**Created Wildlife Tree Literature Review**

**Oregon and Washington, USA**

**02/22/2019**



**Author:**

**Cheryl Ann Friesen, Science Liaison, USFS cfriesen@fs.fed.us**

**Funded by: NW Oregon BLM, Willamette National Forest, R6 Ecology Program, PNW Research Station, and Central Cascades Adaptive Management Partnership**

***Reviewers: John DeLuca, NW Oregon BLM; Josh Chapman, R6 Wildlife Program Manager; Barbara Garcia, R6 Wildlife Ecologist***

****

***This page left intentionally blank***

**Table of Contents**

|  |  |
| --- | --- |
|  | ***Page*** |
| ***Literature Review*** |  |
|  Methods for creating wildlife trees | 4 |
|  Use of created wildlife trees  | 8 |
|  Does treatment type affect use? | 10 |
|  Created wildlife tree mortality, decay, and longevity   | 10 |
|  How do wildlife trees created by fire differ from trees damaged/killed by other methods?  | 12 |
|  Do snags created from trees in young stands (e.g., <17” dbh) provide habitat for wildlife? | 14 |
|  Does the silvicultural prescription of the stand influence use or longevity of created  wildlife trees? ( i.e. clearcut vs thinning vs group selection) | 15 |
|  Does arrangement of wildlife trees matter? i.e. dispersed versus clumped versus within  patches? | 16 |
|  What are the benefits of creating a “tree in decline” vs. a dead tree/snag? | 18 |
|  Does landscape composition surrounding harvest units with created wildlife trees influence  use?  | 18 |
|  What do we know about use over time as the re-establishing stand develops? | 18 |
|  Table 1: Studies that documented condition of created wildlife trees over time | 20 |
|  Table 2: Summary of literature that documented condition of fire-created snags over time | 24 |
| **Bibliography** | 26 |

***Created Wildlife Tree Literature Review***

***Oregon and Washington, USA***

Hope and McComb (1994) surveyed Pacific Northwest wildlife biologists on their approaches to wildlife tree management. Their findings highlighted numerous issues related to communication, education, funding, politics, and lack of ecological data. Many of the issues appear to still exist, even though snag habitat enhancement techniques have been occurring for several decades.

This document attempts to address some of the lingering issues through a review of over 100 papers on wildlife tree creation. Methods, longevity, and influences of stand and landscape conditions are summarized. This paper does not provide guidance on how to evaluate snag habitat or species use at the stand or landscape scale. That information is available in the Mellen-McLean et al. 2017 DecAid Tool (<https://apps.fs.usda.gov/r6_decaid/views/index.html>).

The science presented here strongly indicates that not all snags are created equal in terms of suitability for cavity excavation and use by cavity nesters (Bednarz et al. 2004 and Jackson and Jackson 2004). Also, simply creating a certain number of snags per area in all likelihood will not result in the retention of natural keystone processes needed to support wildlife tree users. Appropriate conservation strategies to protect interdependent forest communities must be designed to maintain the complex biotic interactions among fungi, insects, microorganisms, cavity excavators, and other wildlife.

***Methods for creating wildlife trees***

Bull et al. (1981) and Bull 1980 first reported experiences using explosives to top trees in combination with inoculation of *Polyporus anceps* to create Ponderosa pine snags. They found that woodpeckers readily foraged on snags created in this manner: 82% of ponderosa pine and 92% of lodgepole had foraging activity within one year of creation.

Carey and Sanderson (1981) evaluated routing (using a drill to create holes) as a technique to accelerate cavity formation in hardwoods. They also applied biological (fungal culture) and chemical (glycerol) inducing materials they felt may be useful in combination with routing. After 3 years, 139 trees were still structurally sound, but 5 red maples had fractured at the routing site. About a third of the cavities contained standing water; 18% were closed by callus. Partially closed cavities (about 80% of all cavities) were used by southern flying squirrels (*Glaucomnys volans*) for feeding and denning. This treatment was in hardwoods only: it is undocumented how well it would work for conifers.

As interest in creating wildlife trees increased so did the number of methods used. Bull and Partridge (1986) tested the following 6 methods in ponderosa pine: saw-topping, blasting, girdling, fungal inoculation, girdling combined with inoculation, herbicide injection, and insect pheromone baiting. Girdling occurred approximately 1 meter above the ground. Inoculation species included *Fomitopsis pinicola* and *Dichomitus squalens*, while pheromone baiting was done to attract *Dendroctonous brevicomis*. They found that saw-topping yielded the best cost/benefit results. Trees died immediately, had low fall rates, and were used statistically more frequently by cavity nesting birds than snags created by other methods.

Lewis (1998) completed a summary of snag and wildlife tree creation techniques. He found that topping trees with chainsaw or explosives, and girdling at or near the base of the crown, were extensively used methods. He reported costs of treatment, as well operational specifications, safety considerations, and the numbers of trees created using these methods. The use of chainsaw to top trees was less expensive than explosives, while girdling was the least expensive method. Fungal inoculation, cavity creation, and limbing were all reported to be cheaper when used in conjunction with topping or girdling.

Parks et al. (1999), saw close to l00% mortality of girdled ponderosa pine after 3 years, with the girdle at 1m above ground. Bull and Partridge (l986) girdled trees with two parallel saw cuts, but did not remove the bark and cambium. Girdling trees above the first whorl of branches did not result in loss of the entire snag due to wind-shear breaks at the wound site (Lewis 1998). Parks et al. (1999) reported cavities in girdled ponderosa pine trees after 7 years.

Lewis (1998) has a thorough paper comparing treatments. His paper states that girdling can create a dead but intact top, providing a taller snag; however, this intact top makes a girdled tree more susceptible to wind-shear at the wound site. If girdling is done at breast height (basal girdling) and wind-shear breaks the tree at the wound site, little or no snag habitat will remain. Alternatively, girdling in or near the base of the crown (crown girdling) can preserve much of the bole if wind-shear breaks the snag at the wound site. Girdling can be done in conjunction with fungal inoculation and limbing, at increased cost. Girdling may result in a sap rot rather than a heart rot, potentially reducing the suitability of some snags and nesting habitat (Carey and Gill 1983, Neitro et al. 1985). Sap rots, however, can provide suitable excavating conditions in tree species with a wide layer of sapwood ( e.g., ponderosa pine; Bull et al. 1997). Snag monitoring on the Colville National Forest documented natural fungal infection, insect infestation, and wildlife use of crown-girdled trees (M. Borysewicz, USDA Forest Service, Metaline Falls, WA, pers. comm.). In New Mexico, Parks et al. (1999) found that most of 102 ponderosa pines killed by basal girdling were used by woodpeckers as foraging substrate and that 20% contained woodpecker nest cavities <10 years after being girdled. Girdling appeared to be the safest and least expensive of the commonly used snag-creation techniques.

 Hallett et al. (2001) found that initial decline (i.e., reaching decay class 2) was faster for ponderosa pine and western larch than for Douglas-fir. Western larch lost bark (decay class 4) earlier than other species. Topped trees declined more quickly than girdled trees, but girdled trees reached decay class 4 faster. The proportion of trees with evidence of foraging and cavities increased with decay class. Western larch was used more for foraging than other species, but there was no effect of treatment on foraging use. In contrast, topped Douglas-fir and grand fir were used more for foraging than girdled trees at later decay classes. Cavities were observed only in trees that were topped. Interspecific differences in presence of cavities were not observed before decay class 1. Western larch had the lowest frequency of cavities, whereas grand fir had the highest. Their conclusion was that the type of treatment and the tree species need to be considered together to determine the longevity of these habitat elements over long time periods.

For example, Hallett et al. (2001) felt that the period of availability of artificial snags can be lengthened by selecting a mixture of tree species for snag creation and by staggering treatment. Western larch became less useful for foraging earlier than other species, whereas species such as grand fir may provide nesting habitat earlier. Similar recommendations have been made to forest managers to strive for high species richness, density, and diversity when selecting suitable habitat to manage for cavity nesters (Scott et al. 1977; Mannen et al. 1980; Steeger and Hitchcock, 1998; Zarnowitz and Manuwal 1985). It also could be advisable to stagger treatment of leave trees over a period greater than 10 years. This strategy would ensure a more natural distribution of snags in all decay classes over a longer period of time.

Brandeis et al. (2002) looked at creating snags by girdling, silvicide treatment, and saw-topping. 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 took almost 3 years to die. Top breakage began 4 years after treatment. 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 use.

Doerr (2008) found base-girding (at base of trunk) killed trees 32% more effectively over a 13-year period than mid-stem girdling (30-50 feet above ground) and did not result in higher “fall-down” rates over this period. Thirty two percent of mid-stem girdled trees were alive - but stressed - compared to 8% of base-girdled trees. The mid-stem treatments are likely to add more additional snags to the stand over time than base-girdled treatments. However, diameter growth of the stressed trees (estimated at about 4” dbh in 13 years) has been slowed by the girdling, so resultant snags will likely have smaller diameters than the average live trees in the regrowth stand.

Cox (2009) also looked at base girdling and found it to be a low-cost method with benefits expected to last at least 15−20 years post-treatment, given that 77% of the base-girdled trees persisted as snags greater than 20 feet tall 10 years after treatment, and that over 92% of these snags/trees had excavated cavities and holes. He also saw that 10 to 20% of the girdled trees did not die within the first ten years and therefore, they would not contribute to achieving any snag objectives within that period. Sick/dying trees however would likely contribute to snag objectives in the next decade.

In Shea et al. (2002), after 6 years they found differences in the rate of deterioration (tree fading rates, branchlet retention, bole failure, top breakage, bark sloughing), woodpecker feeding activity, cavity excavation, and insect diversity comparing girdled versus pheromone-baited trees (western pine beetle (*Dendroctonus brevicomis* Leconte). Their data indicated that bark beetle-killed trees provided a more biologically rich snag that is both suitable and acceptable to cavity dependent species.

The use of bark beetle pheromones was also tested by Ross and Niwa (1997) as a means to create standing dead trees and improve wildlife habitat. This study found that bark beetle pheromones could be used effectively to create snags for improving wildlife habitat: all of the trees baited were attacked, and many were dead within 1 year.

Bull and Partridge (1986) found that western pine beetle (*Dendroctonus brevicomis LeConte*) pheromones were less effective than topping for producing ponderosa pine snags.

Arnett (2010) found that creating snags with a feller-buncher was a viable option for increasing snags in young forests. But he acknowledged there is research indicating that certain bird species require taller and larger snags than those created with this tool.

Wooley et al. 2007 looked at ~ 15 year old treatments in young plantations, including girdling, topping, and inoculation. Aggressive treatments, such as saw-topping, blasting, and girdling, were effective in killing trees. Girdling treatments showed a slightly lower rate of mortality, requiring several more years before reaching at least 80% mortality. Inoculation only treatments showed very low mortality among created trees.

Weiss et al. 2018 characterized decay patterns in jack pine snags (*Pinus banksiana*) that had been killed by prescribed fire, topping, and girdling and determined the effects of these treatments on subsequent snag use by subcortical insects and primary cavity-nesting birds. Topped snags had the highest levels of past insect colonization, were softer, and had higher proportions of loose bark remaining on the boles. Trees killed by prescribed fire had the greatest number of foraging excavations and cavities. Girdled snags had the lowest evidence of past insect colonization and showed different levels of decay and insect use at different vertical positions on the snag bole. Their findings suggest that different jack pine snag treatments result in unique decay trajectories that may influence snag use by an array of wildlife taxa.

The use of fungal inoculum was adapted by Baker and others (1996) using a shotgun or rifle approach. They found that fungal inoculum was viable after being fired into Douglas-fir bolts. Filip and others (2004) put this method into practice and also found it to be a viable way to introduce decay to the inside of Douglas-fir trees. In 2013, Bednarz et al. continued this work with *Fomitopsis pinicola* and found a higher proportion of treatment trees displayed *F. pinicola* conks than did control trees. At least 36.8% of the treated trees had conks. There was also significantly more woodpecker excavations and sapsucker (*Sphyrapicus spp*.) foraging holes associated with the fungal inoculations than at control trees. In addition to *F. pinicola*, an ensemble of fungi and other micro-organisms was found in the wounds, suggesting that wounding of a healthy tree under the right circumstances may be sufficient to initiate this natural process in younger forests.

The authors also felt that results from their study and Bull et al. (1981) suggested that fungal inoculation is probably not useful to employ in conjunction with some other snag-creating techniques (i.e., tree topping, herbicide injection) because the relatively rapid death caused by these techniques and the natural exposure to attacking bark beetles and the ambient presence of spores and hyphae are probably satisfactory to quickly and naturally infect snags with local fungi. They recommend *F. pinicola* for inoculation into western hemlock and other soft-wood species: not for Douglas-fir. Based on limited results reported by Filip et al. (2011), *F. cajanderi* or *F. officinalis* might be a useful species to evaluate further for inoculation into Douglas-fir. Importantly, they recommended inoculations be made at least at the height of the lower live crown of trees, but higher (8-15m) would probably be more effective as decay columns grow downward more rapidly with the force of gravity (Jackson and Jackson, 2004).

Hildebrand et al. (2006) studied Douglas-firs on Alsea Ranger District that had been inoculated with stem decay fungi (*F. cajanderi*) within the crown, coupled with a lower dowel with *F. pinicola* or *Phellinus pini* below the crown. Though destructive sampling revealed decay at 90% of dowels, the extent of the advanced decay in most trees was not yet sufficient to accommodate a cavity nest by year 5, and no foraging activity was seen.

High cut stumps could also be considered as a created habitat for snag users. Gustaffson et al. 2012 documented high cut stumps being used as a wildlife management technique in both Sweden and Norway. Morrison et al. 1980 did a summary of cavity heights preferred by cavity nesters, and concluded that few species will readily use high-cut stumps. Raphael (unpubl. data; Raphael and White 1984) in the eastern Sierra Nevada found only one species (Mountain Chickadee) used stumps under 1 m in height. Taller stumps (1-2 m tall) were also used by white-headed woodpecker, northern flicker, mountain bluebird, and house wren, though rarely. They recommended stumps be created in groups, rather than as scattered individuals (Bull 1980, Evans and Conner 1999). Morrison (1978) studied the deterioration of high cut stumps and their use in the Sierra Nevada for 5-6 years post-treatment. All conifer species studied, except incense cedar, were heavily used for foraging. Few nests were excavated in any tree species. Pine stumps deteriorated more rapidly than fir.

***Use of created wildlife trees***

Bull (1980) found that the size of tree, time since death, and broken tops were important for cavity creation. Woodpeckers excavated cavities in 8% of the studied ponderosa pine snags within 8 years: 85% of those trees had broken tops. No cavities were found in lodgepole pines or ponderosa pines less than ~10” dbh. The mean dbh of snags with cavities was 20”, which indicated a preference for large diameter trees. Foraging use of created snags appeared to increase with snag age regardless of creation method. Bull and Partridge (1986) found that created snags were used for foraging within 2-4 years of creation and most had foraging use after 5 years. Hallett et al. (2001) found little foraging use of snags during their first year of creation, but reported a significant increase in foraging use as decay class increased for all methods of snag creation. Brandeis et al. (2002) reported that woodpeckers foraged most actively on Douglas-fir snags in western Oregon 3 years after creation regardless of time after inoculation.

Bull (1980) found 82% of the ponderosa pine snags and 92% of the lodgepole snags within the first year after trees were attacked by bark beetles had foraging activity. Woodpeckers chipped the bark off (scaled) the trunks to obtain bark beetles or larvae. The bark beetle larvae generally remained in the tree 1 year before they developed into adults and moved to a new host tree.

Bull and Partridge (1986) found topped trees were used for foraging the most frequently and trees treated with herbicides were used the least. The majority of dead trees had been attacked by bark beetles. Filip et al. (2004) also found ~ 50% of topped snags being used 7-14 years post-treatment. Their inoculation treatments (rifle, shotgun, no shot) didn’t show a difference in use, indicating it may take several more years before a sufficient decay column to form for wildlife use.

In a study comparing girdling and pheromone-baiting to attract bark beetles in Ponderosa pine, Shea et al. (2002) found that beetle-killed trees provided a more biologically rich snag than girdling, due to the high level of insect activity. They also found higher woodpecker activity (both foraging and cavity creation) in beetle killed trees. Six years following treatment nearly half of beetle-killed trees had cavities, while no girdled trees possessed cavities. In contrast, Brandeis et al. (2002) did not find that treatment method (girdling, herbicide, topping, or inoculation) affected beetle activity, fungal fruiting body presence, or woodpecker activity. With the exception of mid-topped trees (topped midway in the crown), all snags appeared to be suitable for nest cavity excavation. Results from Bull and Partridge (1986) showed the majority of nests were found in saw-topped trees.

Boleyn et al. (2002) reported few nesting or roosting cavities, which he attributed to a lack of decay due to trees only being treated within <10 years. However, nearly half of the created snags monitored (49%) had new foraging excavations from other woodpeckers and other unidentified excavators within 10 years. Chambers and others (1997) also found few excavated cavities in newly created snags, but found significantly more 5 years following treatment. In addition, they detected a positive relationship between the decay class and cavity excavation in snags created by saw-topping.

Doerr (2008) found that base-girdling promoted meaningfully greater cavity use than the more expensive mid-stem girdling method, in part because mid-stem girdling only killed 68% of the trees compared to 90% for the base-girdling treatment.

Cox (2009) found that ten years after girdling <1% of his sample of snags had cavities that would function as nesting habitat, however foraging activity was recorded on 79%.

Wooley (2007) found that by year 5 following treatment, approximately 80% of trees were being used by birds for foraging, regardless of treatment. Although there was a high degree of variation between stands, new foraging continued to increase over time. Blasted trees had a higher rate of foraging use than other trees. No potential nest cavity excavation was observed until year 7 following treatment, regardless of the type of treatment. Blasting and saw-topping treatments incurred the most potential nest cavity use by birds, however trees treated by either girdling or inoculation also had cavities. Potential nest cavities were not observed until year 9 and were observed most frequently in blasted trees. No trees inoculated with fungus were found to have nesting cavities within 9 years. By year 15, 60% of trees created by blasting were used for nest cavities

Bednarz et al. 2004 asked the question: does a tree simply need to die to become a cavity-ridden snag occupied by a succession of birds, mammals, and other forest creatures? One pattern they saw emerging from intensive studies of keystone linkages is that most often only one, or sometimes two, primary excavator species supply the bulk of the cavities that support the entire nest webs in those systems. For example, Martin et al. (2004) documented that the Northern Flicker furnished most cavities used by the variety of secondary cavity nesters in the mixed interior forests of British Columbia. In that system, a distant second in importance was the Pileated Woodpecker, which especially provided cavities for the larger species of the nest web. In the burned ponderosa pine and Douglas-fir forests of Idaho, data collected by Saab et al. (2004) suggested that Hairy Woodpeckers and Northern Flickers engineered most of the cavities that supported the nest web in that system. In natural fire-maintained southern pine ecosystems, Conner et al. (1983) proposed that the Red-cockaded Woodpecker was essentially the exclusive keystone cavity excavator. In the western hemlock - Douglas-fir forests of the Olympic Peninsula, the Hairy Woodpecker has been documented as the principal cavity provider in that system (Huss et al. 2002, Ripper et al. 2005). The idea that community diversity among secondary cavity users is strongly influenced by one or two principal keystone species was a huge conservation finding of the last century.

Lorenz et al. 2015 also highlighted a key factor related to cavity building/nests and snag hardness. They found that interior wood hardness at nests differed from random sites. All six of the cavity excavator species in their study had nests with significantly softer interior wood than random trees. Interior wood hardness was the most influential factor in models of nest site selection at both spatial scales that we examined: in the selection of trees within territories and in the selection of nest locations on trees. Moreover, regardless of hypothesized excavation abilities, all the species in their study appeared constrained by interior wood hardness, and only 4–14% of random sites were actually suitable for nesting. By not accounting for this factor that limits nest building, the amount of suitable habitat might be overestimated. Since the method used to create a dead or dying tree influences decay processes, this is an important factor to keep in mind.

***Does treatment type affect use?***

Schepps et al. (1999) found that external characteristics of snags have been shown to be poorly correlated with internal decay**.**

Wooley et al. (2007) found that by year 5, 80% of trees had died and were being used by birds for foraging, whether they were topped, girdled, or inoculated. Use increased as trees approached 15 years since treatment, then leveled off. Blasted trees had a higher rate of foraging than others. Nest cavities were not observed until year 9, most frequently in blasted trees. No inoculated trees were found to have nesting within 9 years. By year 15, 60% of trees created by blasting were used for potential nest cavities.

Hallet et al. (2001) found that topped snags receive more use by birds than snags created through girdling within 4-7 years since creation. All snags created by topping had indications of use by birds over time.

Brandeis (2002) found that woodpeckers foraged most actively on trees dead for 3 years regardless of how the snag had been created.

Bull (1980) found cavities in ponderosa pine snags within 3-8 years, and 87% of those cavities were in snags with broken tops.

Chambers et al. (1997) found that Douglas-fir created snags (created by chainsaw topping) were used within 5 years of treatment, with greater use by cavity excavators in clearcut and two-story stands vs. patch cuts. Clumped vs. scattered pattern of snags did not seem to influence cavities. The stands were 80-120 years old, 29” dbh snags created on average.

Parks et al. 1999 felt that girdling may not be effective in tree species other than ponderosa pine because other tree species have relatively thin sapwood that, when decayed, is not wide enough to accommodate a cavity nest. Because girdling weakens the bole at the point of girdle, as demonstrated by the fact that most fallen snags of the girdled treatment broke at the girdle in their study, they recommended girdling higher on the bole (>3.5 meters) of ponderosa pine to promote cavities.

An interesting side note: recent research (Pasanen et al. 2018) found that a greater number of sporocarp species were associated with girdled logs compared to the other types of dead wood. The method of felling the trees (uprooting vs. chainsaw-felling) also resulted in diﬀerences in community composition. If decay organism communities are influenced by the mechanism that causes damage or death to a tree, this may be one more reason to vary treatments.

***Created wildlife tree mortality, decay, and longevity***

Long term studies of wildlife tree mortality, decay and longevity are lacking. The longest study follows created wildlife trees 28 years (See Table 1).

Bull and Partridge (1986) first reported that mortality was significantly higher in topped trees than other treatments such as girdling, herbicides, inoculations, and pheromones. In 2002, Brandeis and others reported that mortality of topped trees depended on where in the crown trees were topped (i.e., the amount of crown remaining). The majority of fully topped trees (i.e., no crown remaining) were dead within 3 years, while mid-crown topped trees had not reached 50% mortality by year 4. They also found that all trees girdled (at tree base) and treated with herbicides were dead within 3 years. Inoculations alone have not proven to be successful at causing mortality (Filip and Parks, 2004).

Shea et al. (2002) found that both girdling combined with pheromone baiting were highly effective in killing Ponderosa pine trees. The beetle-killed trees died quicker than girdled trees (3 months and 2 years, respectively) and also deteriorated more rapidly, creating more suitable conditions for cavity excavation earlier. Boleyn and others (2002) reported that the majority of Douglas-fir trees top killed were still in decay class 1 or 2 within 10 years.

Bull and Partridge (1986) concluded fall down rates were highest for herbicide-killed trees, followed by girdled and inoculated trees, while topped trees persisted the longest. Since this study, most published literature on fall down rates has been focused on natural snags, generally following fire. Raphael and Morrison (1987) reported 47% (small diameter class) to 82% (large diameter class) of snags remained standing, and that firs fell at a slower rate than pines on both burned and unburned plots. Similarly, Russell and others (2006) found persistence was greater for Douglas-fir than for Ponderosa pine following wildfire in western Idaho. Snags that were smaller and in less dense stands fell sooner than larger stems in more dense stands. They predicted the half-life was 9-10 years for Ponderosa pine and 15-16 years for Douglas-fir. Simulation analyses performed by Wilhere (2003) indicate that, after ~ 15 years, between 78-93% of snags will persist depending on size of the snag. Bull (1983) found that 14% of ponderosa pines over 20” dbh class had fallen within 8 years, and 70% had fallen in the 10” dbh class.

Edworthy et al. (2012) found that cavities in trees with advanced decay had a relatively short median longevity of 7 years, whereas those in living trees had a median longevity of more than 15 years. Cavity longevity was greater in continuous forest than in aspen grove habitat. Interestingly, cavities formed by weak excavators survived as long as those created by Northern Flickers despite occurring in more decayed tree stems. Thus, weak excavators may be selecting for characteristics that make a tree persistent, such as a broken top.

Weiss et al. 2018 used a large data set of 19,622 snags from permanent plots in second-growth forests of coastal British Columbia to model snag longevity (time from tree mortality to snag fall) for three species: Douglas-fir, western hemlock, and western redcedar. Snag longevity was strongly related to species and snag diameter. The median snag longevity was 16 years for Douglas-fir, 11 years for hemlock and 5 years for redcedar. Western redcedar was predominantly in the subcanopy, and its rapid fall rate was related to the small size of the snags. In addition to diameter, other attributes (height to diameter ratio, height, and live crown ratio before death) contributed significantly to models for one or two of the species. Site level variables did not contribute significantly to any of the models. Snags greater than 20” dbh, especially Douglas-fir snags, have the potential for persistence well beyond 20 years in these second-growth forests, and could be important for wildlife.

Hane et al. 2019 documented the fate of 1197 created snags in 31 harvest units from 1997 to 1999 in the Cascade and Coast Ranges, Oregon. The trees were topped with harvesting equipment in second growth timber (~45 years old) and arranged at three densities and as either single or clumped created snags. Median survival time for Douglas-fir was 21.0 years. For western hemlock, median survival times were 12-13 years. Under a log-logistic model, 5% of Douglas-fir snags are predicted to still be available at rotation age, so 40 snags per hectare (16/acre) would be required at harvest to maintain 2 snags per hectare (0.81/acre) through stand rotation. Snags created from western hemlock could provide an early rotation pulse but are unlikely to last longer than 20 years. Their results suggested that longevity can be increased by maximizing the snag size within the safety constraints of harvesting equipment.

Gainey et al. (2015) found in mixed conifer stands in Arizona that standing rates were positively related to snag diameter, negatively related to snag height, and were lower for snags with intact tops than for broken-topped snags. Standing rates also were positively related to topographic roughness, elevation, tree density, and an index of northness, and negatively related to slope and relative topographic exposure.

***How do wildlife trees created by fire differ from trees damaged/killed by other methods?***

There is limited science to draw from for this question. Table 2 displays a summary of mortality of trees following fire: rarely is there long term data on response by snag-using birds. DecAID Version 3 has a comprehensive literature section that includes science related to this topic.

Raphael (1983) modelled potential response of cavity-nesting birds to the pattern of snag-fall on a burned forest (assuming that no snags are harvested following the burn). The model was run for 45 years, specifying that each pair of primary cavity nesters required at least 48 snags (from Thomas et al. 1979) and that each primary cavity nester (PCN) excavated only 1 cavity per year. He also set the maximum density of secondary cavity nesters (SCN) at 240 pairs per 100 ha (calculated from the upper 95% confidence interval of the mean breeding density of secondary cavity nesters from 63 censuses published in American Birds). Many of the findings were as expected: larger snags fell at a slower rate than smaller ones, and fir snags fell slower than pine. By year 20 nearly all of the pine snags had fallen; by year 25 nearly all the fir snags had fallen. By year 35, no snags were left.

The simulated response of cavity-nesting birds revealed interesting patterns. First, density of PCN did not reach a maximum until year 18. Until then, snags were abundant but bird numbers were limited by the lack of sufficiently decayed snags or by their territoriality. Hairy Woodpeckers are opportunistic species that rapidly invade burned forests and are capable of excavating nests in harder (more recently killed) snags (Raphael and White 1984). Northern Flicker and Lewis's Woodpecker require softer snags for nesting; these species do not reach maximum densities until year 15 and 19, respectively. Other species achieved maximum densities at intermediate years. Beyond 18 years, snags were sufficiently decayed for all species, but snag density had become too low to support maximum densities of PCN. The PCN population crashed as snag numbers were further reduced; none remained by year 30. The populations of secondary cavity nesters lagged behind the PCN for the first 2 years, until the supply of cavities began to build up. Thereafter, SCN numbers rose rapidly due to the accelerating rate of cavity production and the larger inventory of cavities persisting from previous years. Maximum density was reached in year 16, 2 years earlier than achievement of maximum density of PCN. The SCN maximum persisted until year 22. During this period, the model assumed that SCN were limited by territoriality rather than availability of cavities. Beyond year 22, the accelerating rate of snag fall caused the number of cavities to decline to the extent that SCN were again limited by cavity ·availability. It is interesting that the SCN persisted at maximum density for 3-4 years beyond the year when PCN began declining. Apparently, PCN became limited by numbers of suitable snags while SCN were still finding surplus cavities present from previous years.

This model provides an interesting framework for understanding the dynamics of snag habitat following fire. Unfortunately, bird census data did not support the model prediction. Both PCN and SCN declined at nearly the same rate over this 15 year period. Perhaps the model was wrong, or perhaps the small size of the study grid (8.5 ha) exaggerated year-to-year variation, masking subtle differences. Modeled population sizes of PCN and especially SCN are higher than those actually estimated from the censuses. Raphael recommended further monitoring and comparison with other long-term censuses on burned plots to validate model predictions.

Saab et al. (2004) collected extensive data on factors that influence cavity occupancy related to time after fire in western forests. They examined patterns from the temporal perspective and modelled cavity nester use over time, as opposed to using the snapshot approach and diagramming the way cavities pass among species groups (Martin et al. 2004). They explored the influence of several variables potentially affecting post-fire occupancy by cavity-nesting birds, including the length of time since fire, the proximity of unburned forest, and tree characteristics within the burn site (e.g., tree height and diameter). These factors were examined for their effects on both strong cavity excavators (e.g., Hairy Woodpecker) and a weak excavator, Lewis’s Woodpecker. They documented a succession of use by cavity nesters, especially in relation to time since fire. This modeling effort indicated that strong excavators occupied cavities longer in the larger burned area. These patterns suggest that woodpecker populations may depend substantially on forest landscape structure as well as individual tree characteristics, and that these are ephemeral habitats that change rapidly after fire. Importantly, occupancy of cavity excavators declined more rapidly in the smaller, patchier burned area. They hypothesized this was due to colonization by predators from adjacent undisturbed habitat. Their data suggest that periodic stand-replacement fires are needed to provide high-quality habitat on a continuous basis for several important keystone woodpeckers using western conifer forests. What proportion of the landscape should be composed of recently burned areas to sustain viable populations of primary keystone excavators is not known.

Lehmkuhl et al. (2003) sampled occurrence of bird-excavated cavities in snags in a chronosequence of 26 wildfire burns (ages 1-81 years) on the east slope of the Washington Cascade Range. Cavities occurred in 5.5% of the recorded snags; most (69%) were in burns of subalpine fir. Important predictors of cavities in ponderosa pine and Douglas-fir snags included large diameter (>34cm), burn age >20 years, soft-decay condition, broken-top condition, and moderate height (>2m). Cavity-bearing ponderosa pine snags were best characterized as large- diameter (>13” dbh) snags >2 m tall and located in middle-age to older burns (>19 years old). Cavity-bearing Douglas-fir snags were best characterized as large-diameter snags (>13” dbh), or as smaller soft snags.

Parks et al. (1999) found that snags created by both girdling and fire began to fall after 2 years. Seven to nine years after treatment, 53-57% had fallen. Burned trees most often fell as a whole unit, usually breaking off belowground owing to structural failure of buttress roots. They speculated that the intense basal fires caused the buttress roots to burn extensively, thereby making them more susceptible to colonization by decay fungi. The intense heating of the main root structure and subsequent root failure of burned trees may be in part due to the light, volcanic soils common to the project areas. In comparison, girdled snags that fell generally broke at the girdle, leaving the root system intact. Although burned trees fell sooner and had fewer cavities than trees that received other treatments, this may be explained in part by the fact that burned trees had smaller diameters and died up to one year sooner than girdled trees. The burn intensity may have been excessive, leading to the failure of the main root system. A lower intensity burn may provide snags that stand longer.

Dunn and Bailey (2012) looked at snag longevity along a chronosequence of 7 stand replacing fires in eastern Oregon. They found longevity rates varied from 14-46% depending on species. In their 2016 paper that studied wildfires, they found that larger snags were less likely to fall after fire, and higher fire severity increased potential for fall, except for Douglas-fir, which had a higher proportion that fell following low-severity fire.

Chambers and Mast (2005) in N. AZ found 41% of snags created in fires had fallen within 7 years, and the largest diameter snags with broken tops had the greatest chance of having cavities.

Everett (1999) found in E. Washington Cascades that 50% of ponderosa pine, Douglas-fir, lodgepole pine and subalpine fir <9” dbh snags had fallen or broke within 7-12 years after wildfire. Sixty percent of Douglas-fir >16” had fallen by 81 years, and 50% of Engelmann spruce had fallen within 20 years that were >16”.

A study of pines and true firs following fire (Raphael and Morrison, 1987; Morrison and Raphael, 1993) showed rapid decay within the first 5 years (decay class 4 after 10 years), but also indicated that pines decayed more rapidly than firs.

Dunn and Bailey 2016 found that the volume of dead wood as snags peaked at year 6 in both Pacific Silver and western hemlock zone. They also found that smaller snags are more likely to fall than larger snags, and larger snags are more likely to fragment than smaller snags. Brown et al. 2013 saw similar results, but also had data to show an increase in down wood volume representing a range of diameter classes over the first 15 years, suggesting a steady influx of fire-killed wood of various sizes over that time period.

***Do snags created from trees in young stands (e.g., <17” dbh) provide habitat for wildlife?***

Manning and Friesen (2013) specifically looked at this question. In 50 year old thinned Douglas-fir plantations where wildlife trees were created by saw topping and saw topping/ inoculation, they found that within 6 years of snag creation, cavity-nesting birds were foraging on and nesting in mid-sized snags created by saw-topping; inoculation of snags with heart-rot fungi increased the frequency of bark beetle and pouch fungus. Foraging use by birds was greater in snags created by saw topping and inoculated, versus snags created by topping alone; and the usefulness of snags in the 13-17” dbh range for nesting is likely marginal, as demonstrated by the low detection rate of active nests.

Brandeis (2002) studied this size class in thinned units and found woodpeckers foraging actively on trees dead for 3 years, regardless of how the snag had been created. Partially topped trees that were still alive did not show any foraging. They observed only a few partial cavities, all on fully topped trees that were dead four years after treatment.

Bunel et al. (2002) addressed this issue indirectly by stating that smaller snags are used as foraging sites, and foraging sites may be more often limiting than cavity sites. Moreover, through provision of perching, foraging, and hawking sites, snags of all sizes tend to increase richness and abundance of birds other than cavity nesters (Dickson et al.1983, Scott et al. 1977).

Hallet et al. (2001) studied snags created in the 11”dbh range, and found (with the exception of the few Englemann spruce and white pine monitored at decay class 2), some evidence of foraging was observed on all species at all decay classes. Some were used for foraging as early as one year after treatment. The percentage of trees used for foraging increased significantly between decay class 2 and decay class 3 and between decay class 3 and decay class 4. Compared across all species, there were no differences in the frequencies of foraging use between the different methods of snag creation at any stage of decay on these smaller snags.

Snags <19”dbh were found to be infrequently used as nest or roost sites by cavity-using wildlife in western Oregon (Mellen-McLean et al., 2017).

***Does the silvicultural prescription of the stand influence use or longevity of created wildlife trees? ( i.e. clearcut vs thinning vs group selection)***

Manning and Friesen (2013) found weak evidence that use of created snags by cavity-nesting birds was greater in thinned stands compared to unthinned control, however they did not see any difference between thinning intensities, which ranged from light to heavy in Douglas-fir plantations 50 years old.

Huff and Bailey (2009) found 3.5 times greater chance of survival for non-fatally treated wildlife trees under group selection vs. a clearcut. Barry et al. (2017) found higher estimates of bird-formed cavities and more direct observations of nesting and foraging by cavity nesting birds in 2 story and clearcut treatments. They postulated that the open stands with lower live tree densities might provide better habitat for some species. Siebold et al. (2016) found that species richness of proxylic beetles was higher in dead wood in open forest plots compared with closed forest plots.

Hagar et al. (2013) investigated wildlife use of snags 14-18”dbh in commercially thinned Douglas-fir units. Eighty-nine percent of treated trees were dead within 5-6 years (saw-topped). Trees saw-topped and also inoculated had a higher frequency of pouch fungus. Wood boring beetles did not vary with or without inoculation. Trees used for foraging was greater for trees killed by saw topping plus inoculating than for trees saw topped only. Twelve percent of trees had nest cavities within 6 years. Unthinned stands had fewer nest cavities on average than thinned stands. Inoculum and saw-topping of trees saw greater infestations of bark beetles and pouch fungus, as well as higher proportion of use for foraging. Most were in snags that exceeded the average diameter of created snags. Hairy woodpeckers and red breasted sapsucker responded to thinning. Hagar also found that 50% of the trees non-fatally treated were still alive in the heavy thin treatments after 6 years, and postulated that was related to the dynamics of epicormic branching.

Walter and MaGuire (2005) examined cavity-nesting bird use of snags created by topping mature conifers in 3 silvicultural treatments (group-selection cuts, 2-story regeneration harvests, clearcuts with retained trees) and 2 snag arrangements (clustered, scattered) in 30 Douglas-fir stands in the Oregon Coast Range. Eight bird species nested in the created snags. Open-canopy stands (2-story and clearcut treatments) had higher levels of avian nesting, species richness, and species diversity compared to closed-canopy, group-selection stands. They did not find a difference in nesting levels between clustered and scattered snags. In created snags, most active nests were in the top 25% of the bole, cavity entrances typically faced northeast, and the presence of dead branches did not alter use of snags for nesting. Topped conifers that remained alive were rarely used for nesting or foraging. Cavities per created snag averaged 5.1 in treatments >12 years old. Only 1 created snag fell in the decade since topping. Snags created by topping large conifers provided nesting and foraging structures for cavity-nesting birds under a range of silvicultural conditions, and use was influenced more by residual green tree density than snag arrangement. In addition, created snags increased in value for birds through their first decade (88% had cavities).

Their data suggests that silvicultural systems that maintain some cover somewhere at all times (continuous-cover) are effective at sustaining cavity nesters. Secondary cavity nesters were higher in areas experiencing some timber removal than in mature or old growth forests. That increase likely reflects the fact that many secondary nesters forage more effectively in openings. In most instances the abundance of primary cavity nesters was little affected by partial harvesting, and in some instances increased in abundance. That may reflect the fact that several primary excavators also favor small openings and edges (e.g., hairy woodpeckers; northern flicker; three-toed woodpeckers; and downy woodpecker). For three-toed woodpeckers, Klenner and Huggard (1997) noted that preferred nest sites were within 20 meters of an edge.

Barry et al. (2017) looked at created Douglas-fir snags 25-27 years following treatment. The snags averaged 30” dbh. They documented that snags in the group selection treatment experienced less bark loss and had lower evidence of use by cavity-nesting birds (as measured by total cavity cover) relative to snags created with clearcut and two-story harvest treatments.

***Does arrangement of wildlife trees matter? i.e. dispersed versus clumped versus within patches?***

It has been theorized that, similar to harvest treatment, the spatial configuration in which snags are created may also influence bird use. For example, snags created in clusters may provide concentrated foraging opportunities, but territorial activity could exclude other individuals from using those structures (Raphael and White 1984). Therefore, these authors hypothesized that cavity-nesting bird use of snags (i.e., nesting and foraging) in clusters would be lower than on scattered snags because clustered snags may be more easily defended than scattered snags.

Walter and MacGuire (2005) examined cavity-nesting bird use of snags created by topping mature conifers in the Oregon Coast Range. They did not find a difference in nesting levels between clustered and scattered snags. Angers et al. (2012) and Siebold et al. 2016 hypothesized that clustered snags may be more likely to attract beetles or decomposer organisms that accelerate decay and cause sapwood to break down more quickly. An increase in insect density on clustered snags may also attract more foraging birds that drill for prey (Raphael and White, 1984), resulting in accelerated effect on snag decay and bark integrity.

Chambers et al. (1997) found that Douglas-fir snags created by chainsaw topping left in clumped vs. scattered patterns did not seem to influence cavities. The stands were 80-120 years old, with snags an average of 29” dbh.

Kroll et al. (2012a) found that clumping may lead to reduced levels of nesting use. They recommended distributing created snags in both clusters and individually within individual harvest units. Linden et al. (2012) data suggested that the diversity of birds using structure retention in harvest units can be maximized at patches of >10-15 rotation age trees (i.e. species richness estimates increased with tree count). They encouraged grouping green trees around high quality snags and other unique wildlife trees where possible. Edge distance did not significantly affect occupancy probability for any observed species.

Bunnell et al. (2002) found that cavity nesters as a group respond asymptotically to snag density and attain half their maximum density at about 1snag/acre. However, individual species show different responses, and there is no apparent effect of territoriality among smaller species. They found that dispersed retention of trees and snags strongly favored secondary cavity nesters and increased their abundance and richness above that found in mature or old-growth forests. However, abundance of primary nesters was much reduced with dispersed trees. They also felt that large patches appeared to favor primary nesters. Other reasons they felt that retaining trees in patches was favorable included increased improved safety during timber falling, and windthrow is much reduced relative to dispersed retention or large clearcut edges (Coates 1997, Franklin et al. 1997). Operational efficiency can also be gained in patches with a more desirable range of diameter and decay classes that might prove difficult to select among the individual trees of dispersed retention.

Aggregated retention may better emulate natural patterns, and nests of primary excavators often are concentrated in dense patches of snags (Bull 1980, Lundquist and Mariani 1991, Raphael and White 1984). It is unclear whether this implies selection of dense patches for some associated value (i.e. social facilitation) or merely reflects the patchy way trees are killed by insects and disease.

Aggregated retention of wildlife trees has been shown to be effective when larger patches are retained. The utility of small patches appears undocumented, but Gyug and Bennett (1996) studied large seed-tree reserves in large clearcuts 25 to 29 years after harvesting. They found more primary cavity nesters were detected in the patches than in the nearby forest, including pileated and hairy woodpeckers.

Arnette et al. (2010) found that the highest fractions of snags with nest cavities were found in clearcut units with low density and scattered snags, but the mean did not differ among treatments. Treatments included low-high density clumped and scattered. They also did not find a strong relationship between snag density and foraging use.

Hane et al. (2012) tested nest survival of cavity-dependent birds in response to creating snags (using a feller buncher) in clumps of 5–7 snags or dispersed individual snags. The snags were monitored 10 years after creation, and their average dbh was 19”. Three species nested in sufficient numbers for analysis. Chestnut-backed chickadee nest success was highest in the medium density clumped created snag treatment and lowest in the low density clumped treatment. The nest success for house wrens and northern flickers did not vary by experimental treatments. They felt that leaving either clumped snags (5-7/ha) or dispersed created snags (0.5-2.0 snags/ha) would support nest survival rates that are similar to those reported from unmanaged forests for the 3 species they were able to analyze.

Barry et al. (2018) looked at created Douglas-fir snags 25-27 years following treatment. The snags averaged 30” dbh. They did not detect an effect of snag configuration on the proportion of snags used for foraging by cavity-nesting birds.

***What are the benefits of creating a “tree in decline” vs. a dead tree/snag?***

There is limited science to draw on for this question. Live, decadent trees in the forest are likely important in providing long-lasting wood decay habitat and the future provision of snags (Bunnell et al., 2002). Significant survival can be expected when Douglas-fir trees are topped in such a way that a portion of their live crown is retained. However, Walter and Maguire 2005 found that non-fatally topped trees (10-12 years since treatment) were rarely used for nesting or foraging, presumably because of their lack of decay. The candelabra crown structure that was observed 16-18 years after treatment in the Huff and Bailey study (2009) is known to be a classic feature of many old growth forest ecosystems (Franklin et al. 1981), and provide nesting platforms for species like marbled murrelet. Those that remain living may not be useful to snag dependent birds immediately, but they may still provide a valuable habitat for other species.

Edworthy and Martin (2014) found that cavities in living trees significantly increase in volume as they age and likely increase in quality over time, while cavities in dead trees maintain relatively constant dimensions.

***Does landscape composition surrounding harvest units with created wildlife trees influence use?***

There is limited science to draw on for this question. Kroll et al. (2012a) found that more forest species colonized created snags as the amount of forest declined within 1000m of the unit. Early seral species colonized units when there was less forest in the vicinity.

***What do we know about use over time as the re-establishing stand develops?***

Studies documenting use of created snags for more than a decade following creation are lacking. Barry et al. (2018) looked at created Douglas-fir snags in clearcuts 25-27 years following treatment. The snags averaged 30” dbh. Their surveys recorded few observations of birds using created snags as foraging substrates: only 11% of the created snags were used for foraging. Most foraging observations were of chestnut-backed chickadees (41%) or pileated woodpeckers (26%). Eighteen percent of the created snags were used for foraging or nesting. Nesting attempts were documented by only 4 bird species (chestnut-backed chickadee, red-breasted nuthatch, red-breasted sapsucker, and northern flicker) even though there were 12 cavity-nesting species present on the study sites. Nearly all of the nests (94%) belonged to the chestnut-backed chickadee, a weak cavity-excavating species that requires well-decayed wood for creating nest cavities. They concluded that by year 25–27 post-treatment, created Douglas-fir snags provided limited opportunities for nesting and foraging by most cavity-nesting birds. The greatest amount of use occurred 5–15 years post-creation.

This study indicated that even though created snags provided habitat for cavity-nesting birds in the past, they no longer experienced widespread use by the broader cavity-nesting bird community 25–27 years after creation. The authors postulated that changes in vegetation and stand structure contributed to changes in the species composition using snags. A subset of cavity-nesting species that require well-decayed wood for creating nesting cavities, such as the chestnut-backed chickadee or those that forage on insects in especially decayed wood within closed-canopy forests (e.g., pileated woodpecker) were the primary users of this habitat. Most of the secondary cavity-nesting species using snags during historical surveys were open-canopy associates (e.g., violet green swallow, European starling, house wren, western bluebird; Maguire and Chambers 2005, Walter and Maguire 2005). Thus, most of the stands at year 25-27 are now unsuitable for these species because regeneration of planted conifers in 2-story and clearcut stands has resulted in dense cover of tall vegetation surrounding created snags.

***Table 1: Studies that documented condition of created wildlife trees over time.***

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Tree Species** | **Time Since Damage/ treatment** | **Diameter/****height** | **Condition** | **Method**  | **Odds +/- of standing** | **Study** |
| Douglas-firW. Hemlock | 19 yrs19 yrs | 18” mean /19’19” mean /19’ | 40% fallen90% fallen | Fatally topped with feller buncher | Estimated 5% would still be standing at 40 years | Hane et al. 2019 |
| Douglas-fir | 16-18 yrs | 33” avg/55’ | 4% broken96% not broken | Fatally topped |  | Huff and Bailey 2009 |
| Douglas-fir | 16-18 yrs | 33” avg/55’ | 23% still living\*3% broken74% dead\*50% vigorous\* 8% declining | Non-fatally topped | Odds increase in group harvest and w/> DBH | Huff and Bailey 2009 |
| Douglas-fir | 20-100 yrs |  |  | natural | > longevity w/> dbh | Cline and Phillips 1983; Smith and Cluck 2007 |
| Douglas-fir | 25-27 yrs | 30” avg / 50’ tall | 91% standing35% broken8% that had fallen broken at base | Fatally topped w/chainsaw | < bark loss in group harvest and < use | Barry et al. 2017, 2018 |

***Table 1, continued: Studies that documented condition of created wildlife trees over time.***

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Tree Species** | **Time Since Damage/****Treatmnt** | **Diameter/****height** | **Condition** | **Method**  | **Odds +/- of standing** | **Study** |
| Douglas-fir | 6 yrs | 18” | 50% still alive | Non fatally topped |  | Hagar et al. 2013 |
| Douglas-fir | 10 yrs | 12” | 88% dead | Fatally topped |  | Kroll et al. 2012a |
| Douglas-fir | 10 yrs | 14-75” | 67% dead | Fatally topped |  | Bolyn et al. 1999 |
| Douglas-fir | 13 yrs | 16” | 90% dead68% dead | Base GirdledMid-bole girdled \*\*8% girdled at mid bole broke | All live were in decline | Doerr 2008 |
| Douglas-fir | 10 yrs | 15”avg | 80% dead<1% broke/fallen10% alive/ healthy10% alive/declining | Girdled breast ht. Used an ax |  | Cox 2009 |

***Table 1, continued: Studies that documented condition of created wildlife trees over time.***

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Tree Species** | **Time Since Damage/****Treatmnt** | **Diameter/****height** | **Condition** | **Method**  | **Odds +/- of standing** | **Study** |
| Douglas-fir | 15 yrs~9yrs | 15” | 80% dead0% dead | Girdled,Blasted & InoculatedInoculated only |  | Wooley et al. 2007 |
| Douglas-fir | 3 yrs4 yrs | 16” | 100%dead 90% dead30% dead | Girdled breast httopped below crowntopped mid crown | All still standing | Brandeis et al. 2002 |

***Table 1, continued: Studies that documented condition of created wildlife trees over time.***

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Tree Species** | **Time Since Damage/****Treatmnt** | **Diameter/****height** | **Condition** | **Method**  | **Odds +/- of standing** | **Study** |
| Ponderosa Pine and Lodgepole | 8yrs | <10” and>20” | 50% dead PP38% dead LP70% fallen in the <10” dbh class14% fallen in the >20”dbh class | Mt. pine beetle killed natural snags |  | Bull 1980 |
| Douglas-fir, Grand Fir, PP, Larch, WRC | 4-7yrs | 11” | 93% dead99% dead1.5% fallen | Girdled above 1st whorl.Topped.Both trtmts | Reached decay class IV faster.Cavities only in topped trees. | Hallett et al. 2001 |
| Ponderosa Pine | 7-9 yrs | 10-30” | 50% fallen | Girdled/ Girdled by fire | 96% had use20% had cavities | Parks et al. 1999 |
| Douglas-firHemlock W. redcedar | 16 yrs11 yrs5 yrs | 8”8”4” | 28% fallen61% fallen67% fallen | Natural mortality in managed stands  |  | Weiss 2018 |

**Table 2: Summary of literature that documented condition of fire created snags over time.**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Fire Location** | **Duration** | **Fire type** | **Mortality** | **Author** |
| Eastern boreal Quebec | > 10 yrs | Low-mod. severity only common factor influencing snag persistence: severely burned stands less susceptible to falling. Bypasses of snag stage common (when living tree falls directly to forest floor)  | w/in 2 yearscontinued over 10 yrs | Angers et al. 2011 |
|  CA | 5 yrs | Varied. Crown injury significant predictor of mortality | 70-80% mortality within 2 yrs. Stabilized by yr 3 | Hood et al. 2010 |
| N. AZ | 3 yrs7 yrs | Varied. Largest diameter with broken tops most likely to have cavities | Most still standing41% had fallen | Chambers and Mast 2005 |
| E. Slopes Cascades WA |  7-81 yrs chrono-sequence | Wildfire  | 50% fallen PP, DF, LPP, SAF <9”dbh60% fallen DF in 81 year old fire;50% Engleman spruce >16” fallen within 20 yrs | Everett et al. 1999 |

**Table 2, continued: Summary of literature that documented condition of fire created snags over time.**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Fire Location** | **Duration** | **Fire type** | **Mortality** | **Author** |
| E. OR | 8 yrs | Wildfire | LP 30% fallen | Bull 1980 |
| CA | 18-23yrs | Wildfire | LP 62% fallen <16”dbhJeff pine 65% fallen 9-15”dbh | Raphael and Morrison 1987 |
| CO | 10yrs | Prescribed fire | 75% fallen 16” dbh ponderosa pine | Harrington1996 |
| ID | 18-20 yrs30-32 yrs |  Wildfire | Ponderosa pineDouglas fir(Predicted ½ life) | Russel et al. 2006 |
| ORPinus sp., Abies sp., P. menziesii | 14-22 yrs24- 34 yrs34- 46 yrs | unmanaged high severity fire sites<9”9-16”>16 | Lifespan > by size | Dunn and Bailey 2016 |

 **Bibliography**

**Review of created wildlife tree literature**

**Oregon and Washington, USA**

**Underlined articles were used in this review. Additional papers listed may be of interest for a greater understanding of this topic. All papers are available on request from** **cfriesen@fs.fed.us****, and they will be posted online at** <https://ecoshare.info/projects/central-cascade-adaptive-management-partnership/synthesis-papers-tools/> **after April 1, 2019.**

Angers, V.A., Drapeau, P., and V. Bergeron. 2012. Mineralization rates and factors influencing snag decay in four North American boreal tree species. Can. HJ. For. Res 42:157-166.

Angers, V. A., Gauthier, S., Drapeau, P., Jayen, K., and Y. Bergeron. 2011. Tree mortality and snag dynamics in North American boreal tree species after a wildfire: a long-term study. *International Journal of Wildland Fire, 20(*6):751-763.

Arnett, E. B., Kroll, A. J., and S.D. Duke. 2010. Avian foraging and nesting use of created snags in intensively-managed forests of western Oregon, USA. *Forest Ecology and Management* 260, 10:1773-1779.

Baker, F. A., S. E. Daniels, and C.A. Parks. 1996. Inoculating trees with wood decay fungi with rifle and shotgun. *Western Journal of Applied Forestry* 11:13-15.

Bagne, K. E., Purcell, K. L., and J.T. Rotenberry. 2008. Prescribed fire, snag population dynamics, and avian nest site selection. *Forest Ecology and Management*, 255(1):99-105.

Barry, A.M., Hagar, J.C., and J. W. Rivers. 2017. Long-term dynamics and characteristics of snags created for wildlife habitat. *Forest Ecology and Management*, 403, 145-151.

Barry, A.M., Hagar, J.C., and J.W. Rivers. 2018. Use of created snags by cavity-nesting birds across 25 years. Journal of Wildlife Management 10:1-9.

Bednarz, J.C., Ripper D., and P.M. Radley. 2004. Emerging concepts and research directions in the

study of cavity-nesting birds: keystone ecological processes. The Condor 106:1–4.

Bednarz, J.C., Huss, M.J., Benson, T.J., and D.E. Varland. 2013. The efficacy of fungal inoculation of live trees to create wood decay and wildlife-use trees in managed forests of western Washington, USA. Forest Ecology and Management 307:186-195.

Boleyn, P., Wold, E., and K. Byford. 2002. Created snag monitoring on the Willamette National Forest. USDA Forest Service in Harmon, M. Moving Towards a new paradigm for wood management. PSW-GTR-181.

Boleyn, P., Wold, E. Wold, and K. Byford. 1999. Created snag monitoring on the Willamette National Forest. Pages pp. 765-775 in Proceedings of the symposium on the ecology and management of dead wood in western forests. USDA Forest Service, Reno, NV.

Brandeis, T. J., Newton, M., Filip, G.M., and E. C. Cole. 2002. Cavity-nester habitat development in artificially made Douglas-fir snags. *Journal of Wildlife Management*, 66, 625-633.

Brown, M. J., Kertis, J. and M.H. Huff. 2013. Natural tree regeneration and coarse woody debris dynamics after a forest fire in the western Cascade Range. USDA Forest Service Research Paper PNW-RP-592. 50 pp.

Brown, T.K. 2002. Creating and maintaining wildlife, Insect, and fish habitat structures in dead wood. Report PSW-GTR-181.

Bull, E. L. 1980. Specialized habitat requirements of birds: snag management, old growth, and riparian habitat. Pages 74-82 in R. M. DeGraaf, ed. Workshop Proc., Nongame bird habitat management in coniferous forests of the western U.S. U.S. Dep. Agric. For. Serv. Gen. Tech. Rep. PNW-64. 100pp.

Bull, E.L. 1980. Longevity of snags and their use by woodpeckers**. In:** **Davis**, J. W.; Goodwin, G. A.; Ockenfels, R.A., technical coordinators. 1983. Proceedings of the symposium: Snag habitat management. Gen. Tech. Rep. GTR-RM-99. Fort Collins, CO: Rocky Mountain Research Station, Forest Service, U. S. Department of Agriculture; 64- 67.

Bull, E. and L. Partridge. 1986. Methods of killing trees for use by cavity nesters. *Wildlife Society Bulletin* 14, 142-146.

Bull, E.L, Partridge, A.D., and W.G. Williams. 1981. Creating Snags with Explosives. Forest Service, Pacific Northwest Forest and Range Experiment Station. PNW-393.

Bull, E. L., Twombly, A.D.; and T.M. Quigley. 1980. Perpetuating snags in managed mixed forests of the Blue Mountains, Oregon. In: DeGraff, R. M., technical coordinator. Management of western forests and grasslands for nongame birds. Ogden, UT: Intermountain Research Station, Forest Service, U. S. Department of Agriculture; 325- 336.

Bunnell, F.L., Boyland, M., and E. Wind. 2002. How should we spatially distribute dying and dead *wood? USDA Forest Service Gen. Tech. Rep. PSW-GTR-181.*

Bunnell, F.L., Houde, I., and E. Wind. 2002. How dead trees sustain live organisms in western forest.

USDA Forest Service. Report PSW-GTR-181

Bunnell, F.L., Wind, E., Boyland, M., and I. Houde. 1999. Diameters and heights of trees with cavities: Their implications to management. Pages pp. 717-737 *in* Proceedings of the symposium on the ecology and management of dead wood in western forests. USDA Forest Service, Reno, NV

Carey, A.B., and H.R. Sanderson. 1981. Routing to accelerate tree-cavity formation. Wildlife Society Bulletin 9:14-21.

Carlsson, S., Bergman, K.O., Jansson, N., and T.M. Ranius. 2016. Boxing for biodiversity: evaluation of an artificially created decaying wood habitat. Biodiversity and Conservation 25(2):393-405.

Chambers, C.L., and J.N. Mast. 2005. Ponderosa pine snag dynamics and cavity excavation following wildfire in northern Arizona. *Forest Ecology & Management*, 216(1-3)227-240.

Chambers, C.L., T. Carrigan, T. E. Sabin, J. Tappeiner, & W. C. McComb. 1997. Use of artificially created Douglas-fir snags by cavity-nesting birds. *Western Journal of Applied Forestry,* 12, 93-97.

Cline, S. P., and C. A. Phillips. 1983. Coarse woody debris and debris-dependent wildlife in logged and natural riparian zone forests - a western Oregon example. Pages 33-39 ***in* J. W. Davis**, and et al., editors. Snag habitat management: proc. symposium, Flagstaff, 1983. USDA Forest Service, General Technical Report, RM-99

Cline, S. P., A. B. Berg, and H. W. Wight. (1980.) Snag characteristics and dynamics in Douglas-fir forests, western Oregon. *Journal of Wildlife Management*, 44, 4, 773-786.

Coates, K. D. 1997. Windthrow damage 2 years after partial cutting at the Date Creek silvicultural systems study in the interior cedar-hemlock forests of northwestern British Columbia. Canadian Journal of Forest Research 27: 1695-1701.

Cockle, K.L., Martin, K., and G. Robledo. 2012. Linking fungi, trees and hole-using birds in a Neotropical tree-cavity network: pathways of cavity production and implications for conservation. Forest Ecology and Management. 265:210-219.

Connor, R.N., Dickson, J.G. and J.H. Williamson. 1983. Potential Woodpecker Nest Trees through Artificial Inoculation of Heart Rots. **In Davis**, J.W., Goodwin, G.A., and R.A. Ockenfels. 1983. Technical Coordinators. Snag Habitat Management: Proceedings of the Symposium, Northern Arizona University. June 7·9, 1983.

Cox, R. 2009. Evaluation of Cavity Use of Base Girdled Trees in a Second-Growth Stand 10 Years after Treatment. Cottage Grove Ranger District, Umpqua National Forest. Unpublished.

Crooks, J. B., Waldrop, T. A., Van Lear, D. H., & Shelburne, V. B. 1998. Dynamics of coarse woody debris in unmanaged Piedmont forests as affected by site quality. In: Waldrop, T.A. (Ed.), Proceedings, Ninth Biennial Southern Silvicultural Research Conference. USDA For. Serv. Gen. Tech. Rep. SRS-20, pp. 473–477.

Cunningham, J.B., Balda, R.P., and W.S. Gaud. 1980. Selection and use of snags by secondary cavity-nesting birds of the ponderosa pine forest. For. Serv. Res. Pap. RM-222. United States Department of Agriculture, Fort Collins, CO. <https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fsm91_050030.pdf>

Davis, J. W, G. A. Goodwin, and R. A. Ockenfels. 1983. Snag Habitat Management: Proceedings of the Symposium, June 7-9, 1983, Northern Arizona University, Flagstaff. Fort Collins, Colo: Rocky Mountain Forest and Range Experiment Station, Forest Service, U.S. Dept. of Agriculture.

Davis, R., Ackers, S., Andrews, S., Carlson, P., Horn, R., Reid, J., McCafferty, C., Sovern, S., and J. Swingle. 2018. Northern Spotted Owl Nest Tree Summary. Northwest Forest Plan Interagency Regional Monitoring Program.

Degraff, R.M. 1980. Management of Western Forests and Grasslands for Nongame Birds. USDA Forest Service General Technical Report INT-86, September 1980 Symposium.

Dickson, J., Conner, R., & Williamson, J. (1983). Snag Retention Increases Bird Use of a Clear-Cut. *The Journal of Wildlife Management*, 47, 3, 799-804.

Dodds, K. J., Hanavan, R. P., and T. Wansleben. 2016. Enhancing Stand Structure through Snag Creation in Northeastern U.S. Forests: Using Ethanol Injections and Bark Beetle Pheromones to Artificially Stress Red Maple and White Pine. *Forests*, 7, 6, 1-15.

Doerr, J. 20008. Evaluation of Cavity Use of Base and Mid-stem Girdled Trees in a Second-Growth Stand on the Middle Fork Ranger District, Willamette National Forest, Thirteen Years after Treatment. Unpublished.

Dunn, C., and J. D. Bailey. 2016. Tree mortality and structural change following mixed-severity fire in

*Pseudotsuga* forests of Oregon’s western Cascades, USA. Forest Ecology and Management 365: 107–

118.

Dunn, C.J. and J. Bailey. 2012. Temporal dynamics and decay of coarse wood in early seral habitats of dry-mixed conifer forests in Oregon’s Eastern Cascades. [Forest Ecology and Management](https://www.sciencedirect.com/science/journal/03781127).  [276](https://www.sciencedirect.com/science/journal/03781127/276/supp/C):71-81.

Edworthy, A.B. and K. Martin. 2014. Long-term dynamics of the characteristics of tree cavities used for nesting by vertebrates. Forest Ecology and Management 334:122–128

Edworthy, A.B., Wiebe, K.L. and K. Martin. 2012. Survival analysis of a critical resource for cavity-nesting communities: patterns of tree cavity longevity. Ecological Applications, 22(6), 2012, pp. 1733–1742.

Evans, K.E. and R. N. Connor. 1999. Snag Management. In: Specialized Habitat Considerations For

Nongame Birds. GTR NC051q.

Everett, R.,J. Lehmkuhl, R. Schelhaas, P. Ohlson, D. Keenum, H. Riesterer, and D. Spurbeck. 1999. Snag dynamics in a chronosequence of 26 wildfires on the east slope of the Cascade Range in Washington state, USA*. International Journal of Wildland Fire,* 9:223-234.

Farris, Kerry L. and S. Zack. 2005. Woodpecker-snag interactions: an overview of current knowledge in ponderosa pine systems. In Proceedings of the Symposium on Ponderosa Pine: Issues, Trends, and Management USDA Forest Service Gen. Tech. Rep. PSW-GTR-198.

Farris, K.L. Huss, M.J., and S. Zack. 2004. The role of foraging woodpeckers in the decomposition of ponderosa pine snags. The Condor, 106(1):50-59.

Farris, K. L., E. O. Garton, P. J. Heglund, S. Zack, and P. J. Shea. 2002. Woodpecker foraging and the successional decay of ponderosa pine.

Fassnacht, K.S. and T.W. Steele. 2016. Snag dynamics in northern hardwood forests under different management scenarios. *Forest Ecology & Management*, 363, 267–276.

Filip, G., K. Chadwick, P. Zambino, D. Omdal, A. Ramsey-Kroll, C. Schmitt, H. Maffei, A. Saavedra, W. Rall, and C. Parks. 2011. Seven- to 14-year effects of artificially inoculating living conifers to promote stem decay and subsequent wildlife use in Oregon and Washington forests. USDA Forest Service, Forest Health Protection, Pacific Northwest Region, Portland, Oregon. 24 pp.

Filip, G. M., C. G. Parks, F. A. Baker, and S. E. Daniels. 2004. Technical Note 8212. Artificial Inoculation of Decay Fungi into Douglas-Fir with Rifle or Shotgun to Produce Wildlife Trees in Western Oregon. Western Journal of Applied Forestry 19:211-215.

Fischer, W.C. and B. R. McClelland. 1983. A Cavity-Nesting Bird Bibliography Including Related Titles on Forest Snags, Fire, Insects, Disease, and Decay. General Technical Report INT- 140.

Foster, D. R., D. H. Knight, and J. F. Franklin. 1998. Landscape patterns and legacies resulting from large, infrequent forest disturbances. Ecosystems 1:497-510.

Franklin, J.F., Cromack, K., Denison, W., McKee, A., Maser, C., Sedell, J. Swanson, F. and Juday, G. 1981. Ecological characteristics of old-growth Douglas-fir forests. USA FS Gen. Tech. Report. PNW-118.

Franklin, J.F.; D.R. Berg, D.A. Thornburgh, and J.C. Tappeiner. 1997. Alternative silvicultural approaches to timber harvesting: variable retention harvest systems. In: Kohm, K.A.; Franklin, J.F., editors. Creating a forestry for the 21st Century: the science of ecosystem management. Washington, DC: Island Press; 111-139.

Ganey, J., White, G., Jenness, J., & Vojta, S. 2015. Mark–Recapture Estimation of Snag Standing Rates in Northern Arizona Mixed-Conifer and Ponderosa Pine Forests. *The Journal of Wildlife Management*, 79,

Ganey, J.L., and S.C. Vojta. 2004. Characteristics of snags containing excavated cavities in northern Arizona mixed-conifer and ponderosa pine forests. *Forest Ecology & Management*, 199, 323–332.

Garber, S.M., Brown, J.P., Wilson, D.S., Maguire, D.A., and L.S. Heath. 2005. Snag longevity under alternative silvicultural regimes in mixed-species forests of central Maine. *Canadian Journal of Forest Research*, 35, 4, 787–796.

Gustafsson, L., Baker, S.C., Bauhus, J., Beese, W.J. , Brodie, A. , Kouki, J. , Lindenmayer, D.B. , Lõhmus, A., Martínez-Pastur, G. , Messier, C. , Neyland, M. , Palik, B. , Sverdrup-Thygeson, A ., Volney, W.J. A., Wayne, A. and J. F. Franklin. 2012. Retention Forestry to Maintain Multifunctional Forests: A World Perspective. BioScience, 62(7):633-645.

Gustafsson, L., Kouki, J. and A. Sverdrup-Thygeson. 2010. Tree retention as a conservation measure in clear-cut forests of northern Europe: a review of ecological consequences. Scandinavian Journal of Forest Research, 25: 295-308.

Hagar, J., Schreiber, B., Harris, P., and C. Friesen. 2013. Wildlife Use of Created Snags in Young Conifer Stand. Unpublished draft.

Hägglund, R., and J. Hjältén. 2018. Substrate specific restoration promotes saproxylic beetle diversity in boreal forest set-asides. Forest Ecology and Management 425:45-58.

Hallett, J. G., T. Lopez, M. A. O’Connell, and M. A. Borysewicz. (2001). Decay dynamics and avian use of artificially created snags. *Northwest Science,* 75, 378-386.

Hane, M. E., A. J. Kroll, A. Springford, J. Giovanini, M. Rochelle, and E. Arnett. 2019. Survival dynamics of mechanically topped Douglas-fir *(Pseudotsuga menziesii*) and western hemlock (*Tsuga heterophylla*) snags in Douglas-fir plantations, Oregon, USA. Forest Ecology and Management 433: 105-110.

Hane, M. E., A. J. Kroll, J. R. Johnson, M. Rochelle, and E. B. Arnett. 2012. Experimental effects of structural enrichment on avian nest survival. Forest Ecology and Management 282:167-174.

Harmon, M. E. 2002. Moving towards a new paradigm for woody detritus management. USDA Forest Service. Report PSW-GTR-181.

Harmon, M. E., J. F. Franklin, F. J. Swanson, P. Sollins, S. V. Gregory, J. D. Lattin, N. H. Anderson, S. P. Cline, N. G. Aumen, J. R. Sedell, G. W. Lienkaemper, K. Cromack, and K. W. Cummins. 1986. Ecology of coarse woody debris in temperate ecosystems. Advances in Ecological Research 15:133-302

Harrington, M. G. 1996. Fall rates of prescribed fire-killed ponderosa pine. Ogden, UT: Intermountain Research Station, Forest Service, U. S. Department of Agriculture; 7 p.

Hildebrand, D., Middlebrook, D. and D. Guthrie. 2006. 2002 and 2003 Monitoring Report for Trees Inoculated with Stem Decay Fungi in 1997, Siuslaw National Forest, Alsea Ranger District. Unpublished.

Holden, Z. A., Morgan, P., Rollins, M. G., and R.G. Wright. 2006. Ponderosa pine snag densities following multiple fires in the Gila Wilderness, New Mexico. *Forest Ecology & Management*, 221(1):140-146.

Hood, S.M., Smith, S.L., and D.R. Cluck. 2010. Predicting mortality for five California conifers following wildfire. Forest Ecology and Management, 260:750–762.

Hope, S. and W.C. McComb. 1994. Perceptions of Implementing and Monitoring Wildlife Tree Prescriptions on National Forests in Western Washington and Oregon. Wildlife Society Bulletin (1973-2006), Vol. 22, No. 3 (Autumn, 1994), pp. 383-392.

Huff, T.D. and J. Bailey. 2009. Longevity and dynamics of fatally and non-fatally topped trees in the Oregon Coast Range. Canadian Journal of Forestry. 39:2224-2233.

Huggard, D. 1997. Fall-down rates of subalpine fir snags at Sicamous Creek: implications for worker safety and habitat supply. British Columbia Ministry of Forests Research Program. Extension Note No. 16; 6 p.

Hunt, R.S. and D.E. Etheridge. 1995. True heart-rots of the Pacific region. Forest Pest Leaflet 55. Pacific Forestry Centre, Natural Resources Canada, Canadian Forest Service. ISBN 0-662-23897-4.

Huss, M. J., J. C. Bednarz, D. M. Juliano, and D. E. Varland. 2002. The efficacy of inoculating fungi

into conifer trees to promote cavity excavation by woodpeckers in managed forests in Western Washington, p. 777–794. In W. F. Laudenslayer Jr., P. J. Shea, B. E. Valentine, P. C. Weatherspoon, and

T. E. Lisle [TECH. COORDS.], Proceedings of the symposium on the ecology and management of

dead wood in Western forests. USDA Forest Service General Technical Report PSW-GTR-181

Hutto, R.L. 2006. Toward meaningful Snag-Management Guidelines for Postfire Salvage Logging in North American Conifer Forests. Conservation Biology Volume 20, No. 4, 984–993

Jackson, J.A. and B.J.S. Jackson. 2004. Ecological relationships between fungi and woodpecker cavity sites. The Condor 106:1–4.

Jackman, S. M. 1974. Woodpeckers of the Pacific northwest: their characteristics and their role in the forests. M.S. Thesis. Oregon State Univ., Corvallis. 147pp.

Jackson, J.A. and B.J.S. Jackson. 2004. Ecological relationships between fungi and woodpecker cavity sites. The Condor 106:1–4.

Jusino, M.A., Lindner, D.L., Banik, M.T., and J.R. Walters. 2015. Heart rot hotel: fungal communities in red-cockaded woodpecker excavations. Fungal Ecology 1 4:33-43.

Keen, F.P. 1929. How soon do yellow pine snags fall? Journal of Forestry 53: 735-737.

Kilgo, J. C., & Vukovich, M. A. 2014. Can snag creation benefit a primary cavity nester: Response to an experimental pulse in snag abundance. *Biological Conservation*, 17, 121-28.

Klenner, W. and D. J. Huggard. 1997. Three-toed woodpecker nesting and foraging at Sicamous Creek. Pp. 224–233 in C. Hollstedt, and A. Vyse, eds. Sicamous Creek Silvicultural Systems Project: Workshop proc. B.C. Minist. For., Victoria, BC. Work. Pap. 24/1997.

Korol, J.J., Hemstrom, M.A., Hann, W.J., and R.A. Gravenmier. 2002. Snags and Down Wood in the Interior Columbia Basin Ecosystem Management. USDA Forest Service Gen. Tech. Rep. PSW-GTR-181. 2002.

Kroll, A.J., Lacki, M.J., Arnett, E.B. 2012. Research needs to support management and conservation of cavity-dependent bids and bats on forested landscapes in the pacific northwest, USA Western J. Appl. Forestry.

Kroll, A. J., Duke, S. D., Hane, M. E., Johnson, J. R., Rochelle, M., Betts, M. G., & Arnett, E. B. 2012a. Landscape composition influences avian colonization of experimentally created snags. *Biological Conservation*, 152:145-151.

Kueppers, L.M., J. Southon, P. Baer, & J. Harte. 2004. Dead wood biomass and turnover time, measured by radiocarbon, along a subalpine elevation gradient. *Oecologia*, 141, 641-651.

Lambert. R. L.; Lang, G. E.; Reiners, W. A. 1980. Loss of mass and chemical change in decaying boles of a subalpine balsam fir forest. Ecology 61(6): 1460-1473.

Lawler, J.J., and T.C. Edwards Jr. 2002. Landscape patters as habitat predictors: building and testing models for cavity-nesting birds in the Uinta Mountains of Utah, USA/ Landscape Ecology, 17:233-245.

Lehmkuhl, J. F., R. L. Everett, R. Schellhaas, P. Ohlson, D. Keenum, H. Riesterer & D. Spurbeck. 2003. Cavities in snags along a wildfire chronosequence in eastern Washington. *Journal of Wildlife Management,* 67, 219-228.

Lewis, J. C. 1998. Creating snags and wildlife trees in commercial forest landscapes. Western Journal of Applied Forestry 13(3):97-101.

Linden, D.V. 2011. Impacts of structure retention on avian ecology in managed forests of the Pacific Northwest. Dissertation, Michigan State University, East Lansing. MI 124 pp.

Linden, D.V., Roloff G.J., and A.J. Kroll. 2012. Conserving avian richness through structure retention in managed forests of the Pacific Northwest, USA. Forest Ecology and Management 284 (2012) 174–184.

Lõhmus, Asko. 2016. Habitat indicators for cavity-nesters: The polypore *Phellinus pini* in pine forests. Ecological Indicators 66:275–280.

Lõhmus, A. 2011. Silviculture as a disturbance regime: the effects of clear-cutting, planting and thinning on polypore communities in mixed forests. Journal of Forestry Research 16(3):194-202.

Lorenz, T. 2018. Study Plan**:** Tracking the process of wood softening in snags following fire and thinning in dry forests of eastern Washington.

Lorenz, T.J. and M.A. Jusino. 2018. Mechanisms of Wood Decay in PNW Snags. Final Report for Seattle City Light Wildlife Research Program.

Lorenz, T.J. and M.A. Jusino. 2017. Fungal communities in woodpecker cavities at Pringle Falls Experimental Forest: Preliminary results from post-treatment woodpecker surveys and fungal sequencing on Lookout Mountain.

Lorenz, T.J, Vierling, K.T., Johnson, T.R., and P.C. Fischer. 2015. The role of wood hardness in limiting nest site selection in avian cavity excavators. Ecological Applications, 25(4):1016–1033.

Lundquist, R. W. & J. M. Mariani. 1991. Nesting habitat and abundance of snag-dependent birds in the southern Washington Cascade Range. Pages 221-239 in Wildlife and vegetation of unmanaged Douglas-fir forests. U.S. Forest Service General Technical Report PNW-GTR-285.

Lutz. J.A. 2005. The Contribution of Mortality to Early Coniferous Forest Development. MS Thesis. University of Washington.

Lyon. L. J. 1977. Attrition of lodgepole pine snags on the Sleeping Child Burn, Montana. Res. Note INT-RN-219. Forest Service, U.S. Department of Agriculture; 4 p.

Maguire, C.C. and C. L. Chambers (editors). 2005. College of Forestry Integrated Research Project: Ecological and Socioeconomic Responses to Alternative Silvicultural Treatments, Research Contribution 46, Forest Research Laboratory, Oregon State University, Corvallis.

Mannan, R. W., E. C. Meslow, & H. M. Wight. 1980. Use of snags by birds in Douglas-fir forests, western Oregon. *Journal of Wildlife Management*, 44, 787-797.

Manning, T. and C. Friesen. 2013. The Young Stand Thinning & Diversity Study (YSTDS), Establishment Report, Study Plan, and Key Findings. Unpublished.

Martin, K., Aitken, E.H., and K.L. Wiebe. 2004. Nest sites and nest webs for cavity-nesting communities in Interior British Columbia, Canada: Nest characteristics and niche partitioning. The Condor 106:5–19.

Maziarz, M., Broughton, R.K., and T. Wesołowsk. 2017. Microclimate in tree cavities and nest-boxes: Implications for hole-nesting birds. Forest Ecology and Management 389:306–313.

Mazurek, M. J., and W. J. Zielinski. 2004. Individual legacy trees influence vertebrate wildlife diversity in commercial forests. Forest Ecology and Management 193:321-334

McKenny, H.C., Keeton, W.S., Donovan, T.M. 2006. Effects of structural complexity enhancement on eastern red-backed salamander (*plethodon cinereus*) populations in northern hardwoods forests. Forest Ecol. Manage. 230:186-196.

Mellen-McLean, K., Marcot, B.G., Ohmann, J.L., Waddell, K., Willhite, E.A., Acker, S.A., Livingston, S.A., Hostetler, B.B., Webb, B.S. and B.A. Garcia. 2017. DecAID, the decayed wood advisor for managing snags, partially dead trees, and down wood for biodiversity in forests of Washington and Oregon. Version 3.0. USDA Forest Service, Pacific Northwest Region and Pacific Northwest Research Station; USDI Fish and Wildlife Service, Oregon State Office; Portland, Oregon. [https://apps.fs.usda.gov/r6\_DecAID](https://apps.fs.usda.gov/r6_DecAID/)

Mitchell, R. G. and H.K. Preisler. 1998. Fall rate of lodgepole pine killed by the mountain pine beetle in central Oregon. Western Journal of Applied Forestry 13 (1): 23-26. Morrison. M. L.; Raphael, M. G.; 1993. Modeling the dynamics of snags. Ecological Applications 3(2): 322-330.

Morrison, M.L. 1978. The use of high-cut stumps by birds. California Fish and Game (78)2:78-83.

Morrison, M. L. & M. G. Raphael. 1993. Modeling the dynamics of snags. *Ecological Applications*, 3, 322-330.

Morrison, M. L., M. F. Dedon, M. G. Raphael & M. P. Yoder-Williams. 1986. Snag requirements of cavity-nesting birds: are USDA Forest Service guidelines being met? *Western Journal of Applied Forestry*, 1, 38-40.

Morrison, M.L., Raphael, M.G. and R.G. Heald. 1980. The use of high cut stumps by cavity nesting birds. **In: Davis**, J. W.; Goodwin, G. A.; Ockenfels, R. A., technical coordinators. 1983. Proceedings of the symposium: Snag habitat management. Gen. Tech. Rep. GTR-RM-99. Fort Collins, CO: Rocky Mountain Research Station, Forest Service, U. S. Department of Agriculture; 64- 67.

Neitro, W. A., V. W. Binkley, S. P. Cline, R. W. Mannan, B. G. Marcot, D. Taylor, & F. F. Agner. 1985. Snags (wildlife trees). Pages 129-167 in E. R. Brown, editor. Management of wildlife and fish habitats in forests of western Oregon and Washington. Part 1: chapter narratives. Portland, Oregon, U.S. Forest Service Pacific Northwest Region, R6-F&WL 192-1985.

Newton, L. 1994. The role of nest sites in limiting the numbers of hole-nesting birds: a review. Biological Conservation 70:265-276

Parish, R., Antos, J. A., Ott, P.K., and C. Mario Di Lucca. 2010. Snag longevity of Douglas-fir, western hemlock, and western redcedar from permanent sample plots in coastal British Columbia. Forest Ecology and Management 259:633–640.

Parks, C. G., D. A. Conklin, L. Bednar, and H. Maffei. 1999. Woodpecker use and fall rates of snags created by killing ponderosa pine infected with dwarf mistletoe. RP-515. USDA Forest Service. Portland OR. 11 pp.

Parks, C. G.; Shaw, D. C. 1996. Death and decay: a vital part of living canopies. Northwest Science (Special Issue) 70: 46-53.

Parks, C. G., C. M. Raley, K. B. Aubry, and R. L. Gilbertson. 1997. Wood decay associated with pileated woodpecker roosts in western redcedar. Plant Disease 81:551

Parks, C. G., E. L. Bull, G. M. Filip, and R. L. Gilbertson. 1996. Wood-decay fungi associated with woodpecker nest cavities in living western larch. Plant Disease 80:959.

Pasanen, H., K. Junninen, J. Boberg, S. Tatsumi, J. Stenlid, and J. Kouki. 2018. Life after tree death: Does restored dead wood host different fungal communities to natural woody substrates? Forest Ecology and Management 409:863-871.

Perry, R. W., & Thill, R. E. 2013. Comparison of snag densities among regeneration treatments in mixed pine-hardwood forests. *Canadian Journal of Forest Research*, 43(7):619-626.

Rabe, M., Morrell, T., Green, H., DeVos, J., and C. Miller. 1998. Characteristics of Ponderosa Pine Snag Roosts Used by Reproductive Bats in Northern Arizona. *The Journal of Wildlife Management*, 62, 2, 612-621.

Ranius, T., H. Ekvall, M. Jonsson, and G. Bostedt. 2005. Cost-efficiency of measures to increase the amount of coarse woody debris in managed Norway spruce forests. Forest Ecology and Management 206(1-3):119-133.

Raphael, R. G. & M. L. Morrison. 1987. Decay and dynamics of snags in the Sierra Nevada, California. *Forest* *Science*, 33, 774-783.

Raphael, R. G., & M. White. 1984. Use of snags by cavity nesting birds in the Sierra Nevada. *Wildlife Monograph 86*. The Wildlife Society, Bethesda, Maryland, USA.

Raphael, M.G. 1983. Cavity-Nesting Bird Response to Declining Snags on a Burned Forest: A Simulation Model. **In: Davis**, J. W.; Goodwin, G. A.; Ockenfels, R. A., technical coordinators. 1983. Proceedings of the symposium: Snag habitat management. Gen. Tech. Rep. GTR-RM-99. Fort Collins, CO: Rocky Mountain Research Station, Forest Service, U. S. Department of Agriculture; 211-215.

Remm, J., A. Lohmus, and K. Remm. 2006. Tree cavities in riverine forests: what determines their occurrence and use by hole-nesting passerines? Forest Ecology and Management. 221:267-277.

Ripper, D. , J.C. Bednarz, and D.E. Varland. 2005. Landscape Use by Hairy Woodpeckers in Managed Forests of Northwestern Washington. Journal of Wildlife Management, 71(8) : 2612-2623.

Ross, D. W., B. B. Hostetler, and J. Johansen. 2006. Douglas-fir beetle response to artificial creation of down wood in the Oregon Coast range. Western Journal of Applied Forestry 21(3):117-122.

Ross, D. W., and C. G. Niwa. 1997. Using aggregation and antiaggregation pheremones of the Douglas-fir beetle to produce snags for wildlife habitat. Western Journal of Applied Forestry 12:52-54.

Russell, R.E., Saab, V.A., Dudley, J.G. and J.J. Rotella. 2006. Snag longevity in relation to wildfire and postfire salvage logging. *Forest Ecology & Management,* 232:179–187.

Saab, V., R. Brannon, J. Dudley, L. Donohoo, D. VanDerzanden, V. Johnson, and H. Lachowski. 2002. Selection of fire-created snags at two spatial scales by cavity-nesting birds, p. 835-848. In P. J. Shea, W. F. Laudenslayer Jr., B. Valentine, C. P. Watherspoon, and T. E. Lisle [EDS.], Proceedings of the symposium on the ecology and management of dead wood in western forests, November 2-4, 1999, Reno, Nevada. USDA Forest Service General Technical Report PSW-GTR.

Saab, V.A., Dudley, J., and W.L. Thompson. 2004. Factors influencing occupancy of nest cavities in recently burned forests. The Condor, 106(1):20-36.

Schmid, J. M.; Mata, S. A.; McCambridge, W. F. 1985. Natural falling of beetle-killed ponderosa pine. Res. Note RM-RN-454. Fort Collins, CO: Rocky Mountain Research Station, Forest Service, U. S. Department of Agriculture; 3 p.

Schreiber, B. & D. S. DeCalesta. 1992. The relationship between cavity-nesting birds and snags on clearcuts in western Oregon. *Forest Ecology and Management,* 50, 299-316.

Scott, V. E., K. E. Evans, D. R. Patton, and C. P. Stone. 1977. Cavity-nesting birds of North American forests. U.S. For. Serv. Agric. Handb. 511, Washington, D.C. 112pp.

Shea, P. J., W. F. Laudenslayer, Jr., G Ferrell & R. Borys. 2002. Girdled versus bark beetle-created ponderosa pine snags: utilization by cavity dependent species and differences in decay rate and insect diversity. Pages 145-153 in W. F. Laudenslayer, Jr., P. J. Shea, B. E. Valentine, C. P. Weatherspoon, and T. E. Lisle, editors. Proceedings of the symposium on ecology and management of dead wood in western forests. General Technical Report PSW-GTR-181. USDA Forest Service, Albany, California, USA.

Shepps, J. Lohr, S., and T.E. Martin. 1999. Does tree hardness influence nest-tree selection by primary cavity nesters? Auk 166:3 658-665.

Siebold, S., Bassler, C., Brandt, R., Buche, B., Szallies, A. and S. Thorn. 2016. Microclimate and habitat heterogeneity as the major drivers of beetle diversity in dead wood. J. Appl. Ecol. 53:934-943.

Smith, S.L. and D.R. Cluck. 2007. Fall rates of snags: a summary of the literature for California conifer species. USDA FS Res. Paper NE-SPR-07-01.

Spiering, D. J., and R. L. Knight. 2005. Snag density and use by cavity-nesting birds in managed stands of the Black Hills National Forest. *Forest Ecology and Management,* 214, 40-52.

Steeger, C. and C. Hitchcock. 1998. Influence of forest structure and diseases on nest-site selection by red-breasted nuthatches. Journal of Wildlife Management 62(4): 1349-1358.

Stephens, S. L., and J.J. Moghaddas. 2005. Fuel treatment effects on snags and coarse woody debris in a Sierra Nevada mixed conifer forest. *Forest Ecology and Management*, 214, 53-64.

Stevenson, S. K., Jull, M. J., and B.J. Rogers. 2006. Abundance and attributes of wildlife trees and coarse woody debris at three silvicultural systems study areas in the Interior Cedar-Hemlock Zone, British Columbia. *Forest Ecology and Management*, 233, 1, 176-191.

Stribling, H.L., Smith, H.R., and R.H. Yahner. 1990. Bird community response to timber stand improvement and snag retention. Northern Journal of Applied Forestry 7:35-38.

Thomas, J. W., R. G. Anderson, C. Maser, and L. Bull. 1979. Snags. Pages 60-67 in J. W. Thomas, ed. Wildlife habitats in managed for-ests-the Blue Mountains of Oregon and Wash-ington. U.S. Dep. Agric. For. Serv. Agric. Handb. 553. U.S. Gov. Printing Off., Washington,

Vanderwel, M. C., J. R. Malcolm, and S. M. Smith. 2006. An integrated model for snag and downed woody debris decay class transitions. Forest Ecology and Management 234:48-59

Vierling K. and L. Lentile. 2006. Red-Headed Woodpecker Nest-Site Selection and Reproduction in Mixed Ponderosa Pine and Aspen Woodland Following Fire. *The Condor*, 108, 4, 957-962.

Vuidot, A., Paillet, Y., Archaux, F. and G. Cosselin. 2011. Influence of tree characteristics and forest management on tree microhabitats. Biol. Conserv. 144:441-450.

Walter, S., and C. Maguire. 2005. Snags, Cavity-Nesting Birds, and Silvicultural Treatments in Western Oregon. *The Journal of Wildlife Management*, 69, 4, 1578-1591.

Watson, D.M. and D. Shaw. 2018. Veiled Polypore (*Cryptoporus volvatus*) as a Foraging Substrate for the White-Headed Woodpecker (*Picoides albolarvatus*). Northwestern Naturalist, 99(1):58-62.

Welsh, C. J. E., and D. E. Capen. 1992. Availability of nesting sites as a limit to woodpecker populations. Forest ecology and Management 48:31-41.

Weiss, S. A., Corace, R. G., Toman, E. L., Herms, D. A., and P.C. Goebel. 2018. Wildlife implications across snag treatment types in jack pine stands of Upper Michigan. *Forest Ecology and Management*, 409, 407-416.

Wilhere, G. F. 2003. Simulations of snag dynamics in an industrial Douglas-fir forest. Forest Ecology and Management 174:521-539.

Wilk, R.J., Lesmeister, D.B., and E.D. Forsman. 2018. Nest trees of northern spotted owls *(Strix occidentalis caurina*) in Washington and Oregon, USA. PLOS ONE | https://doi.org/10.1371/journal.pone.0197887 May 31, 2018.

Wilson, S. M., and A. B. Carey. 2000. Legacy retention versus thinning: influences on small mammals. Northwest Science 74:131-145.

Witt, C. 2010. Characteristics of aspen infected with heartrot: Implications for cavity-nesting birds. Forest Ecology and Management 260:1010–1016.

Wooley, T.J., Shaw, D.C., and J.C. Hagar. 2007. Created wildlife tree monitoring report: trends and future recommendations. Willamette National Forest, unpublished. Ppt and manuscript.

Zahner, V., Sikora, L., and G. Pasinelli. 2012. Heart rot as a key factor for cavity tree selection in the black woodpecker. Forest Ecology and Management. 271:98–103.

Zarnoch, S. J., Vukovich, M. A., Kilgo, J. C., and J.L. Blake. 2013. Snag characteristics and dynamics following natural and artificially induced mortality in a managed loblolly pine forest. *Canadian Journal Of Forest Research*, 43(9):817-825.

Zarnowitz, J.E., and D.A. Manuwal. 1985. The effects of forest management on cavity-nesting birds in northwestern Washington. J. Wildlife Management. 49:255-263.