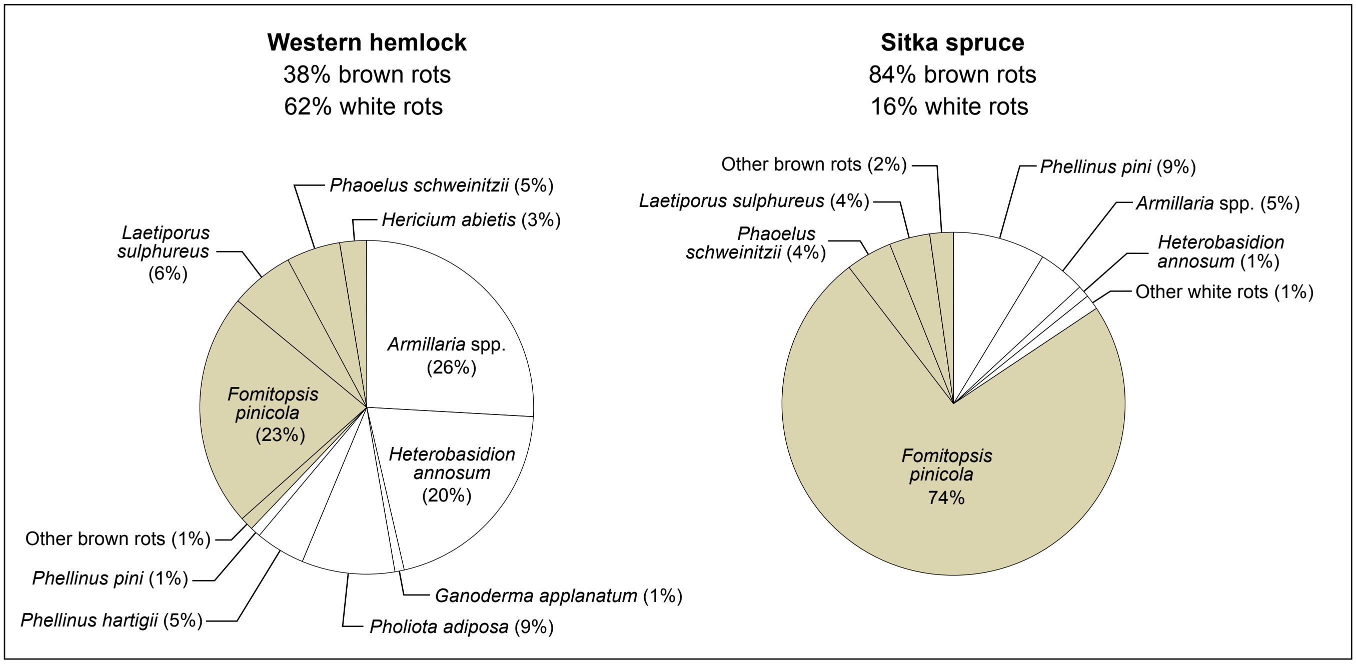

Figure 4—Contribution of fungi that cause brown rot (tan wedges) and white rot (white wedges) in living western hemlock and Sitka spruce in the forests of southeast Alaska. Adapted from Kimmey (1956). Note that Kimmey made classifications to fungal species primarily based on the visual appearance of wood decay, and these results should be validated by modern genetic techniques.

on live spruce, is most often found high on tree boles, perhaps because it infects through top breaks. As with the type of decay, the location of wood decay in trees probably influences wildlife use. For example, Hughes (1985) found that the majority (77 percent) of excavated cavities occurred in the upper one-third of tree boles on Admiralty Island, compared to 22 percent in the middle third and 1 percent in the lower third.

Influence of tree age and species—

Increasing incidence and amount of decay with greater tree age is a consistent feature in forests worldwide, with the actual age-decay relationship differing by tree species, and, in some cases, geography (Boyce 1961). The term "pathological rotation" has been used to indicate the age at which a forest managed for timber begins to incur unacceptable heart rot losses (Meinecke 1916). This age was estimated to be 225 to 275 years for western hemlock in western British Columbia (Buckland et al. 1949) and 250 to 300 for Sitka spruce in the Queen Charlotte Islands, although there was little decay in spruce trees less than 200 years old (Bier et al. 1946).

There are marked differences in the amount of stem decay between young and old forests in coastal Alaska. Stem decay in very young trees cannot develop until trees begin producing heartwood. Even though young trees can initiate heartwood at 14- to 18-years old (Hillis 1987, Moore 2011), conifers less than 100 years old in southeast Alaska have little heartwood decay (Harris and Farr 1974). However, by 200 years old, 65 percent of western redcedar, 50 percent of western hemlock, and 20 percent of Sitka spruce trees have internal wood decay (Kimmey 1956). Decay incidence estimates can be misleading because there may be significant variation in the amount of decay per tree (Farr et al. 1976). For wildlife habitat, the quantity of decay (gross volume loss) may be a more meaningful estimate than decay incidence. Kimmey (1956) calculated percentage of volume decay in terms of percentage of board-foot cull and percentage of cubic-foot cull (fig. 5) and documented defect rates around 30 percent depending on the measure used. Cubic-foot calculations represent decay volume percentage more accurately than board-foot calculations, because board-foot cull calculations were rounded up more liberally. Board-foot calculations tend to be more useful for timber cruisers. Farr et al. (1976) calculated an overall percentage board-foot defect of 31 percent and confirmed Kimmey's (1956) relationship between tree age and the percentage volume of decay in southeast Alaska (fig. 5). Surprisingly, western redcedar (not shown in fig. 5) has the greatest amount of stem decay of the conifer species in coastal Alaska. Western hemlock has more stem decay than Sitka spruce and generally acquires decay at an earlier age. This may result from differences in physiology between the two host species, or in the behavior of fungi that infect them.

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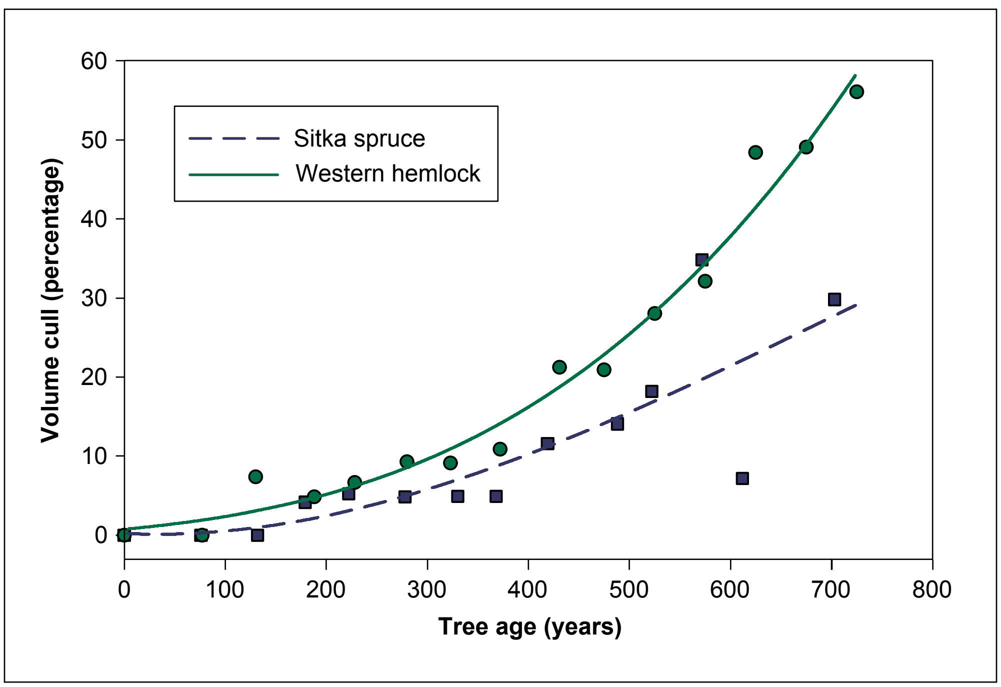

Figure 5—Influence of tree age on percentage of wood volume that is cull. Adapted using data from table 10 in Kimmey (1956) of mean gross volume cull values for dissected trees grouped by 50-year age intervals. Curves were fit with polynomial equations.

Several factors are probably responsible for the high rate of defect in old-growth forests. During their growth from the understory to the upper canopy, large old trees have often experienced multiple, accumulated injuries from storms, neighboring trees falling, and animal damage. Visual indicators of past injuries (e.g., scars, wounds, frost cracks, broken tops) are positively associated with internal wood decay (Farr et al. 1976). The longevity of old trees provides adequate time for extensive decay to develop gradually following fungal infection through wounds and other infection courts (i.e., roots, branches, dead branch stubs). It is thought that the canopy status and vigor of trees may affect their susceptibility to certain decay fungi, because suppressed trees seal off old branch stubs and wounds more slowly than do vigorous trees. For example, *Echinodontium tinctorium*, which is rare in southeast Alaska, infects through small branch stubs; it more commonly affects suppressed trees, because branch stubs of these trees heal more slowly, providing greater time for infection to occur (Filip et al. 2009). Relative bark thickness may also influence tree species' susceptibility to decay, as thin-barked species are more prone to larger and deeper wounds than species with thicker bark. Chemical defense compounds in the heartwood of some tree species may afford them relatively greater resistance to decay. However, even tree species with decay-resistant wood (e.g., western redcedar and yellow-cedar) can be highly defective as old trees, because a few specialized fungi can overcome their chemical defenses.

The general relationship between decay incidence and volume and tree age translates to greater decay in old stands compared to young stands. The abundance of large snags is also reduced in young forests, unless they were retained at the time of harvest. There are few mortality agents that kill larger individual trees in young-growth stands (Tait et al. 1985). Instead, suppression mortality in young stands produces abundant small snags. Because western redcedar and yellow-cedar snags have decay-resistant heartwood, they probably do not offer significant cavity-nesting habitat as snags unless they were decayed as live trees. Note that downed trees with hollows are common in young-growth stands, where they are a legacy of the cull trees left during the initial old-growth harvest.

Many important stem decay fungi, especially those of western hemlock, enter through mechanical wounds.

Influence of tree wounds—
Many important stem decay fungi, especially those of western hemlock, enter through mechanical wounds (fig. 6). For example, an estimated 65 percent of the stem decay in old-growth western hemlock in British Columbia is associated with natural injuries not caused by forest management (Buckland et al. 1949). Natural wounds to tree boles are common in coastal Alaska, and often originate from falling neighboring trees, internal cracks, splitting forks, or broken tops or branches (Hennon and McClellan 2003). Farr et al. (1976) found that trunk scars

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Figure 6— (A) Recent bole wound with sound, exposed wood and (B) older bole wound with extensive internal decay.

Logging damage to trees during both falling and yarding activities produces tree injuries that mimic natural wounds.

extending into the heartwood are the most common injury to western hemlock and Sitka spruce, affecting 24 and 9 percent of trees, respectively, followed by basal scars for western hemlock and frost cracks for Sitka spruce. Animal feeding causes localized tree injury in specific regions of southeast Alaska. Porcupines feed on Sitka spruce and western hemlock forests close to the mainland (Eglitis and Hennon 1997), while brown bears damage yellow-cedar trees on several large islands (Hennon et al. 1990). The vertical position of wounding on tree boles is important to the creation of some forms of habitat, because some animals only use structures far from the ground. Lower bole wounds provide a form of habitat, and also may eventually lead to canopy gap formation as trees die through bole breakage. Natural top damage is mainly caused by wind or loading from snow and ice.

Logging damage to trees during both falling and yarding activities produces tree injuries that mimic natural wounds. The tree species in coastal Alaska have thin bark (in part because of the absence of fire), so their boles and exposed roots are easily wounded. Precommercial thinning of small stems does not cause significant injury to retained trees, but any form of commercial logging with tree removal will result in some tree injury. In a commercial thinning trial of young-growth stands (the Second Growth Management Program on the Tongass National Forest in the 1980s), approximately one-half of the residual trees were injured (Hennon 1990). Most of these wounds were to the lower bole, although exposed roots and tops of some trees were also damaged or broken. Of the bole wounds, however, just over a quarter were large enough to lead to substantial decay (i.e., more than 1 ft^2 surface area of bark removed; Wright and Isaac 1956). The frequent lower bole wounds from logging are similar to common forms of natural tree injury in unmanaged forests. These wounds may eventually provide habitat for some animals, and, over the long term (>100 years), contribute to canopy gaps through bole breakage (Hennon and McClellan 2003). The less frequent logging wounds higher on tree boles may be particularly valuable for some species. Continued monitoring of tree injuries from commercial thinning will yield more information on the incidence and sizes of wounds that can be used to project decay, as described below.

By dissecting and quantifying the amount of wood decay in wounds of different sizes and ages, equations were developed to predict future wood decay of wounded trees (Hennon and DeMars 1997). The development of wood decay is relatively slow in southeast Alaska, developing over the course of decades (fig 7). Wounds less than 5 years old are not significantly associated with decay (Farr et al. 1976). Larger bole wounds lead to more overall wood decay that develops at a relatively

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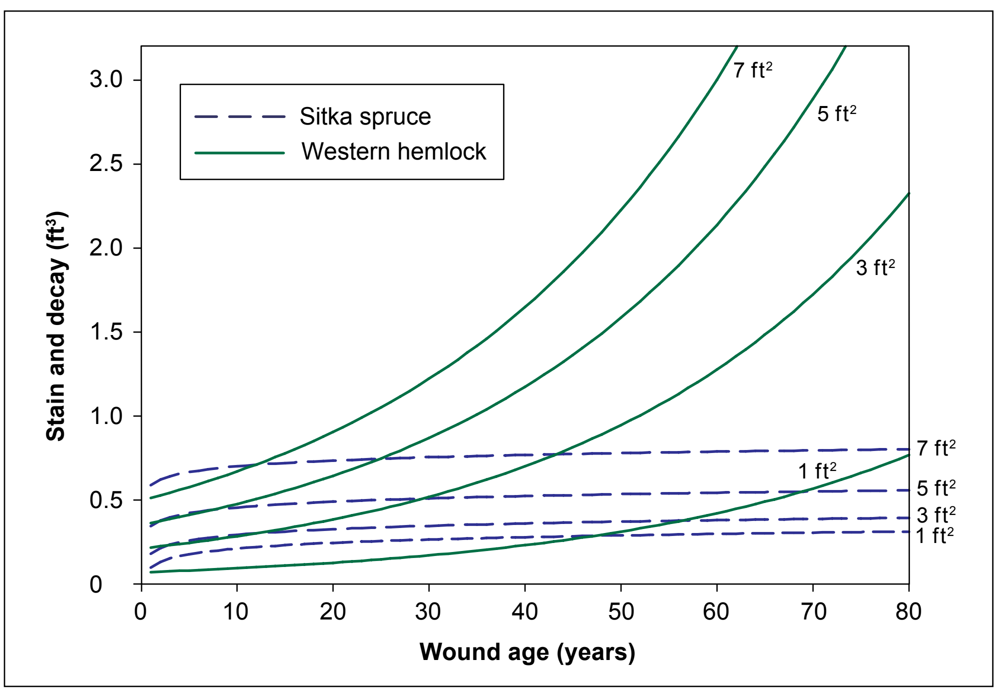

Figure 7—Predicted rate of stain and decay development in western hemlock and Sitka spruce with tree bole wounds of different sizes (given as wound surface area). Modified from Hennon and DeMars 1997.

When top breakage occurs low in the live crown, or below the live crown, the tree will probably die and have no chance of developing an internal decay column.

faster rate. The pattern of wood decay differs between western hemlock and Sitka spruce. Once colonized by fungi, decay develops deep in the wood beneath wounds of hemlock, eventually creating a column of decay. In spruce, decay develops only in the outer wood, and the subsequent rate of advancement is very slow. These differences may explain the greater amount of stem decay in western hemlock than Sitka spruce in old forests.

Harvest activities sometimes cause unintentional top breakage (fig. 8). We know less about decay development in top breaks compared to bole wounds, although more decay is expected to develop in larger diameter breaks. Farr et al. (1976) found that western hemlock trees with evidence of broken tops in the past had similar percentages of decay volume as trees with basal scars, but that broken tops were less common. When top breakage occurs low in the live crown, or below the live crown, the tree will probably die and have no chance of developing an internal decay column.

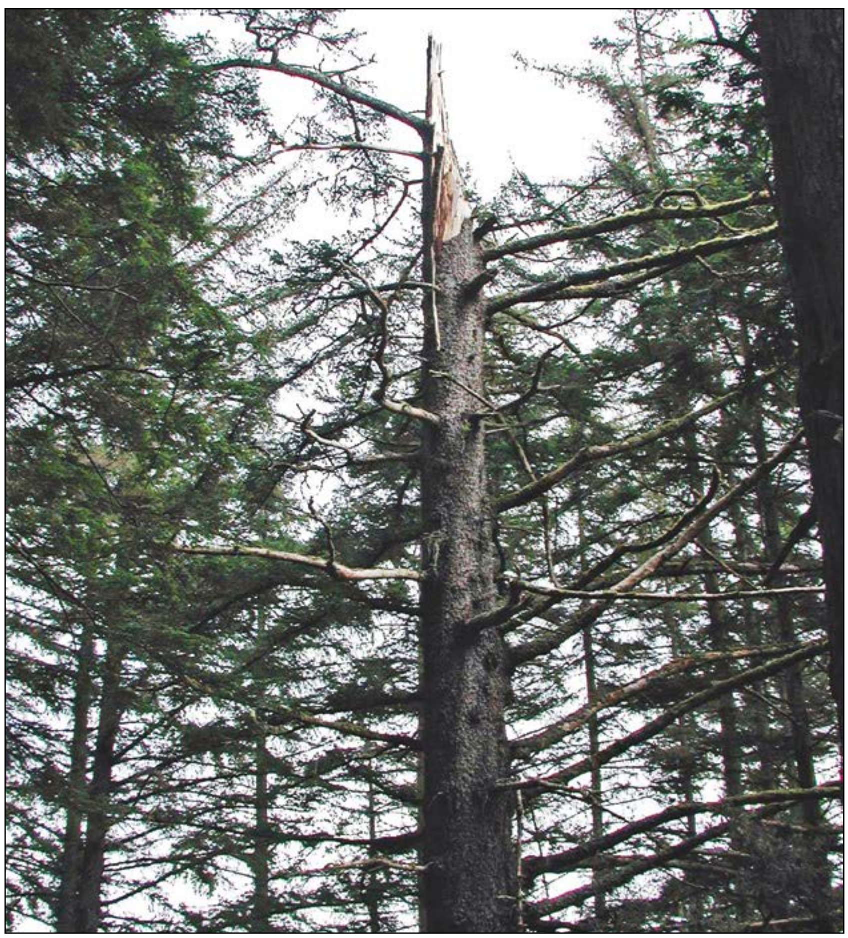

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Figure 8—Top breakage during logging provides large infection courts to fungi that eventually lead to extensive internal decay. Bole breakage that occurs near or below the live crown results in tree death (snag creation), which is less desirable than the development of an internal decay column in a tree that remains alive.

Silvicultural Techniques to Maintain and Restore Stem Decay

Strategies to encourage stem decay in managed forests (table 3) can enhance wildlife habitat but may not be appropriate in forests primarily managed for timber production. Landscape context can help to guide treatment decisions. For example, a small young-growth stand surrounded by old-growth forest may not require the same treatment as a large watershed with a history of extensive clearcuts. Within stands, the desired number of trees with stem decay, tree species with decay, and location of decay on tree boles need to be determined by wildlife biologists and weighed against potential loss to timber values, if timber production is a management objective. These decisions can be made in conjunction with forest pathologists to manage for specific types of wood decay or decay in specific parts of the tree. Stem decays can be maintained by selecting defective old trees to protect during green tree retention harvests of old-growth forests. In even-aged young-growth forests, restoration efforts through tree wounding or direct fungal inoculation may be needed to accelerate the return of stem decays and associated habitat features. Management favoring stem decay fungi could be one part of a young-growth restoration strategy, with other components focused on the creation of canopy gaps, multiple-canopy strata, snag recruitment, and other structural elements of old-growth forests.

A small young-growth stand surrounded by old-growth forest may not require the same treatment as a large watershed with a history of extensive clearcuts.

Table 3—Strategies to maintain and restore stem decay

Management strategy	Description
Maintain stem decay structures through green tree retention harvests.	Trees with indicators of decay can be selected for retention during harvest, and buffered by other retained trees, to maintain habitat refugia within cut stands.
Wait for stem decay to return to young stands without treatment.	Stem decay will return to untreated young stands through natural tree injury and fungal infection and growth over the course of centuries.
Wound trees through logging injury and top breakage.	Intentional or unintentional injury during stand entries will create infection courts for stem decay fungi, significantly accelerating decay development compared to untreated young-growth stands; intentional injury with logging equipment or explosives can target parts of the tree less frequently wounded during logging operations (upper boles) that are preferred by wildlife species.
Artificially inoculate select trees with stem decay fungi.	Particular tree species can be inoculated strategically with specific species of decay fungi that cause desired types of decay in targeted locations on the tree bole; treatments can be tailored to provide habitat for selected bird and mammal species.

Young trees that regenerate on clearcut harvest sites typically lack internal decay for 100 to 150 years or longer.

Maintain stem decay structures through green tree retention harvests—
Young trees that regenerate on clearcut harvest sites typically lack internal decay for 100 to 150 years or longer. To retain stem decays in managed forests, an option at the time of harvest is to conduct a green tree retention (partial) harvest, rather than a clearcut. Trees with conks, cracks, old top damage and other indicators of decay (Farr et al. 1976) could be targeted for retention, and even buffered by other retained trees. These alternative harvests will always result in some level of top, bole, and root injury to residual trees that remain, with damage (to as many as 30 to 40 percent of residual trees) related to the harvest intensity, spatial distribution, and type of yarding (e.g., helicopter vs. ground based) (McClellan and Hennon 2005). Minimizing these injuries during harvest entries is advisable because further injury to old residual trees is not required, as many of them will already contain the important stem decay structures for wildlife.

Young trees growing adjacent to retained large trees are not expected to develop stem decay at a higher rate than young-growth trees that regenerate following clearcut harvests. Injuries and infection courts, rather than the quantity of airborne spore inoculum from nearby infected trees, drive the infection rates of young trees. Management activities that create infection courts through wounding have greater influence on the incidence of stem decay, as spore inoculum is ubiquitous in stands of all ages. Shading from the large retained trees may reduce the growth of neighboring young trees, but a greater infection rate is not anticipated.

Wait for stem decay to return to young stands without treatment—
Young-growth stands in southeast Alaska generally lack damage agents and contain little stem decay. For example, a stand that regenerated after the oldest known industrial clearcut in Alaska, the Verstovia forest near Sitka, is now 160 years old and generally free of defect. Crown breakage from wind or snow and ice loading may be a source of injury that can lead to fungal infection in all young-growth stands. Figure 5 illustrates the relationship between stem decay (percentage volume) and tree age for the two predominant species, western hemlock and Sitka spruce in southeast Alaska. Long rotations will allow stem decay to be restored naturally, but stem decays will be lacking in forests scheduled for repeated short rotations in the absence of management (or other forms of disturbance) that might increase bole injuries and top breakage.

Wound trees through logging injury and top breakage—
Commercial thinning has multiple benefits, which include accelerating timber production and opening canopies for more understory growth and deer browse (Alaback 1982, Alaback and Tappeiner 1991, Tappeiner and Alaback 1989). Another benefit of thinning and tree removal may be the unintentional bole wounding and

top breakage of residual trees, which mimics natural wounding and favors the development of stem decay. In general, wounds greater than 1 ft^2 are considered large enough to lead to substantial decay (Hennon and DeMars 1997, Wright and Isaac 1956). Wounds can begin to lead to decay at any point after heartwood development, which normally occurs when trees are 14 to 18 years old. Stand-entry activities that wound trees may speed the restoration of wildlife habitat and other old-growth functions of stem decays by as much as a century compared to young-growth stands that receive no treatment. In contrast to tree removal, precommercial thinning does not cause significant injury to residual trees.

Stand-entry activities that wound trees may accelerate restoration of wildlife habitat and other old-growth functions of stem decays by as much as a century compared to young-growth stands that receive no treatment.

Because unintentional logging wounds are most common in the lower crown, it may be appropriate to augment traditional logging injuries with intentional injury to the mid and upper boles of selected residual trees. The vertical position of wounding and subsequent decay affects the value and use of cavities as wildlife habitat (Hughes 1985). Some species only use structures far from the ground, while others are less restricted by cavity location. Lower bole injuries may develop into useful habitat features, eventually resulting in canopy gap formation when decayed lower boles snap.

Unintentional top breakage occasionally occurs during harvest activities. Intentional top breakage using a feller buncher or placing explosives in the live crown are other management options that can increase stem decay in second-growth stands. If decay development is the goal, it is important to avoid top breakage in the lower live crown, because the tree will likely die and a decay column will fail to develop. Intentional wounding and upper-crown top breakage can be implemented during planned entries to young stands with standard equipment, thereby eliminating the need for costly supplemental entries.

Artificially inoculate trees with decay fungi—

A recent review (Filip et al. 2011) discussed the results of direct inoculation of live trees with decay fungi in Oregon and Washington. Inoculations are accomplished by placing a substrate colonized with fungi into drilled holes in trees (Parks and Hildebrand 2002) or by firing shotgun or rifle shots loaded with fungi into trees (Baker et al. 1996, Manning 2008). These treatments have the advantage of introducing fungi that are known to cause rapid or a certain type of decay into desired parts of the tree. Filip et al. (2011), Bednarz et al. (2013), and Manning (2008) concluded that fungal inoculation is significantly more effective in causing decay than wounding without fungal inoculum. It is important to use native fungal species and to collect fungal inoculation materials close to the location where they will be used, as these fungi are best-adapted to the hosts and conditions in their local environment.

There may be concerns about the potential to increase stem decay in stands beyond the inoculated trees, especially in or near stands primarily used for timber production. Spores of stem decay fungi are abundant in all forest stands, even young stands with little or no decay. The quantity of stem decay differs among forests of different ages and conditions because the initiation of decay is dependent upon a viable spore landing on a wound, branch stub, or other suitable infection court, which requires time and chance. Fungal inoculation should not increase the likelihood of healthy, non-target trees becoming infected (Parks and Hildebrand 2002).

Few studies have evaluated fungal inoculations of Sitka spruce or western hemlock; one exception is a recent study from western Washington in which western hemlock and Douglas-fir trees were inoculated with *Fomitopsis pinocola* (Bednarz et al. 2013). Nonetheless, protocols and lessons learned from inoculations of other tree species and in other locations in the Pacific Northwest have application in coastal Alaska. Although Parks and Hildebrand (2002) initially suggested that drilling and inserting multiple dowels at the same tree height might cause such extensive decay as to lead to bole breakage, Filip et al. (2011) recommended that three dowels be inserted at the same tree height (spaced evenly for trees <25 in in diameter, or clustered more tightly for larger trees). In contrast to inoculations spaced vertically on the tree bole a few feet apart, multiple inoculations at one height allow adjacent cultures to merge to form a decay column sufficient for cavity nesting more rapidly (<10 years). It is also advisable to insert a PVC (polyvinyl chloride) pipe at least 6 in long halfway into each drilled inoculation hole to prevent the tree from sealing the hole with resin or continued tree growth. Fast-growing trees will form a thicker annual ring around decay compared to slower-growing trees, which may make it difficult for primary excavators to access decay. This is less likely to present a problem in Alaska compared to Oregon and Washington, but is worth considering on particularly productive sites.

Filip et al. (2011) found that species of fungi caused considerably different rates of decay following inoculation. The fungus that caused the most rapid decay was *Fomitopsis cajenderi*, which is not native in Alaskan forests and should not be used there. Instead, other native species listed in this report that successfully caused decay in wet forest types, such as *F. officianalis*, *F. pinicola*, and *Stereum sanguinolentum*, would be good candidates. *Phaeolus schweinitzii* and *Phellinus hartigii* were not evaluated, but are also native to Alaska and were recommended for trial in the research needs section of this review. Bednarz et al. (2013) found that *F. pinicola* inoculations were significantly more effective on western hemlock compared to Douglas-fir, which also suggests that it is important to carefully pair inoculation fungi with susceptible tree hosts. Manning (2008) found that *Phellinus pini* inoculations successfully caused decay of Douglas-fir on Vancouver Island within 5 years of inoculation, but indicated that other fungal species with more rapid growth may be more appropriate. Rifle inoculation methods resulted in slightly higher rates of decay compared to drilled holes in this study, and were less expensive because tree climbers were not needed. Filip et al. (2011) should be consulted to review and make recommendations for any trials in Alaska. Personnel in the Juneau Office of Forest Health Protection have the facilities to culture and develop inoculum of native fungi from Alaskan forests.

Conclusions and Key Points

Stem decays, or heart rots, are caused by native species of fungi that create one of the defining characteristics of old-growth forests in coastal Alaska. They create unique wildlife habitat, and contribute to a number of other ecological processes, including canopy gaps and disturbance dynamics, nutrient cycling, and microbial biodiversity. Old forests are often described as "decadent," but this term is too vague to be helpful in identifying the factors that should be managed to restore wildlife habitat or other old-growth characteristics. Trees in young stands typically lack stem decays, which usually take over 150 years to develop in forests that have few damage agents.

Selection harvests of old-growth forests can target defective trees with existing stem decay for retention to serve as wildlife habitat in managed forests. Strategies to speed the reintroduction of stem decays in young-growth trees include unintentional and intentional tree injuries (lower and upper bole wounds, and top breakage) during silvicultural entries, as well as targeted artificial inoculation of trees with decay fungi.

Strategies to speed the reintroduction of stem decays in young-growth trees include unintentional and intentional tree injuries as well as targeted artificial inoculation of trees with decay fungi.

The type and amount of wood decay in live trees differs considerable by tree species. Treatments that focus on western hemlock will produce a more rapid stem decay and there is considerably more "white rot" than in Sitka spruce. Some wildlife species might prefer to use Sitka spruce, however. The location of tree injuries in the lower or upper bole or as top breaks leads to different forms of wildlife habitat as decay develops and produces soft wood and cavities. This variation results in habitat diversification, and can also influence the length of time that a decayed tree remains alive and standing, which, in turn, affects other ecological processes.

Specific actions to increase internal wood decay may be appropriate for young-growth forests with management goals that favor wildlife habitat and the restoration of old-growth characteristics. However, promoting wood decay in trees is not necessary where defective old-growth trees are protected in green tree retention harvests or in young-growth stands scheduled for repeated short-rotation harvest.

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Metric Equivalents

When you know:	Multiply by:	To find:
Inches (in)	2.540	Centimeters (cm)
Feet (ft)	0.3048	Meters (m)
Acres (ac)	0.4047	Hectares (ha)
Square feet (ft^2)	0.0929	Square meters (m^2)
Cubic feet (ft^3)	0.0283	Cubic meters (m^3)

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Appendix: Common and Scientific Names

Common name	Scientific name
Plants:	
Mountain hemlock	*Tsuga mertensiana* (Bong.) Carr.
Shore pine	*Pinus contorta* Dougl. ex Loud. var. *contorta*
Sitka spruce	*Picea sitchensis* (Bong.) Carr.
Western hemlock	*Tsuga heterophylla* (Raf.) Bong.
Western redcedar	*Thuja plicata* Donn ex D. Don
Yellow-cedar	*Callitropsis nootkatensis* (D. Don) Little
Birds:	
Boreal chickadee	*Poecile hudsonicus*
Boreal owl	*Aegolius funereus*
Brown creeper	*Certhia americana*
Chestnut-backed chickadee	*Parus refeschens*
Downy woodpecker	*Picoides pubescens*
Golden-crowned kinglet	*Regulus satrapa*
Hairy woodpecker	*Picoides villosus*
Northern hawk-owl	*Surnia ulula*
Northern saw-whet owl	*Aegolius acadicus*
Pine grosbeak	*Pinicola enucleator*
Audubon’s warbler	*Setophaga coronata*
Pine siskin	*Carduelis pinus*
Red-breasted nuthatch	*Sitta canadensis*
Red-breasted sapsucker	*Sphyrapicus ruber*
Red-tailed hawk	*Buteo jamaicensis*
Ruby-crowned kinglets	*Regulus calendula*
Sharp-shinned-hawk	*Accipiter striatus*
Sooty grouse	*Dendragapus obscurus*
Three-toed woodpecker	*Picoides tridactylus*
Western screech-owl	*Megascops kennicottii*
Mammals:	
Black bear	*Ursus americanus*
Marten	*Martes americana*
Northern flying squirrel	*Glaucomys sabrinus*
Fungi:	
Shoestring fungus	*Armillaria* spp.
White butt rot	*Ceriporiopsis rivulosa*
Coral fungus	*Hericium abietis*
Coniophora decay	*Coniophora* sp.
Paint fungus	*Echinodontium tinctorium*
Red belt fungus	*Fomitopsis pinicola*
Quinine conk	*Fomitopsis officinalis*
Artist’s conk	*Ganoderma applanatum*
Heterobasidion conk	*Heterobasidion annosum*
Chicken of the woods	*Laetiporus sulphureus*
Velvet top fungus	*Phaeolus schweinitzii*
Hartig’s conk	*Phellinus hartigii*
Pini conk	*Phellinus pini*
Laminated butt rot	*Phellinus weirii*

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