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Author(s): Thomas J. Brandeis, Michael Newton, Gregory M. Filip and Elizabeth C. Cole
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CAVITY-NESTER HABITAT DEVELOPMENT IN ARTIFICIALLY MADE DOUGLAS-FIR SNAGS

THOMAS J. BRANDEIS,[1] International Institute of Tropical Forestry, USDA Forest Service, P.O. Box 25000, San Juan, PR 00928, USA
MICHAEL NEWTON, Department of Forest Science, 321D Richardson Hall, Oregon State University, Corvallis, OR 97331, USA
GREGORY M. FILIP, Department of Forest Science, 321D Richardson Hall, Oregon State University, Corvallis, OR 97331, USA
ELIZABETH C. COLE, Department of Forest Science, 321D Richardson Hall, Oregon State University, Corvallis, OR 97331, USA

Abstract: Standing dead trees, or snags, are a source of foraging habitat and nesting cavities for wildlife. We evaluated the efficacy of creating Douglas-fir (*Pseudotsuga menziesii*) snags (by girdling, silvicide treatment, and topping) and their influence on deterioration rate by describing bark beetle activity, fungal colonization, and use by cavity nesters. To compare the development of artificial with natural fungal infection, we inoculated snags with *Fomitopsis pinicola, Fomitopsis cajanderi, Phellinus pini,* and *Phlebiopsis gigantea.* Silvicide-treated and fully topped trees took just over 1 year to die; girdled trees took slightly over 2 years to die. Trees topped at mid-crown that died took almost 3 years. Top breakage began 4 years after treatment. Neither snag-creation methods nor artificial inoculation directly affected bark beetle (*Dendroctonus* spp., *Ips* spp.) activity or the presence of externally visible fungal fruiting bodies 4 years after treatment. Native decay fungi, particularly *Trichaptum abietinum* and *Cryptoporus volvatus,* extensively colonized snag sapwood. Snag-creation method and artificial inoculation did not appreciably affect woodpecker activity after 4 years. Rather, length of time the snag had been dead had the most influence on bird use. All snags except the living mid-crown topped trees provided foraging habitat and may be a suitable condition for cavity-nest excavation. Pileated woodpeckers (*Dryocopus pileatus*), hairy woodpeckers (*Picoides villosus*), and other species excavated and de-barked the created snags during foraging, and possibly during nesting activity.

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Key words: beetle colonization, decay development, Douglas-fir, *Fomitopsis cajanderi, Fomitopsis pinicola,* fungal inoculation, Oregon, *Phellinus pini, Phlebiopsis gigantea, Pseudotsuga menziesii,* snags, wildlife habitat.

Standing dead trees, or snags, are normal components of both young and maturing forests. These structures are a source of foraging habitat and nesting cavities (Thomas et al. 1979, Miller and Miller 1980). This habitat feature may be in short supply in the Pacific Northwest because previous management practices emphasized the removal of snags as hazards (Thomas et al. 1979, Cline et al. 1980, Cline and Phillips 1983, Hope and McComb 1994, Hayes et al. 1997).

The structural characteristics (minimum heights and diameters, broken tops, etc.) of snags that provide habitat for cavity-nesting species have been established through numerous studies (McClelland and Frissell 1975, Cline et al. 1980, Bull 1983, Conner et al. 1983*a*, Scott et al. 1983). Less immediately evident are the needs for certain levels of insect infestation and fungal decay to be present in the standing dead tree if it is to be of value as a nesting or feeding site (McClelland and Frissell 1975, McClelland et al. 1979, Cline et al. 1980, Bull et al. 1986). Decay in standing dead trees is a prerequisite to their use by cavity-nesting birds and other wildlife species (Conner et al. 1983*a*, Bull et al. 1986). Wood must be physically weakened by decay organisms so that nesting cavities can be excavated. Bark beetles are a principal vector of decay fungi and also are an important food source for many bird species.

ARTIFICIAL SNAG CREATION

Artificial snag creation has been suggested as an alternative for increasing the abundance of nest sites and feeding sites for selected animal species (Cline et al. 1980, Conner et al. 1983*a*, Bull and Partridge 1986, Morrison et al. 1986, Hope and McComb 1994). Land managers must choose techniques that are both biologically sound and cost effective if snag abundance is to be increased on a large scale.

Although there are many ways to kill a tree, the method may alter the course of deterioration that also is necessary for use by the animals. For example, Miller and Miller (1980) were critical of using girdling for snag creation. They observed that sapwood decay predominated in girdled hardwood trees, whereas trees that had heart rot before dying were more suitable for nesting cavities. Harris (1983) did not believe that created snags would have adequate decay characteristics for cavity-nesting bird habitat, and that if attempted, creation should be coupled with artificial inoculation of the potential snags with

[1] E-mail: tbrandeis@fs.fed.us

decay fungi. Harris (1983) hypothesized that topping may be the preferred method of snag creation because it provides entry courts to the heartwood for decay fungi. Girdling and silvicide injection may not give the right combination of heart and sapwood decay necessary for adequate, long-lasting cavity-nester habitat (Harris 1983). Typically, heart-rot fungi enter and begin decay processes well before tree death, resulting in more advanced heart-rot decay before death and eventual toppling (Harris 1983). Bull and Partridge (1986) reported that removing tree crowns and limbs ensured tree death and increased snag longevity by reducing wind resistance. Cavity nesters more frequently used topped trees than snags created with other methods (Bull and Partridge 1986).

Silvicides have been recognized as an effective and economical means of killing trees that subsequently served as wildlife trees (Laird and Newton 1973; Conner et al. 1981, 1983*b*; McComb and Rumsey 1983; Newton 1986). Bull and Partridge (1986) observed that although injection with the silvicide monosodium methanearsonate (MSMA) was the cheapest of all treatments to apply, the herbicide-killed trees showed the least amount of subsequent bird feeding and nesting activity. Differences in drying caused by technique, timing, and toxicity of silvicides may affect fungi and insects, and subsequently the tree's deterioration process. Holt et al. (1978) found that timing of silvicide application affected subsequent cambium moisture content. Changes in cambial moisture content alter the physical characteristics and quality of food for adult and larval bark beetles (Laird and Newton 1973).

Organic arsenate herbicides, such as MSMA, have been shown to reduce adult bark beetle attacks and the breeding success of *Dendroctonus* spp. and *Ips* spp. (Holt et al. 1978, Newton 1986, Hodgkinson 1991). Molds are thought to break down organic arsenicals to insecticidal organic arsines (Newton 1986). After application, arsenic is concentrated in the phloem where bark beetles are active and the insects cannot breed successfully in treated trees (Newton 1986). Holt et al. (1978) found that 60-year-old ponderosa pine (*Pinus ponderosa*) trees treated with MSMA were not attacked by pine engraver (*I. pini*) or mountain pine beetle (*D. ponderosae*), whereas untreated trees had heavy infestations. Mountain pine beetles entered the trees but formed few larval galleries and showed brood mortality (Holt et al. 1978). *Dendroctonus* spp. beetles are known to be more susceptible to organic arsines than are other insects (Holt et al. 1978).

Lethal trap trees are commonly used to reduce *Dendroctonus* spp. and *Ips* spp. populations in forests of British Columbia (Hodgkinson 1991). Frill-injected MSMA and cacodylic acid are the recommended silvicides and have been shown to have a significant impact on survival and mating of adult beetles (Hodgkinson 1991). Brood reductions of 90% have been reported with applications of 80 g/L active ingredient of MSMA, whereas higher concentrations may have a repellant effect (Hodgkinson 1991). *Buprestis* spp. appear to tolerate post-treatment arsenic levels in the cambium better than do *Dendroctonus* spp. because larvae and adults were found in MSMA-treated trees. These insects probably were exposed to nonlethal levels of arsenic (Holt et al. 1978, Newton 1986). If birds consume these beetles, arsenic may enter the forest food chain, although in the low-toxicity pentavalent arsenate form (Newton 1986).

Organic arsenical herbicides also have fungicidal effects (Laird and Newton 1973, Ahrens 1994). Stumps treated with MSMA tended to be infected by saprophytic fungi that have much higher tolerance to the chemical than the stem-decay fungus *Heterobasidium annosum* (cited as *Fomes annosus* in the publication), which was killed (Laird and Newton 1973).

Other silvicides, such as picloram and 2,4-D, have been used to kill trees and provide snags for birds without arsenic residues (Laird and Newton 1973; Conner et al. 1981, 1983*b*; McComb and Rumsey 1983; Newton 1986). Southern red oaks (*Quercus falcata*) injected with 2,4-D were colonized with both heartwood and sapwood decay fungi (Conner et al. 1983*b*), and stumps treated with a mixture of 2,4-D and picloram were colonized by *H. annosum* (Laird and Newton 1973).

Artificial Inoculation with Decay Fungi

Several investigators have reported the relationship between cavity-nest sites of birds and internal decay of trees (Shigo and Kilham 1968, McClelland and Frissell 1975, Conner et al. 1976, Miller et al. 1979). If a snag-creation method in some way interferes with the natural process of fungal colonization and decay, for example, by repelling bark beetles that are fungi vectors, then artificial inoculation might ensure success of fungal colonization. Based on this rationale, trees have been artificially inoculated with wood-decay fungi to speed adequate wood decay (Conner et

al. 1983*a*, Bull and Partridge 1986, Parks et al. 1996). Snag-creation treatments that are expected to quickly kill a tree (topping, herbicide injection) have been accompanied by inoculation with saprophytic fungal species, whereas treatments that kill trees more slowly receive heart-rot fungal species or a combination of heart-rot and saprophytic species. Examples are dynamite topping and inoculation with *Dichomitus squalens*, or girdling and inoculation with *Fomitopsis pinicola* and *D. squalens* to create ponderosa pine wildlife trees (Bull and Partridge 1986). Conner et al. (1983*a*) reported an 80% success rate for inoculation of *Spongipellis pachyodon* and *Laetiporus sulphureus* into living oaks (*Quercus* spp.). Parks et al. (1996) reported that after 5 years, cavity-nesters in northeastern Oregon were using 50% of artificially inoculated living western larch (*Larix occidentalis*) in 1 stand.

Although completely dead trees are the most common habitat for cavity dwellers, live trees with suitable decay also may accommodate them. Affeltranger (1971), Miller and Miller (1980), and Conner et al. (1983*a*,*b*) suggested that live trees might be made suitable for cavity excavation by artificial inoculation with heart-rotting decay fungi. Successful inoculation of living trees could produce sufficient decay in a living tree that would be less likely to fall within a short time or to be harvested for firewood. A live tree will form a sound rind of wood around the decayed area, compartmentalizing it within the tree (Shigo and Kilham 1968, Miller and Miller 1980). If heartwood decay suitable for excavation by cavity-nesting wildlife could be induced in a tree without immediately killing it, the useful life spans of snags so treated could be extended greatly (Affeltranger 1971; Miller and Miller 1980; Conner et al. 1983*a*,*b*).

Our objectives were to evaluate the efficacy of 5 snag-creation methods in second-growth Douglas-fir stands. We were particularly interested in looking for alterations in the progress of deterioration of standing dead trees after they were killed with a silvicide or girdled. Topping is a proven method for creating snags that are used by foraging and nesting animals. If significant differences exist in the deterioration of injected or girdled trees and that of topped trees, it may be an indication that snags created using these other techniques will not provide suitable habitat. To address these questions, we examined 5 processes in snag formation: death, physical deterioration, bark beetle activity, fungal colonization, and subsequent woodpecker use. Additionally, fungi were artificially introduced into the snags to assess their colonizing success and whether their development was influenced by the snag-creation method.

METHODS

These results document cavity-nester habitat development during the first 4 years (winter 1994–1995 to late 1998) after treatment application. This ongoing study was carried out on the Oregon State University McDonald-Dunn Research Forest located in western Oregon (lat 123°12′W, long 44°38′N) in 50- to 55-year-old Douglas-fir stands that had been thinned to residual basal areas ranging from 18 to 31 m^2/ha. All stands were on similar northwest aspects and within 1.5 miles of each other, and many were directly adjacent to one another. Based on data collected from a concurrent thinning study, we decided that the stands were sufficiently similar to not warrant blocking the treatments by stand. Therefore, 99 trees were selected from the stands for treatment and were randomly assigned to 1 of 5 snag-creation methods or to the control, a set of untreated green trees (18 trees per snag-creation method, plus 9 untreated) for a completely randomized experimental design. Treated trees had an average diameter at breast height (DBH; 1.4 m above the ground) of 42.3 cm (range 28.5–72.7 cm) and an average height (pre-treatment) of 37 m. (These trees were too small to provide nesting sites for larger cavity nesters such as pileated woodpeckers. The trees in these stands were representative of thousands of acres of second-growth Douglas-fir present throughout western Oregon and Washington.)

The 5 snag-creation methods were (1) girdling with an axe at breast height, (2) cut and frill application of triclopyr herbicide, (3) cut and frill application of MSMA herbicide, (4) topping at the base of the live crown (fully topped), and (5) topping at the middle of the live crown (mid-crown topped). Approximately 2 ml of undiluted concentrates (Garlon-3A® containing 23.4 ml/l [3 ounces/gal] of triclopyr as the amine salt, and MSMA at 39.07 ml/l [5 ounces/gal] as the sodium salt, both in aqueous solutions) of the silvicides were injected with a syringe into axe cuts spaced about 10 cm apart at breast height for the 2 silvicide treatments. Although there are questions concerning the residual toxicity of MSMA, we chose to include this chemical in the study to test for possible negative effects.

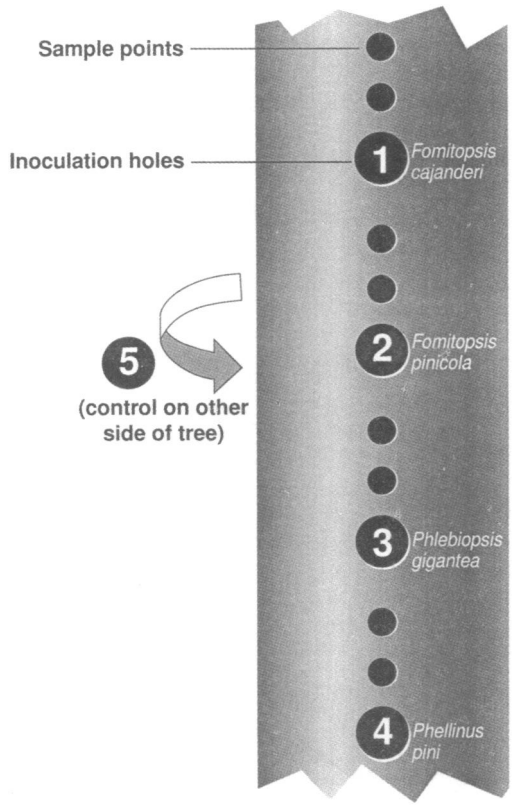

Fig. 1. Arrangement of fungal inoculation holes and sample points along each Douglas-fir tree trunk used for artificial snag creation in western Oregon, USA. The arrangement of fungal inoculum by species was consistent for each tree. Inoculation occurred in early 1996; sampling and culturing took place in 1998.

One year after treatment, 9 trees were randomly chosen from within each of the 5 snag-creation methods to also be artificially inoculated with fungi. Nine additional trees that had not been treated with any snag-creation methods also were artificially inoculated to act as controls. We drilled 5 2-cm diameter holes 10–12 cm into sapwood at a height of 6 m above the ground. Four fungal inoculation holes were arranged vertically along the tree trunk with approximately 40 cm between holes (Fig. 1). We placed the fifth hole (sterile control) on the opposite side of the trunk. Either a wooden dowel inoculated with 1 of 4 species of fungus or a sterilized control dowel was inserted into each hole. Finally, we inserted a 10-cm polyvinyl chloride pipe about halfway into each hole to prevent the tree from sealing the wound and depriving the fungi of oxygen, as well as ensuring intimate contact between the inoculum and heartwood (C. Parks, USDA Forest Service, personal communication). The inoculation fungi consisted of 2 heart-rot species, *Phellinus pini* and *Fomitopsis cajanderi*, and 2 saprophytic species, *Fomitopsis pinicola* and *Phlebiopsis gigantea*.

Data Collection

We assessed foliage, branch, bark, and cambium conditions each year for 4 years after snag-creation treatments were applied. We counted and identified external fungal fruiting bodies over the entire surface of the tree. A square bark sample (100 cm^2) was removed from each tree twice at breast height and once at a height of 6 m to count beetle entry holes and aeration holes (perforations) and to measure the length of larval and adult beetle galleries. When possible, we identified the species of insect responsible for the observed activity. Although more intensive bark sampling would have given a better estimate of bark beetle activity, further bark removal would affect snag deterioration and confound the results.

During the final 2 years of the study, we assessed signs of woodpecker use. Woodpecker activity was divided into 4 categories: small foraging holes (<5 cm in diameter), large foraging holes (5–10 cm in diameter), partially excavated cavities (at least 15 cm into the sapwood and typically 10–20 cm wide), and removal of bark patches (sections of bark >100 cm^2) by foraging birds. We counted up to 50 small foraging holes for each tree, then classed them as "50+". In mean calculations, these observations had to be treated as simply 50 counts for the 10 snags where this occurred; therefore, mean values for small foraging holes are conservative. Plots of residuals versus predicted values did not indicate excessive skewness in the data, so these data are useful for a relative comparison of woodpecker activity.

Three years after artificial inoculation, wood samples were taken with an increment borer to a depth of 10–12 cm at 5 and 30 cm above each inoculation point (Fig. 1). We visually assessed decay in each wood sample prior to culturing. Brown, softened, punky wood and dark, discolored wood were classified as decayed. Core samples were then sectioned into 1.5–2.0-cm pieces, cultured on 2% malt agar medium with 3 ppm of benomyl, and incubated for 8 weeks in the dark at room temperature. After incubation, we noted and attempted to identify the presence or absence of fungal hyphae. Throughout this procedure, sample location on the trunk of the snag (Fig. 1) and section position (depth) on the core were recorded.

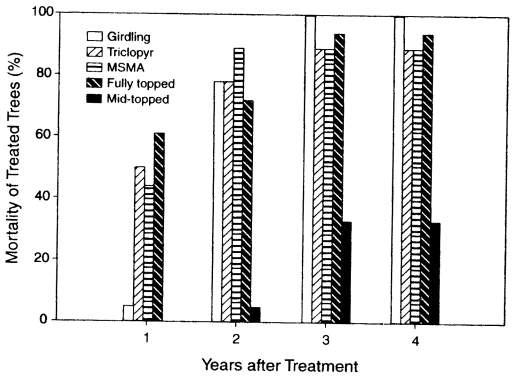

Fig. 2. Percentage of treated Douglas-fir trees that were dead 4 years after treatment, by snag-creation method, in a study of artificial snag creation in western Oregon, USA, 1995–1998.

We looked for significant differences in the incidence of wood decay (1) in the sample as a whole, (2) just from the sapwood, and (3) just from the heartwood of inoculated trees. The 2 sections of each wood sample closest to the bark were considered to be sapwood, while the 2 sections closest to the tree's pith were considered heartwood.

Data Analysis

We used analysis of variance (ANOVA) to test for significant treatment effects (snag-creation method) on bark beetle perforation, bark beetle gallery length, number of externally visible fungal fruiting bodies, number of woodpecker foraging holes, bark patches removed, and partially excavated cavities. If treatment effects were found to be significantly different at $\alpha = 0.05$ in these tests, multiple means were compared with Duncan's Multiple Range Test.

In snags that were artificially inoculated with fungi, variables examined with Fisher's Exact Test (when testing for equal odds for 2×2 tables) and Cochrane-Mantel-Haenzel (CMH; testing for equal odds in several 2×2 tables; Ramsey and Schafer 1995) tests as potentially affecting the presence or absence of wood decay were snag-creation method, years since tree death, distance from inoculation point, and fungal species inserted at the nearest inoculation point.

RESULTS

Death and Physical Deterioration

Three years after treatment, all 18 girdled trees were dead. Two MSMA-injected, 2 triclopyr-injected, 1 fully topped, and 12 mid-crown-topped trees remained alive. Only 1 girdled tree died in the first year after treatment, while 11 of the fully topped trees died (Fig. 2). Most girdled trees died 2 years after treatment, while herbicide-injected trees died in the first or second year. Six of the mid-crown-topped trees were dead after 3 years. No additional mortality occurred in year 4, and it appears that some of the surviving trees will remain alive unless suppressed by adjacent healthy trees.

Top breakage was first observed 2 years after treatment. Four years after treatment, 12 trees had broken tops; 6 of those had been injected with triclopyr, 2 had been injected with MSMA, 2 had been mid-crown-topped, 1 had been fully topped (snag broke further down the stem), and 1 had been girdled. Although there were too few occurrences for statistical analysis, there may be a trend toward greater top breakage lower on the stem in herbicide-injected trees.

Bark Beetle Activity

Douglas-fir beetles (*Dendroctonus pseudotsugae*), ambrosia beetles (typically *Gnathotrichus retusus*), and flatheaded borers (*Buprestis* spp.) were the principal species found feeding on and reproducing in the snags. Snag-creation method did not affect the number of insect-caused perforations in the bark ($P = 0.43$; Fig. 3). Trees that had been injected with triclopyr had more centimeters of bark beetle galleries per 100 cm^2 of bark surface than did trees that were mid-crown-topped ($F_{4, 85} = 2.55$, $P = 0.05$; Fig. 3).

Fungal Colonization

Natural Colonization.—Native fungi, particularly the saprophytes *Trichaptum abietinum* and *Crypto-*

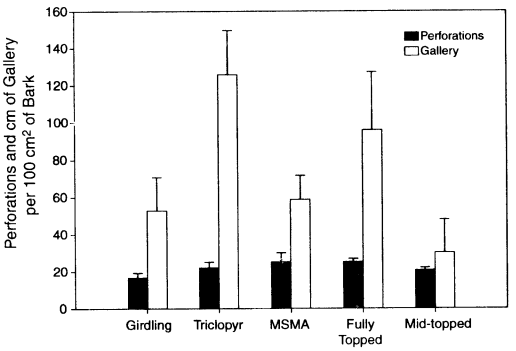

Fig. 3. Bark beetle perforations and centimeters of galleries per 100 cm^2 (with standard errors) of Douglas-fir bark surface 4 years after treatment, by snag-creation method, in a study of artificial snag creation in western Oregon, USA, 1995–1998.

porus volvatus, were ubiquitous on the created snags. *T. abietinum* fruiting bodies (a small white to gray shelf-like fungus) were found on 71% of all snags, regardless of snag-creation method. Counting individual fruiting bodies was impossible due to their great number, so the percent of stem coverage was recorded. Where it was found, *T. abietinum* covered, on average, 24.7% of the snag stem. *T. abietinum* fruiting bodies were most frequently (69% of the time) located on the lower half of the stem, and only 9% (6 trees) had *T. abietinum* fruiting bodies over the entire stem surface. Small traces (1%) of *T. abietinum* were observed on 2 live snags; otherwise, live trees did not have *T. abietinum* fruiting bodies. Snag creation method did not have an effect ($F_{4, 67} = 1.22$, $P = 0.31$) on the percent stem coverage of *T. abietinum* on dead snags. To further explore the relationship between tree death and fungal colonization, we tested the number of years the snag had been dead (maximum of 3 years) but was not found to significantly affect the coverage of *T. abietinum* fruiting bodies on snags ($P = 0.95$).

Fungal fruiting bodies of *C. volvatus*, *Phellinus pini*, and 2 unidentified species were observed in lesser numbers than *T. abietinum*, so they were individually counted. *P. pini* was found in 3 trees, 2 of which were mid-crown topped and still alive, and 1 that had been treated with triclopyr and was dead. Infection may have been the result of artificial inoculation. Snag-creation method did not significantly affect the occurrence of any of these fungal fruiting bodies, nor did the number of years the snag had been dead.

Artificial Inoculation.—Artificial inoculation did not appreciably affect the total numbers of externally visible fungal fruiting bodies ($F_{9, 80} = 1.99$, $P = 0.16$) on the snags, nor was the interaction between inoculation and creation method significant. One unidentified species with fruiting bodies may have been of the species used in inoculation, but we were not able to make a positive identification. This fruiting body was found in only 2 non-inoculated trees; all other occurrences were in inoculated, dead snags. Also, the fungal fruiting bodies were located at approximately the height of artificial inoculation.

Prior to culturing, wood samples extracted from the sapwood (7.5%–25% occurrence of decay) showed more visible evidence of decay than did samples from heartwood (2.5%–7.5% occurrence of decay), regardless of snag-creation method or inoculum. Samples collected near *Phellinus pini* and *Phlebiopsis gigantea* (Fisher's Exact Test 2-sided $P = 0.68$ and 1.00, respectively) inoculum had the same, low incidence of decay as samples collected near the control inoculation points, while samples taken near *F. cajanderi* and *F. pinicola* inoculation points had a significantly higher incidence of decay (Fisher's Exact Test 2-sided $P = 0.0006$ and 0.03, respectively). There is a strong suggestion that decay decreased with increasing distance from the point of inoculation, regardless of the species of inoculum (Fisher's Exact Test 2-sided $P = 0.06$). Including species of inoculum in the analysis indicated that decay significantly decreased with distance from the inoculation point for *F. cajanderi* (CMH test $P = 0.03$), but not for *Phellinus pini*, *Phlebiopsis gigantea*, or *F. pinicola* samples collected from the sapwood. The higher incidence of decay near points inoculated with *F. cajanderi* (CMH test $P = 0.03$) and also near *F. pinicola* points (CMH test $P = 0.003$) was found more on girdled trees than control trees or snags receiving other treatments.

After 3 years, each of the artificially inoculated fungal species were recovered from at least 1 of the sampled trees, but most decay fungi that were cultured were not identified. The most frequently isolated fungal species was *Antrodia carbonica*, which causes brown-cuboidal rot in conifers. After culturing, the formation of wood-decaying fungal hyphae on the samples was not appreciably affected by distance from the point of inoculation, or the species of inoculum. Samples extracted in the vicinity of *Phellinus pini* inoculum were the only ones that had an appreciably higher incidence of hyphae (Fisher's Exact Test 2-sided $P = 0.01$) than did samples near control inoculations. Snag creation method had little effect on the formation of fungal hyphae in cultured samples. Samples extracted from mid-crown topped trees developed less fungal hyphae during incubation than samples taken from living control trees (Fisher's Exact Test 2-sided $P = 0.001$).

Wildlife Use

Four years after treatment, triclopyr-injected and fully topped trees had the greatest frequency of woodpecker activity (Fig. 4). Mid-crown-topped trees had the lowest frequency of woodpecker activity, and girdled trees had the second lowest.

This pattern of use changed slightly when considering the intensity of woodpecker use on dead snags. There was a strong suggestion that girdled trees had the fewest small foraging holes, and that mid-crown-topped trees and MSMA-injected trees had more small foraging holes than the

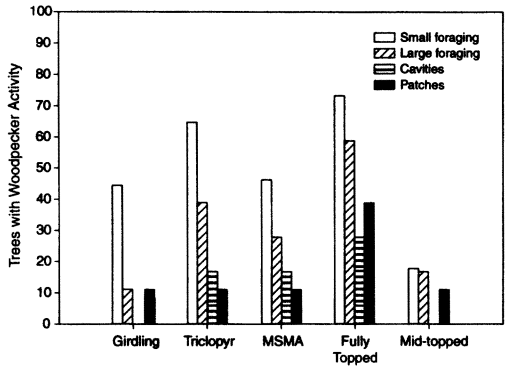

Fig. 4. Percentage of Douglas-fir trees with woodpecker activity 4 years after treatment, by snag-creation method, in a study of artificial snag creation in western Oregon, USA, 1995–1998.

snags killed with other methods ($F_{4, 67} = 2.40$, $P = 0.06$; Fig. 5). However, no appreciable differences occurred in the numbers of larger foraging holes by snag-creation method ($P = 0.56$). Significantly more cavities were excavated on fully topped trees than on girdled, triclopyr-injected, or mid-crown-topped trees ($F_{4, 67} = 2.65$, $P = 0.04$). There is also a strong suggestion that more bark patches were removed from fully topped trees than from snags created by the other treatments ($F_{4, 67} = 2.41$, $P = 0.06$).

To further explore differences in woodpecker use due to snag-creation method, years the tree had been dead was incorporated into the models. When this variable was tested, how the snag was killed (creation method) was no longer significant. Woodpeckers foraged most actively on trees dead for 3 years regardless of how the snag had been created ($F_{3, 86} = 9.25$, $P < 0.0001$, for small foraging holes; $F_{3, 86} = 3.46$, $P = 0.02$, for large foraging holes). There were no differences in the number of partially excavated cavities ($P = 0.10$) or removed bark patches ($P = 0.10$) with the number of years since the snag's death.

There were greater lengths of bark beetle galleries found beneath the bark where there was more woodpecker foraging ($P < 0.001$ for small foraging holes and for large foraging holes, $P = 0.03$ for partially excavated cavities, and $P = 0.0002$ for bark patches), but there were not more bark beetle perforations.

DISCUSSION

There have been no indications that the processes of physical deterioration of the created snags have been altered by any of the methods we used to kill the trees. Topping and silvicide injection were effective in killing trees quickly without any apparent loss of cavity-nesting wildlife habitat suitability so far. The bark beetles observed colonizing the snags created for this study were the same species described by Wright and Harvey (1967) as typically found in beetle-killed snags in western Oregon. Although we expected that beetle attack densities and gallery formation would be lower in trees that received MSMA applications because of the known repellant and insecticidal properties of organic arsenates (Holt et al. 1978, Newton 1986, Hodgkinson 1991), no significant differences occurred in number of beetle-caused bark perforations or length of galleries among the 5 treatments. It is possible that the dosage used to kill each tree was too low to have any repellant or toxic effects on beetles or fungi. Perhaps our beetle attack sampling was inadequate, but the positive correlations between observed beetle activity and woodpecker feeding seem to indicate that our sampling captured any biologically meaningful trends.

The created snags were colonized by most of the same species of fungi found in naturally killed trees. Wright and Harvey (1967) found that *F. pinicola*, *C. volvatus* (cited as *Polyporus volvatus*), and *T. abietinum* (cited as *Polyporus abietinus*) were the principal sap-rot species in beetle-killed snags. These species also are well established in the sapwood of many of the created snags and are a good indication that the snag-creation methods did not interfere with the snag deterioration processes. *C. volvatus* fruiting bodies normally appear on the boles of dead trees within 1–3 years after being introduced into the trees by Douglas-fir beetles

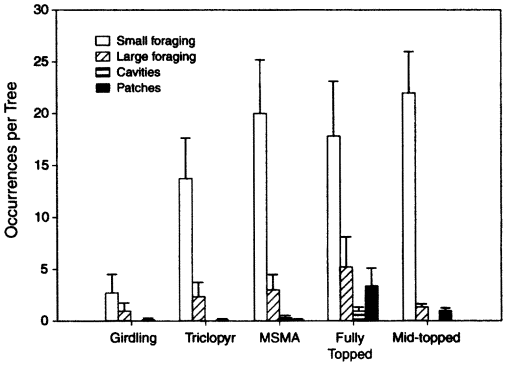

Fig. 5. Intensity (mean number of occurrences with standard errors) of woodpecker activity on Douglas-fir trees 4 years after treatment, by snag-creation method, in a study of artificial snag creation in western Oregon, USA, 1995–1998.

(Wright and Harvey 1967, Castello et al. 1976). The fungi actively decaying these created snags appear to closely match those found in naturally killed trees.

Woodpecker activity did not appear to be affected by snag-creation method or artificial inoculation, and activity intensified over time. The most important factor in snag habitat suitability to date has been length of time the tree has been dead. All snags except the mid-crown-topped trees, many of which are still alive, are providing foraging habitat. The snags may soon be in an adequate condition for nest-cavity excavation. Based on their size and depth, the partial excavations observed on the snags appear to have been created by pileated woodpeckers and may be early attempts at nest-cavity excavation. The low number of these deeper excavations may indicate that the heartwood is still relatively sound. Hairy woodpeckers and red-breasted sapsuckers (*Sphyrapicus ruber*) also are probably responsible for some of the excavations observed (Chambers et al. 1997; J. Hagar, Oregon State University, personal communication).

MANAGEMENT IMPLICATIONS

The snag-creation methods used in this study have not hindered the development of cavity-nester habitat to date. Methods that are more efficient and economical than tree topping can be used to quickly supplement the supply of standing, dead trees where they are lacking. Two elements of snag creation represent significant costs: (1) the value of the tree for logs, and (2) contract costs for the actual snag creation. The average value of the trees treated in this experiment ranged from $50 to $100 each, depending on their size. (Using defective trees, where possible, can minimize this cost.) The cost to contract a tree climber to do the topping treatments was $30 for each tree. Girdling and chemical injection costs were all less than $1 per tree, with chemical treatment the least costly. Cost for fungal inoculum and inoculation would have approached those of topping if labor had been contracted because of the cost in climbing and hole boring. The need for artificial inoculation to ensure adequate decay in created snags has not yet been demonstrated for the trees killed in this study.

Despite the apparent success in creating snags that provide wildlife habitat, a note of caution should be sounded. Treatments expedite the onset of death, but also shorten the functional longevity of a created wildlife tree. Short useful life spans and frequent blow-down are cited as problems common to artificially made snags (Hope and McComb 1994). Southern red oaks injected with 2,4-D decayed more rapidly than girdled trees and fell in only 3–4 years (Conner et al. 1983*b*). With western conifers, herbicide-killed trees began falling after 3–5 years (Bull and Partridge 1986). Initiation of decay took longer with girdling treatments, which was expected to result in a longer useful life as a wildlife tree (Conner et al. 1983*b*). None of the treated trees in our study has fallen after 4 years. Future observations will tell whether any of the creation methods affect snag longevity, whether decay has been established in the artificially inoculated living trees, and whether the inoculated trees develop into suitable wildlife habitat.

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