12 Dead Wood Management

Dead trees are the losers in density-dependent competition and a product of forest disturbance and disease. Considered by many to be a waste of wood fiber and a fire hazard, dead wood provides habitat for many animal species, nursery sites for germination of plants, and pathways for energy in a cellulose-based environment (Harmon et al. 1986). A large western redcedar may live to be 300 years old, and then may take another 300 years or more to decay (Embry 1963). Throughout its life, and after its death, a tree can play a role in contributing to habitat quality for a succession of organisms (Maser et al. 1979). Consider the pathway of energy following a natural disturbance that creates an early successional forest (Figure 12.1). Photosynthesis leads to allocation of energy to leaves, fruits, tree boles, and roots. In later stages of forest succession, most forest energy is stored in cellulose, and cellulose must be broken down into simpler molecules to allow the stored energy to become available to other organisms. Following an intense disturbance, that cellulose is abundant and can be decomposed to provide energy to other life forms. This process is the primary mechanism allowing energy flow through trophic levels in detrital-based systems. Cellulose is also the primary source of stored carbon in forest systems. Carbon is slowly released as CO_2 during wood decomposition (Harmon et al. 1986). The decaying wood is also associated with nitrogen-fixing bacteria, which may contribute to the soil nitrogen, thereby influencing soil fertility in some forest types (Sollins et al. 1987).

The fungi and invertebrates responsible for decomposing and fragmenting the wood become the basis for energy flow into other organisms. The organisms responsible for decomposition can differ markedly between aquatic and terrestrial systems, often leading to slower rates of decay in submerged wood versus wood exposed to air. Further, dead wood can affect the function of terrestrial and aquatic systems. Dead wood adds complexity to forest floors, increasing ground-surface and below-ground heterogeneity. Trees and snags that fall into streams can have significant impacts on sediment deposition and scouring within the channel, leading to a more complex channel structure than would be present without these logs (Bisson et al. 1987).

When a tree dies it may: (1) remain standing in some cases for decades, (2) be uprooted by wind, or (3) progressively break into pieces from damage or decay (Putz et al. 1983, Tyrrell and Crow 1994) (Figure 12.2). As trees die and decay, the species that can use the tree change as well. Further, changes in the structure of forest through ecological succession influence the function of the dead and dying trees. Many cavity-nesting species rely on dead and dying wood as a source for their nest or roost cavity. In New England forests, 41 species of birds and mammals use standing trees with decay present (DeGraaf and Shigo 1985). Scott et al. (1977) listed 85 species of cavity-nesting birds (CNB) that occur in North American forests. Forest management decisions have become increasingly based on habitat relationships of animals dependent on dead wood in forests around the world. Often these relationships are summarized for large functional groups of species, such as primary and secondary cavity users, and log users.

PRIMARY CAVITY EXCAVATORS

Up to 40% of the bird species in North American forests are cavity nesters (Scott et al. 1977, Evans and Conner 1979). In many forest systems, primary CNB (species such as woodpeckers that excavate their own cavities) play a key role by providing cavities that are used by secondary cavity nesters (species that use cavities excavated by primary cavity nesters or natural cavities created by decay). Much attention has been given to management of primary cavity nesters based on the

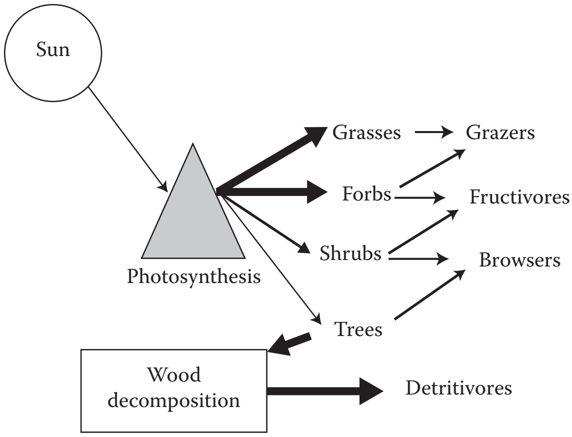

FIGURE 12.1 Early in succession following a natural disturbance, energy is transferred to higher trophic levels through both grazing-based systems and detrital systems due to the high levels of dead wood at this successional stage.

assumption that if they are present and excavating cavities then secondary cavity nesters will have the habitat that they need to survive (Neitro et al. 1985). Although some species of primary cavity nesters can excavate cavities in living wood, most excavate cavities in either dead wood or through live wood into decaying heart wood (Conner et al. 1976). Because most hardwoods and some conifers compartmentalize heart rot (Shigo 1984), excavation through sapwood into softened heartwood may allow organisms to create cavities in tree sections that are only 2–3 times the diameter of a bird's body. However, in many conifers and some hardwoods, decay of sapwood must occur to a sufficient depth toward the heartwood to allow excavation of the sapwood alone (Miller and Miller

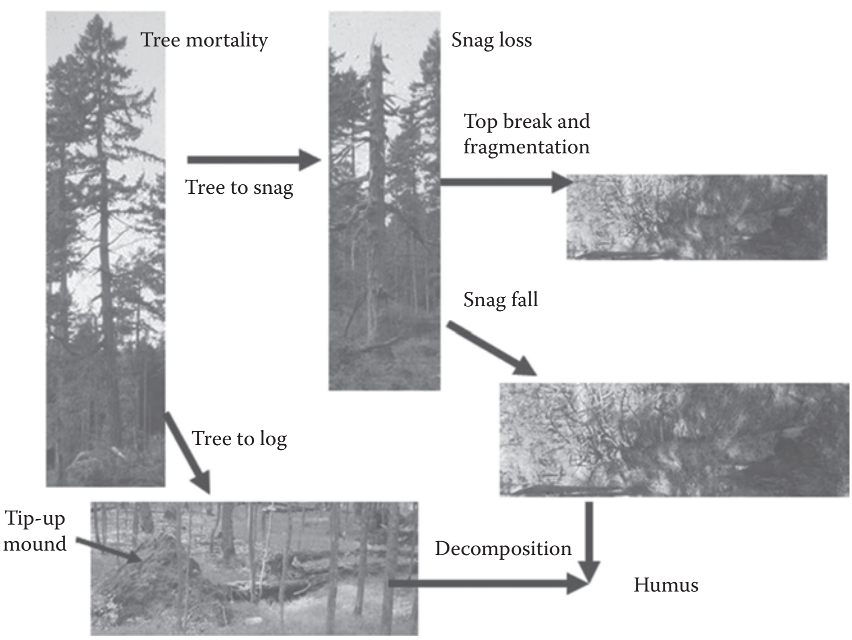

FIGURE 12.2 The fate of trees, snags, and logs in forests. Live trees can die and become snags, fragment and fall and become logs, or fall directly and become logs. Each step in the process provides habitat for a different suite of animals.

1980). For instance, pileated woodpeckers may excavate a cavity in a tree of only 55 cm (22 in.) in diameter in eastern hardwood forests of the United States (Evans and Conner 1979) but often select much larger conifer snags for nesting in the Pacific northwest of the United States (Nelson 1988). Generally, snags or dead limbs <10 cm (4 in.) in diameter are of little or no value as nest sites for primary cavity-nesting vertebrates. Small pieces of dead wood may become important feeding substrates for some species, but foraging probably is more energy efficient on larger stems than on smaller ones, leading to selection of large stems for foraging by most species (Brawn et al. 1982, Weikel and Hayes 1999).

Most species of primary CNB use only one nest cavity per year, although a few species may use different cavities if they raise more than one brood of young in a year (Bent 1939). The excavation of a cavity is a required part of the nesting ritual for most primary cavity-nesting species (Nilsson 1984). Additional cavities often are created and used by CNB as roost and rest sites (Bent 1939). A pair of CNB may use 1–10 or more cavities within a territory for nesting and roosting each year. For instance, species such as acorn woodpeckers and red-cockaded woodpeckers have nesting clans that include helpers to help raise the young (Lennartz and Harlow 1979, Neitro et al. 1985). Roost sites must also be available for the breeding pair as well as the helpers. Consequently, primary cavity excavators create many cavities in a pair's nesting territory over time.

Many species of primary CNB feed on wood-boring insect larvae and so require dead wood as a foraging substrate within a territory (Otvos and Stark 1985). Consequently, there must be a continual replacement of feeding sites as well as nest sites within territories to allow them to remain occupied. Other species, such as common flickers, feed primarily on insects found on the ground or in understory vegetation; dead substrates are not as important as foraging sites for these species (Brawn et al. 1982). In summary, the need for dead trees or limbs as feeding sites varies considerably among different species of primary CNB occupying any given tract of forest.

SECONDARY CAVITY USERS

Secondary cavity nesters can be conveniently placed into one of two groups: (1) obligate cavity users (those species that must have a cavity for nesting or breeding) and (2) opportunistic cavity users (those that use cavities but do not require them). There are many species in the second group ranging from invertebrates to black bears (McComb and Lindenmayer 1999) that opportunistically use dead or dying trees as cover, but we will focus on obligate cavity users.

Secondary cavity nesters can use cavities created by primary cavity nesters or cavities created by wood decay following damage to a tree. Trees that sustain physical damage from wind or fire often become infected with fungal decay (Shigo 1965). The death of branches by self-pruning, incomplete branch shedding, and wound occlusion, or mechanical damage usually provide avenues for decay microbes to enter live trees. Compartmentalization of decay can lead to isolated columns of decay, commonly producing a cavity (Shigo 1984). If the tree remains alive, then compartmentalization of the wound may allow cavity formation, or subsequent healing may preclude development of a cavity (Sedgwick and Knopf 1991). Tree cavities provide a very secure and microclimatically stable den, nest, or roost site (McComb and Noble 1981b).

The number of cavities used by an individual varies widely among species. Some secondary CNB change nest sites between broods presumably to avoid parasite burdens (Mason 1944); some mammals also move among den sites in response to high ectoparasite loads (Muul 1968). For example, house wrens and bluebirds may use 1–3 nest cavities each year and defend each from other species. Cavity-using mammals also tend to use many den sites. In North America, northern flying squirrels use multiple cavities as well as external nests within their home range (Martin 1994). Some species use communal nest and roost sites. Swifts and bats may roost communally, with hundreds of individuals occupying one site.

There are many more species of secondary cavity nesters than of primary cavity nesters, and each species has its own requirements for the type of cavity or roost site used (Balda 1973). Long-legged bats and brown creepers use spaces behind loose bark on snags (Scott et al. 1977, Ormsbee and McComb 1998). Species such as wood ducks have more specific requirements and occupy large cavities usually near water (Lowney and Hill 1989).

Cavities may be particularly important roost sites during the winter for species in temperate climates (Haftorn 1988). Energy savings of cavity-roosting species can be significant where ambient temperatures drop below freezing over long winter nights (Weigl and Osgood 1974).

LOG USERS

Logs are used by many species of vertebrates and invertebrates as cover (e.g., red-backed voles), foraging sites (e.g., shrews and moles), and sites for attracting mates (e.g., ruffed grouse). Logs in streams provide cover for fish and influence the scouring and deposition of sediments in streams thereby increasing stream complexity for many fish species (Bisson et al. 1987). In terrestrial environments, the interior of hollow logs, or the spaces beneath a log, provide a stable and often moist microenvironment that is especially important to the survival of some species of amphibians and reptiles (deMaynadier and Hunter 1995). Other species use the space between the bark and the wood (e.g., scarlet kingsnakes) and some use the interior of well-decayed logs (e.g., clouded salamanders, Stelmock and Harestad 1979).

Log size dictates the area or volume of space available to be occupied (Maser et al. 1979). Logs smaller than 10 cm (4 in.) in diameter are probably of little value to most vertebrates; large logs seem to be used by more species than small ones. Moreover, large logs persist longer than small logs. Decay status also affects log use by organisms. Few species are capable of using undecayed logs (e.g., ruffed grouse, Figure 12.3); most use well-decayed logs (e.g., clouded salamanders and California red-backed voles). Ideally, the habitat requirements of each species must be considered when deciding where logs should be retained and what log characteristics are sufficient to meet their needs. Obviously, with species representing a range of organism sizes from microbes, mites, and tardigrades to salamanders, fishers, and bears, managing the spatial distribution of logs must

FIGURE 12.3 Ruffed grouse use logs in dense patches of forest as drumming sites where males attract females during the spring. Ermine use hollow logs as den sites. (Photos by Michele Woodford. With permission.)

consider a wide range of home range sizes. Realistically, the needs of most species will probably best be met if large logs are retained in clumps of various sizes ranging in numbers that are representative of the range of conditions one might expect following a natural disturbance (Landres et al. 1999).

There are several key attributes of logs that influence their value to vertebrates: piece size and condition (decay stage), biomass or areal cover, and the successional stage in which it occurs. Piece size can be important to vertebrates for a number of reasons. Large-diameter logs provide more cover per piece than small-diameter logs. Western red-backed voles select large logs as cover (Hayes and Cross 1987), and logs provide cover and a source of fungi for food for southern red-backed voles (Buckmaster et al. 1996). A wide variety of other species also reportedly use logs as cover: shrews, weasels, mink, and northern river otters, among many others (Maser et al. 1981). Further, long logs provide more connectivity across the forest floor than short logs. Connectivity throughout a home range theoretically can influence animal fitness because an individual can remain under cover during movements, thereby reducing the risk of predation while also possibly providing microclimatic advantages to the organism.

The distribution of log sizes in a forest generally reflects the site quality for tree growth, stage of stand development, and sources of mortality that in the past have led to tree death. Trees dying from suppression mortality are typically 50% the diameter (but similar in length) of dominant and codominant trees in the stand (McComb and Lindenmayer 1999). Because large-diameter pieces take longer to fully decay than small-diameter pieces, large piece sizes may last longer as functional habitat for more species. The desired size class distribution for the suite of species being managed in a stand or landscape should be determined by the species requiring the largest piece size.

The areal cover or biomass of logs may influence the function of the wood as cover to some mammal and amphibian species (McComb 2003). The physical structure of the log is also important to some species. Maser et al. (1979) described stages of log decay that are similar to that used to describe snag decay stages. Each stage of decomposition can provide different resources to a suite of organisms (Maser and Trappe 1984). Early in the decay process, sloughing bark and infestation by bark beetles, carpenter ants, and termites provide food and cover resources for small mammals, bears, and woodpeckers (Maser and Trappe 1984, Torgersen and Bull 1995). Once the wood has softened and fragmented, vertebrates can begin to excavate the wood to extract insects and/or build nests. Red-backed voles and shrews use very decayed logs as nest sites (Zeiner et al. 1990, Tallmon and Mills 1994) that provide cryptic, dry, and thermally stable environments for their young. Eventually, the structural integrity of the log is so severely compromised by the fungal infection that the log loses value as a potential nest site or feeding site.

Some species such as woodrats, foxes, black bears, skunks, and ermine also use hollow logs as dens (Figure 12.3). Hollow trees form because a column of decay develops following top breakage that extends up and down the bole of the tree from the wound (Shigo 1984). Logs become hollow only after a hollow tree falls to the ground. Recruiting hollow logs into managed stands requires the identification and retention of injured and decaying trees, allowing them to grow to sufficient size or to decay to an acceptable extent, then allowing or promoting their death. Black bears use hollow logs averaging 106 cm (42 in.) in diameter for winter denning in British Columbia (BC) (Davis 1996), so recruitment of potential den sites for bears may take centuries. It is apparent that logs can function as a habitat element for many species in all successional stages of forests in North America.

PATTERNS OF DEAD WOOD FOLLOWING DISTURBANCE

Two processes contribute to dead wood recruitment in a stand over time: (1) the number of trees dying increases rapidly shortly after stand establishment, then declines in a negative exponential manner through the period of "self-thinning" (Oliver and Larson 1996), and (2) the biomass of dead wood increases immediately after an intense disturbance (unless biomass is removed during logging), declines slowly over time, then recovers as large trees die late in stand development (Spies

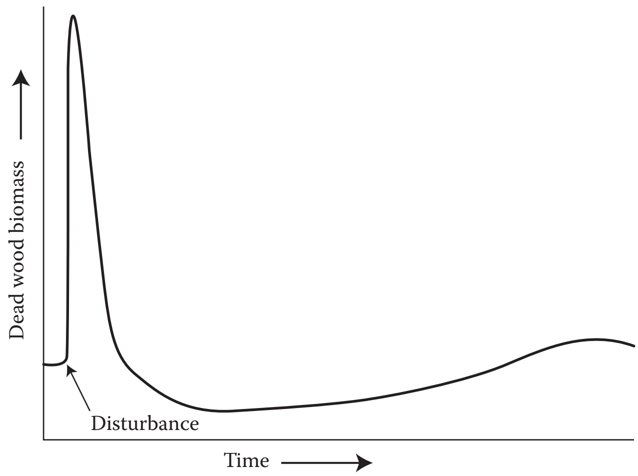

FIGURE 12.4 Generalized pattern of changes in dead wood biomass over time following a natural forest disturbance that creates a pulse of dead wood followed decompositional losses and a slow recovery from tree mortality.

et al. 1988, Figure 12.4). Dead wood biomass accumulates when inputs of dead wood are greater than decomposition losses. Inputs (suppression mortality or exogenous disturbance) and losses (decomposition or fire) interact to produce a “U”-shaped trend in dead wood biomass over time seen in forest types throughout North America (Gore and Patterson 1986, Spies et al. 1988, Van Lear and Waldrop 1994, D’Amato 2007) (Figure 12.4).

Natural old forests contain high volumes of large pieces of dead wood, but not to the level found following intense disturbances such as fires or hurricanes. Infrequent but severe disturbances create pulses of dead wood (Spies et al. 1988). High levels of dead wood produced following a disturbance also may represent a fuel source for subsequent fires in fire-prone systems (Spies et al. 1988). Fear of recurring fire led to salvage logging and snag removal several decades ago in the Pacific Northwest of the United States (McWilliams 1940). Now managers often try to recruit dead wood to stands that were salvaged in past years.

Changes in Dead Wood Over Time

Dead wood changes over time through decomposition (Miller and Miller 1980). When a tree dies, fungal decay usually begins. Fungal decay facilitates wood fragmentation when combined with the activities of invertebrates, such as termites (Atkinson et al. 1992). Tree mortality and wood decomposition rates interact to dictate dead wood biomass on a site. The size and species composition of the live trees influence the potential dead wood production on the site. Hardwood forests generally have less dead wood than conifer forests (Harmon et al. 1986, Harmon and Hua 1991). Eastern hardwood forests may support 11–220 m^3/ha of dead wood (Tyrrell and Crow 1994, D’Amato 2007), but western coniferous forests may have 376–1421 m^3/ha of dead wood (Huff 1984). Variability in the amounts and distribution of both standing and fallen dead wood is considerable (Everett et al. 1999). Indeed, managing dead wood to reflect variability among sites over a landscape may be a more meaningful approach than mandating a minimum retention level in managed stands or trying to manage for individual species (Everett et al. 1999).

The size of the dead wood influences the rate of decomposition and its value to organisms. Large pieces of dead wood provide habitat for a large number of species in various seral stages. These large remnant snags and logs can last for centuries before becoming an unrecognizable part of the forest humus (Tyrrell and Crow 1994). Trees that die and remain standing provide habitat as snags.

TABLE 12.1
Comparison of Decay Constants (*k*) among Tree Species in Various Parts of North America (Listed from Slowest to Fastest Decay Rates)

Taxon	Location	*k* (per Year)[a]	Citation
Douglas-fir	Oregon	0.005–0.10	Harmon and Hua (1991)
Douglas-fir	Oregon	0.0063	Means et al. (1985)
Balsam fir	New Hampshire	0.011	Lambert et al. (1980)
Western hemlock	Oregon	0.012	Grier (1978)
Western hemlock	Oregon	0.016–0.018	Harmon and Hua (1991)
Mixed oaks	Indiana	0.018	MacMillan (1988)
Western hemlock	Oregon	0.021	Graham (1982)
Eastern hemlock	Wisconsin	0.021	Tyrrell and Crow (1994)
Red spruce	New Hampshire	0.033	Foster and Lang (1982)
Jack pine	Minnesota	0.042	Alban and Pastor (1993)
Mixed maples	Indiana	0.045	MacMillan (1988)
Red pine	Minnesota	0.055	Alban and Pastor (1993)
White spruce	Minnesota	0.071	Alban and Pastor (1993)
Trembling aspen	Minnesota	0.080	Alban and Pastor (1993)
Mixed hardwoods	New Hampshire	0.096	Arthur et al. (1993)
Mixed hardwoods	Tennessee	0.110	Onega and Eickmeier (1991)

[a] k = a decay rate constant when calculating decay rates as $D_t = D_0e^{-kt}$ where D = wood density, t = time (years).

Fall rates of live trees and snags vary among tree species (McComb and Lindenmayer 1999). Ten-year fall rates (the proportion of trees expected to fall in a 10-year period) for pine and fir snags in the western United States and many hardwoods in the eastern United States exceed 50% (Morrison and Raphael 1993, Wilson and McComb 2005). Fall rates of large-diameter Douglas-fir snags may be <20% per decade (Cline et al. 1980).

The combination of a tree's size and the variability among species in their resistance to decay leads to considerable variation among trees in rate of decay and fragmentation (Harmon et al. 1986). As fragmentation of the tree bole advances, the diameter and height of snags (or length of logs) decreases (Figure 12.2). Tree species and size also influence other characteristics of dead and dying trees. Decomposition rates are generally described using decay rate constants (Olson 1963):

$D_t = D_0e^{-kt}$ where D = wood density, t = time (years), and k = a decay rate constant. Decay rates vary among species, with conifers generally being more decay resistant than hardwoods (Harmon and Hua 1991, Table 12.1). As decay proceeds within a bole of wood, the bole becomes subject to fragmentation (Harmon et al. 1986, Tyrrell and Crow 1994). Consequently, the dead wood biomass on a site at any one time will be dependent on a number of factors. These include site quality and tree species composition, the disturbance regime for the site, and the climatic factors that influence tree growth and decomposition (Muller and Liu 1991).

Dead Wood during Stand Development

Stand establishment following a disturbance often results in over 1000 tree seedlings per hectare in some western U.S. coniferous stands and over 40,000 seedlings per ha in eastern hardwood stands. In plantations, stand density is controlled. In both cases, as stands develop, inter-tree competition results in mortality among those trees that are intolerant of shade or drought (Oliver and Larson 1996). It is common to see over 90% of the trees in a stand die during the first few decades following natural stand establishment. High-density stands produce many small dead stems early in stand development. Competition mortality commences later in stand development in lower density stands, allowing trees to grow rapidly for many years prior to competition (Figure 8.5A). Thinning that reduces stand density may benefit the production of dead wood of large sizes later in stand development. Manipulating stand density allows the manager to influence the size and numbers of dead trees throughout even-aged stand development, and manipulating stocking rates in uneven-aged stands can produce similar results.

MANAGEMENT OF TREE CAVITIES AND DEAD WOOD

There are two general approaches to dead wood and tree-cavity management, and they represent two complementary philosophies. The first is based on the concept of a historical range of variability (HRV) or the range conditions produced through natural disturbances over an area (Figure 12.5). So a manager might ask, "Do the levels of dead wood biomass, piece size, and condition over large areas fall within the range of conditions to which the species should be adapted, the range that might be represented under natural disturbances (HRV)?" If the answer is "no," then you might question which species (if any) might be at risk based on this departure from the HRV, and if management actions should be taken to address these risks. If impacted species and processes are adequately addressed elsewhere in the landscape, then allowing some stands or landscapes to fall outside the HRV may be an acceptable risk. If, however, the addition of another stand or landscape to areas that already fall outside the HRV means that there is a likelihood of cumulative risks on species or processes over space and time, then the manager may wish to take actions that contribute to goals related to the HRV (Table 12.2, Landres et al. 1999).

Alternatively, the manager can assess functional relationships between animals and dead wood and manage for these conditions as part of a desired future condition (McComb and Lindenmayer 1999, Mellen et al. 2005). These functional relationships are not clear for most species, but they can be hypothesized and tested in an adaptive management approach. Indeed, some habitat relationships models already include estimates of the abundance of dead wood as a component contributing to habitat quality for a species (e.g., Allen 1983). The compilations of these relationships for desired species in future landscapes would dictate the dead wood goals (Mellen et al. 2005) (Figures 12.6 and 12.7).

Regardless of the dead wood management approach chosen, managers should identify high-priority sites for dead wood management. Intensively managed plantations might fall within this group because they have dead wood and tree-cavity levels that often fall outside of the HRV (Butts and McComb 2000). Modest inputs of dead wood to these stands may make a greater impact on

FIGURE 12.5 Expected range of variability of old-growth forests in the Oregon Coast Range over the Oregon Coast Range. As seral stages change in abundance over time, so do patterns of dead wood associated with them. (Wimberly, M.C. et al. Simulating the historical variability in the amount of old forests in the Oregon Coast Range. *Conservation Biology*. 2000. 14:167–180. Copyright Wiley-VCH Verlag GmbH & Co. KGaA. Reproduced with permission.)

TABLE 12.2
Likely Ranges of Dead Wood (CWD) among Variability among Forest Age Classes in the Oregon Coast Range Under the Historical Range of Variability

Age Class (years)	Coast Range (%)	Coast Range (ha × 100,000)	Number of Patches	CWD Range (m^3/ha)
0–30	4–11	0.9–2.5	1–4	376–1421[a]
31–80	6–19	1.4–4.3	1–6	163–305[b]
80–200	15–45	3.4–10.1	2–14	93–165[b]
>200	25–75	5.6–16.9	4–24	219–324[b]

Source: Based on Wimberly et al. 2000. *Conservation Biology* 14:167–180; McComb, W.C. 2003. *Mammal Community Dynamics: Management and Conservation in the Coniferous Forests of Western North America*. Pages 567–586. Cambridge University Press, Cambridge, England.

[a] From Huff (1984).

[b] From Spies and Franklin (1991).

animal habitat and/or ecological processes than a similar treatment in stands that already contain dead wood.

The steps in the management process that I recommend are

1. Inventory dead wood at the desired scale at time 0 (see Harmon and Sexton (1996) and Bull et al. (1990) for inventory techniques). The chosen spatial scale should be biologically meaningful to the species of interest.
2. Compare dead wood levels to the HRV estimates for the region and/or compare estimates to your habitat goals for species. In western U.S. forests, DECAID can provide a useful reference for comparison (Mellen et al. 2005) (Figures 12.6 and 12.7).

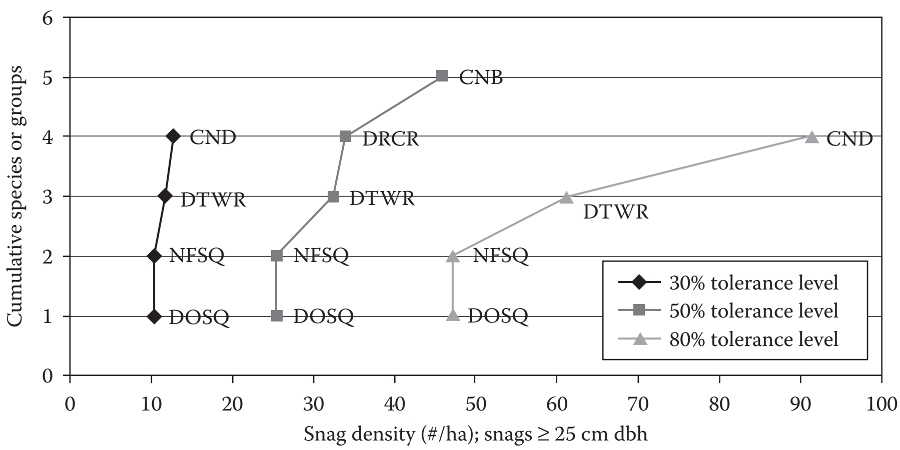

FIGURE 12.6 Cumulative species curves of snags (number per hectare) supporting species use of areas for nesting, roosting, and occurrence for 30%, 50%, and 80% tolerance levels, Westside Lowland Conifer–Hardwood habitat type in the small tree structural class. (From Mellen, K. et al. 2005. *DecAID, the Decayed Wood Advisor for Managing Snags, Partially Dead Trees, and Down Wood for Biodiversity in Forests of Washington and Oregon*. Version 2.0. USDA For. Serv. Pac. Northwest Res. Sta. and USDI Fish and Wildl. Serv., Oregon State Office, Portland, OR.) CNB = cavity-nesting birds.

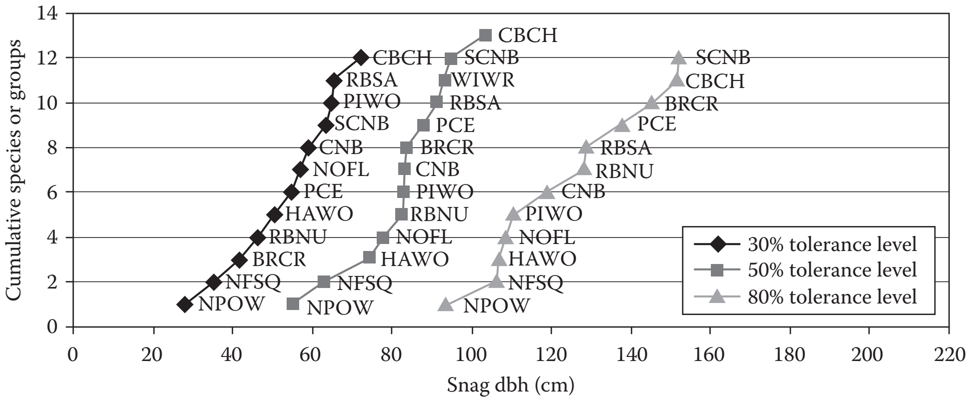

FIGURE 12.7 Cumulative species curves of snag dbh (cm) supporting species use of areas for nesting and denning for 30%, 50%, and 80% tolerance levels, Westside Lowland Conifer–Hardwood habitat type in the small tree structural class. (From Mellen, K. et al. 2005. *DecAID, the Decayed Wood Advisor for Managing Snags, Partially Dead Trees, and Down Wood for Biodiversity in Forests of Washington and Oregon*. Version 2.0. USDA For. Serv. Pac. Northwest Res. Sta. and USDI Fish and Wildl. Serv., Oregon State Office, Portland, OR.) CNB = cavity-nesting birds.

3. Conduct this analysis across your planning area and prioritize stands for dead wood management based on the risk of not meeting future dead wood goals.
4. Beginning with the highest priority stands, determine if there are trees of sufficient size that could be felled or killed now to fulfill the snag or log goals or that could be retained into the future to replace those snags that fall over time.
5. If trees in the current stand are not appropriate for meeting dead wood goals, then silvicultural actions should be considered to achieve goals. Thinning from below to allow dominant and codominant trees to grow more rapidly may be preferable to allowing an overstocked stand to grow slowly and to contribute small amounts of dead wood to the stand.
6. Monitor species of highest concern prior to and following active management and assess population changes. Given the long-term nature of wood decay and the habitat functions that develop throughout decay processes, monitoring may need to occur periodically for decades.
7. Assess monitoring results and decide if changes should be made to the dead wood goals for the area.

Many states and provinces have either regulations, or standards (you shall do them) and guidelines (you should do them) regarding dead wood retention levels. Several factors come into play when regulating dead wood levels in managed stands. First, the minimum level of the range chosen for regulation is usually the level that managers will strive to retain in stands. Providing one dead wood level in all managed stands homogenizes that condition over managed landscapes. Although current dead wood guidelines could be rewritten to ensure that dead wood levels fall *within* the HRV, it is much more difficult to develop regulations that will lead to dead wood levels that *represent* the HRV for the region. Incentives such as dead wood credits provided to landowners by local, state, or federal agencies may allow better representation of the HRV in dead wood conditions across landscapes than mandating it by law (McComb 2003).

Clearly, such management actions will require a commitment of time and money to providing dead wood. Costs can be modest if management is for one or a few species, but much higher if dead wood is managed to represent goals for multiple species or the HRV. Dead wood guidelines should be scale dependent, however. Dead wood biomass among many stands should collectively contribute to landscape goals. Landscapes should also represent variability in dead wood levels, but collectively contribute to regional goals.

A delay in dead wood management in a stand with low levels of dead wood now may result in a gap in dead wood availability in the future. Certainly a few stands with low dead wood levels in an area with otherwise high levels may be relatively unimportant, unless overall dead wood levels decline over time and no action is taken now to ensure that advanced decay class (class 5) logs will occur in the stands 50 years from now.

Live Cavity-Tree Management in Managed Stands

Managing forests to achieve goals for secondary cavity nesters can partially be achieved by managing habitat for primary cavity nesters, but not entirely (Figure 12.8). Clearly, there are some secondary cavity users that are larger in body mass than the largest primary cavity nesters. There are more species of secondary cavity nesters than primary cavity nesters. Based on nest box studies, they can occur at much higher densities than primary cavity nesters. Providing natural cavities can be an important supplement to the cavities created by primary cavity nesters.

Nest boxes are one alternative to providing natural cavities, but nest boxes are expensive to build and maintain and they are likely to last only a fraction of the time that a natural cavity would last in a live tree (McComb and Lindenmayer 1999). Nonetheless, nest box programs have been very successful for some species such as bluebirds and wood ducks. Nest boxes are widely used to increase nesting and roosting site availability for a number of species, and the proportion of nest boxes used by animals can be higher than use of natural cavities for many species (McComb and Noble 1981a). However, maintenance costs for nest boxes are high, microclimates are less stable than natural cavities (McComb and Noble 1981b), and primary cavity nesters rarely use them unless they are filled with a substance that can be excavated. Nest boxes should only be considered a temporary solution to a shortage of nest cavities and one that can only be used in a relatively small area for a small number of species.

Managing natural cavity abundance in forests is a bit more challenging than managing dead wood because they are more difficult to inventory and the rate of gain and loss in a forest is very slow, and somewhat unpredictable. Estimating cavity abundance is difficult. Sampling trees for

FIGURE 12.8 Dead limbs on live hardwoods and cavities in live hardwoods both contribute to cavity resources for secondary cavity nesters. Hence providing some hardwoods in conifer stands can add to snags as a source of cavities for cavity-nesting species. Natural cavities also provide nest sites for species such as barred owls (owlet shown here), which cannot use cavities created by primary cavity nesters.

FIGURE 12.9 Leaving snags and logs must be balanced with worker safety and fuels management in managed stands to meet the needs for species such as woodpeckers (nest cavities on left) and alligator lizards (right).

cavities often is complicated by inadequate access to or visibility of cavities in standing trees. Cavities judged to be suitable from the ground may not be useable by a given species (Healy et al. 1989). Typically, sampling for cavities is conducted during the leafless period in temperate climates if hardwoods are present in the stand. The size and number of plots used to sample for cavities will be largely a function of the density and among-plot variability in cavity density. To adequately predict the prevalence of trees with cavities, a very large number of plots may be required to sample cavity abundance (Healy et al. 1989). DeGraaf and Shigo (1985) provided guidelines for managing natural cavities in eastern U.S. forests.

Predicting cavity availability in a stand from tree size and species information is even more problematic. Cavity occurrence in a tree is a function of tree size and tree age, as well as the often highly stochastic disturbance factors that initiate cavity formation. Nonetheless, it seems that there are relationships that can be developed for some hardwood species in North America (McComb et al. 1986, Allen and Corn 1990). In general, large-diameter trees with some past injury are more cavity-prone than small-diameter trees that lack obvious signs of past injury (Figure 12.9). Assumptions made regarding the processes of cavity formation, such as the continued role of insects and fire, must be monitored carefully throughout prescription development and implementation in order to ensure that cavities will be available over time in a stand.

Dead Wood Retention and Harvest System Considerations

Due to the logistics of harvesting around dead and green trees reserved from harvest, snags and replacement green trees often are left in clumps between cable corridors or between skid trails, and soft snags are left opportunistically between the clumps. But clumping snags can have adverse effects on snag use. Location matters. In clumps, a territorial individual can exclude other individuals of the same species from a clump. If the same number of snags were distributed at a spacing consistent with the territory size of the species being managed, then snag use can be optimized. Where human safety issues occur, then some balance must be achieved between the optimum distribution for animal use of snags and reducing risk to forest workers. In the United States, harvest operations must be coordinated with retention of snags, logs, and cavity trees to avoid interference with harvest systems (e.g., skid trails and cable corridors) and to ensure worker safety during the operations (Hope and McComb 1994) (Figure 12.9). In the United States, the Occupational Health and Safety Administration (OSHA) places restrictions on loggers working around dead or dying trees limiting options when managing dead wood in stands.

Creating Snags and Logs for Wildlife

The goals for dead wood abundance in a stand should be compared with the levels of dead and dying trees predicted to occur in the stand over time. These estimates can be developed using a forest growth model that includes a tree mortality function (e.g., Forest Vegetation Simulator (FVS), Dixon 2003). Once we know how many trees are likely to die each decade and what size they are likely to be, then we can predict additions of dead wood over time. We can also estimate dead wood loss through decomposition (Table 12.1) or snag fall rates. If the predicted recruitment of dead wood does not balance the losses to meet or maintain dead wood goals, then some trees can be killed to meet the goals.

The process for deciding which trees to retain as replacement snags during management activities have largely been driven by tree species, tree size, and costs associated with forgoing timber value (Washington DNR et al. 1992). Generally, large trees with some timber defect have the potential to provide tree cavities and dead and dying wood (Healy et al. 1989). In intensively managed stands, defective or diseased trees may be thinned early in stand development. In these stands, dominant and codominant trees may provide habitat for cavity-using species early in the rotation if some of these large trees are retained and killed (Bull and Partridge 1986) or injected with fungal spores (Parks et al. 1995). Indeed, thinning can accelerate tree diameter growth tremendously in some forest types, providing an opportunity to kill some large trees much sooner than would occur in the absence of management.

There is a range of methods available for killing trees to produce snags or cavity trees for vertebrates (Bull and Partridge 1986). Topping the trees with a chain saw or explosives is effective for both Douglas-fir and ponderosa pine (Bull and Partridge 1986; Chambers et al. 1997, Figure 12.10). Herbicides also have been shown to be an effective method for killing trees that are then used by primary cavity nesters (McComb and Rumsey 1983). Girdling, although potentially effective, may be less cost effective than other techniques simply because trees often break at the point of girdling, creating short snags of limited value to some species (Figure 12.10). Hardwoods have been killed to increase invertebrate food resources for woodpeckers in Europe (Aulen 1991), but live hardwoods may be used by more species for a longer period of time than dead hardwoods. Killing trees as habitat management for selected vertebrates must be done based on needs for primary cavity excavators

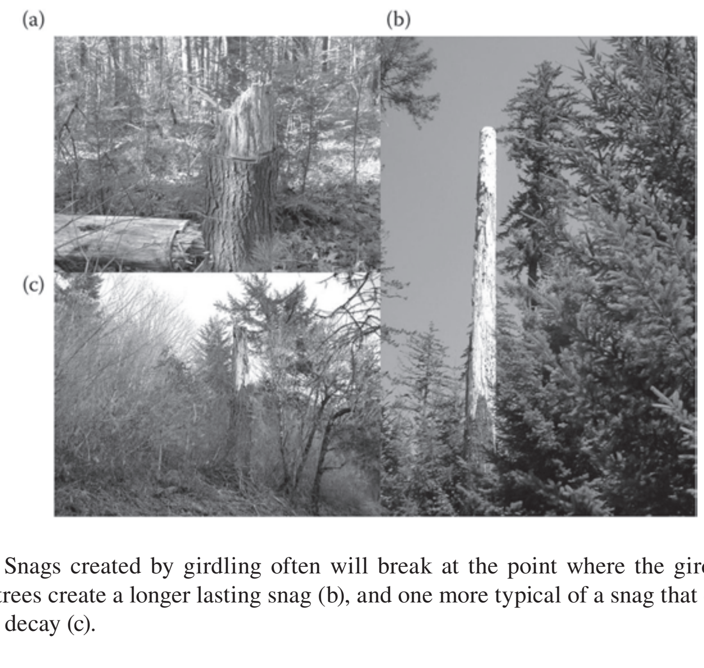

FIGURE 12.10 Snags created by girdling often will break at the point where the girdling occurred (a), whereas topping trees create a longer lasting snag (b), and one more typical of a snag that develops following natural death and decay (c).

and the potential for subsequent use of these cavities by secondary users. Generally, killing trees as a remedial measure is most appropriate in managed conifer forests.

Other techniques are available, but rarely used. Wood-decaying fungi have been experimentally injected into live trees to create a pocket of rot that can be excavated by cavity nesters at some later date (Parks et al. 1995). Artificial cavities also have been created by excavating holes in live trees in eastern hardwood forests (Carey and Sanderson 1981), and cavity inserts have been used to create artificial nest sites for red-cockaded woodpeckers in pine trees without heart rot.

Monitoring Cavity Trees, Snags, and Logs

Most goals for dead wood management in managed forests are based on a number of assumptions. These include, but are not limited to: estimates of the number of snags required by each individual or breeding pair; distribution of trees, snags, and logs within territories; estimates of fall rates and decay rates of snags; and persistence of populations that may become isolated over time. Monitoring of management effectiveness becomes a key part of the management process, especially given the uncertainties associated with requirements for each species, stand projection estimates, and estimates of snag decay and fall rates. Effective management of dead wood habitat will require consideration of not only the primary cavity nesters (Neitro et al. 1985), but also foraging and nesting sites for those secondary cavity nesters that do not use nest sites abandoned by the primary cavity nesters (e.g., bats, wood ducks, and some invertebrates, Figure 12.8). Secondary cavity nesters are generally dependent on the activities of primary cavity nesters and on cavities formed by wood decay processes. Consequently, secondary cavity nesters may be better candidates to monitor the effects of forest management on dead-wood-dependent species.

CASE STUDY: MANAGING DEAD WOOD IN OREGON FORESTS

To illustrate the process of managing dead wood in a managed stand and the effects of biofuels management on dead-wood-dependent species, let us consider a 100-year-old stand in the Oregon Coast Range.

1. *Inventory dead wood at the desired scale now.* The stand is fully stocked at 75 m^2 of basal area per ha (250 ft^2/acre) and is dominated by Douglas-fir with minor components of grand fir, western hemlock, bigleaf maple, and red alder. A stand exam (a systematic or random sample of trees and habitat elements in the stand) revealed an estimate of 10 snags/ha (4 snags/acre) >76 cm dbh (diameter at breast height) (30 in. dbh) and 7/ha (3/acre) are larger than 80 cm dbh (32 in. dbh). The remainder of dead trees in the stand (12/ha; 5/acre) are <5 cm dbh (2 in. dbh). There are 106 trees/ha (43 trees/acre) >76 cm dbh (30 in. dbh).
2. *Compare dead wood levels to your goals.* Using the Dead Wood Adviser (DECAID) developed by Mellen et al. (2005), we chose to manage for snag levels that represent a 50% tolerance level, or a likelihood of providing ecosystem functions intermediate between management providing primarily ecosystem function goals (80% tolerance level) and providing primarily timber production (30% tolerance level). DECAID uses empirical relations from dead wood–species relationships to develop these curves (Figures 12.6 and 12.7). Since we intend to use a clearcut regeneration system with legacy to regenerate the stand yet provide habitat elements, we selected the early successional condition of the Westside Lowland Conifer Hardwood habitat type to best represent the stand that will result from our management (Mellen et al. 2005). Our species goal is to manage to provide snags at a level that will meet the needs for CNB as a group at the 50% tolerance level, or approximately 42 snags/ha >25 cm dbh (17/acre >10 in. dbh) (Figure 12.6). But not all cavity nesters can use such small snags; so we also need to set snag size goals. DECAID indicates that 80-cm dbh snags (32 in. dbh) are needed to meet the size goals (Figure 12.7); so at least some of the

snags in the stand should be greater than this diameter. Hence we want >42 snags/ha that are >25 cm dbh, and as many as possible of these should be >80 cm dbh.

3. *Prioritize stands for dead wood management based on the risk of not meeting future dead wood or species goals.* Since there are only 10 snags/ha (4 snags/acre) in the stand now and we want to have 42 snags/ha (17/acre) following harvest, this stand becomes a high priority stand for increasing dead wood availability.
4. *Determine if there are trees of sufficient size that could be felled or killed now to fulfill the snag or log goals.* Since we have 106 trees/ha >76 cm dbh then there are sufficient live trees that can be killed to provide these snags.
5. If trees in the current stand are not appropriate for meeting dead wood goals, then silvicultural actions should be considered to achieve goals, including retaining trees for future snags, and killing trees to create snags and logs. We know that we will need more than the simply 43 snags/ha (17/acre) goal because some snags will fall during the future development of the stand. But how many more? We may choose to mark and retain 50 trees/ha (20/acre) of which we will kill 32/ha to supplement the 10/ha that are on the site now to meet our goal. The remaining reserved trees (18/ha) are retained as live trees as a future source of dead wood, if needed later in stand development. The stand is then harvested and, after harvest, 32 of the 50 retained trees per ha (13 of the 20 retained trees per acre) are killed by topping the tree (cost = $50/tree, or $1600/ha; $650/acre). The tops will be left on the site to add to the log availability. Because the largest trees in the stand were retained as logs for species requiring dead wood on the forest floor, 108 MBF/ha (44 MBF/acre) were harvested and 141 MBF/ha (57 MBF/acre) were retained and killed. If Douglas-fir sold for $500/MBF, then the gross timber receipts would be $53,340/ha ($22,000/acre); $69,160/ha ($28,000/acre) would have been allocated as timber value forgone to create dead wood.
6. *Monitor species of highest concern prior to and following active management and assess if populations decline.* Following harvest and snag creation, we will monitor snag fall rates and populations of CNB every 5 years until the stand moves into another vegetative structural condition (Mellen et al. 2005). Projections of snag loss using the Snag Recruitment Simulator (SRS, Marcot 1992) suggests that of the 42 snags/ha (17 snags/acre) available immediately after harvest, there would be 37/ha (15/acre) available after 10 years, 35/ha (14/acre) after 20 years, 20/ha (8/acre) after 30 years, 10/ha (4/acre) after 40 years, and 5/ha (2/acre) after 50 years due to snag decomposition, decay, and subsequent fall. Of course these fallen snags add to the log biomass available for other species, but substrates for cavity nesters would decline considerably during the first 50 years of stand development due to snag fall. Monitoring data collected over the 50 years would allow the managers over that time to assess if these projections were correct and if additional trees should be killed.
7. *Assess monitoring results and decide if changes should be made to the dead wood goals for the area.* Recall that we retained 50 trees/ha (20/acre) and only killed 32/ha (13/acre) of them after harvest. So there are still 18 trees/ha (7 trees/acre) carried into the new stand that have grown for 50 years and that could be killed if monitoring indicated that more snags were needed. These retention trees represent the insurance policy for dead wood in the stand so that future goals can be met as the created snags fall over (Figure 12.10).

Approaches such as this that also consider the cavity tree resources and logs on the forest floor can be used to help ensure that the species and ecological processes associated with dead and decaying wood are maintained in stands and across landscapes. But it should be apparent that these activities come at a financial cost, sometimes a significant cost, to a landowner. On public lands, where timber profits are not a goal, such a dead wood recruitment and maintenance strategy is clearly feasible, but on private lands different goals and approaches may be necessary.

SUMMARY

Forest management activities that influence the frequency, severity, and pattern of disturbances in forest systems can have marked effects on the abundance of cavities and dead and dying trees in the system. Dead and dying trees function differently in each stage of forest succession and the trees themselves progress though a succession of decay stages. Decay stages provide opportunities for use by vertebrates, with a different suite of species selecting each decay stage. If forest managers wish to maintain these functions in managed forests, then they must actively manage the dead wood resource.

Live trees with decay are especially important to animals in hardwood forests. Standing and fallen dead trees are particularly important in conifer forests. Integration of management of dead, dying, and decayed trees in forest management will be key in any management prescription designed to balance biodiversity conservation with commodity production. Delay in initiating active management can have long-term implications because of the time needed to both recruit large trees and for the large wood to decay to a stage suitable for certain organisms. There are seven steps to managing habitat for species that depend on cavities, snags, or logs.

1. Inventory dead wood at the desired scale now.
2. Compare dead wood levels to your goals.
3. Prioritize stands for dead wood management based on the risk of not meeting future dead wood or species goals.
4. Determine if there are trees of sufficient size that could be felled or killed now to fulfill the snag or log goals.
5. If trees in the current stand are not appropriate for meeting dead wood goals, then silvicultural actions should be considered to achieve goals, including retaining trees for future snags, and killing trees to create snags and logs.
6. Monitor species of highest concern prior to and following active management and assess if populations decline.
7. Assess monitoring results and decide if changes should be made to the dead wood goals for the area.

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