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CASCADE CENTER FOR ECOSYSTEM MANAGEMENT

RESIDUAL TREES AS BIOLOGICAL LEGACIES

The purpose of this Communique is to share information, to promote understanding of live tree retention, and to facilitate communication between those who are interested in ecosystem management of the forests of western Oregon and Washington. The Communique examines some of the history, current thought, research, and management practices involving retention of live trees during and after timber harvest. Although the Communique focuses on retention of live trees, some of the concepts and questions are applicable to other forms of structural and biological retention.

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INTRODUCTION

The Pacific Northwest has a long history of retaining live trees and other structures during more than a century of logging. Reasons for leaving trees have changed from a lack of marketable value, to ecological objectives embodied in the concept of "biological legacies". Some level of retention is currently mandated by the President's Forest Plan for the "spotted owl forests." Retention of trees is being implemented amid concerns and questions. Economic and operational concerns involve safety of workers, feasibility of logging operations, the threat of windthrow, fire hazards, and reduced growth of regeneration. Ecological concerns stem from current examples of live tree retention where natural snags are often scarce, and remnant green trees are often scattered and other vertical layers are absent. There are also questions about the effects of retention on early seral species, from plants to bugs, birds, and bats. Will the benefits outweigh the costs? Many of these concerns are being addressed by current research listed in this Communique. Others await energetic sponsors and investigators.

AN OVERVIEW OF STRUCTURAL RETENTION IN THE PNW

Logging in the Pacific Northwest began over a century ago. For the most part, technological improvements and changes in forestry practices have been economically motivated. Loggers typically removed higher grade logs, while less valuable material was left. A primary exception was in cases of special silvicultural prescriptions, e.g. seed tree or shelterwood systems. What was taken and what was left was dependent to a high degree upon the current market for wood products, and on logging and transportation costs. For example, land owners that had a pulp and paper outlet often removed more and smaller material, while those mainly feeding the lumber market removed primarily large sound material (Hodgson 1930). Additionally, type of timber available, topography, and individual interests and attitudes of logging companies have always influenced what could or would be removed (Sandstrom, pers. comm.). Geographic and temporal differences in available markets, accessibility, and individual interests have resulted in a diversity of residual material in logged areas of the Pacific Northwest (for example see Bergvall et. al. 1979).

In the past twenty years, a paradox of values has arisen. While the market for wood and other forest products has diversified dramatically, the public has increasingly demanded management of forests for non-extractive amenity values. While the economic feasibility to remove material from the forest is greater than ever before, public and some private land managers are beginning to leave more residual material, including live and dead trees, in harvest units for ecological and social reasons. Objectives include 1) reduce visual impact of timber harvest along scenic travel corridors, 2) maintain live root systems in areas of unstable soils, 3) provide snags and replacement trees for cavity-nesting species, 4) enhance future supply of down woody material, 5) transfer ecosystem structures and processes to regenerating forests, and 6) allow some trees in stands to develop old tree characteristics (e.g. large diameter boles and limbs, thick bark, and some rotted portions of the bole).

The practice of incorporating more structure into managed stands has spread rather rapidly in the last few years. Some who are aware of the shortcomings of "partial cutting" as practiced in the 1930s and 1940s, warn that we are headed that same direction now (Atkinson 1992). Although lessons from the past should be heeded, major changes have been made in land management planning, administration and practices over the past 50 years. "The concept of retaining biological legacies is neither a return to an early period of poor practices nor an abandonment of the important lessons from decades of intensive forestry research" (Swanson and Berg 1991). In today's world, a combination of ecologic, economic, social, and operational factors determine the amount and type of trees left after logging.

Example of recent green tree retention unit. Slim Scout Timber Sale, Blue River Ranger District, Willamette National Forest.

Today, silvicultural aspects are being incorporated into design and study of structural retention. Short-term testing of consequences of retention may be difficult or impossible, particularly since some theoretical benefits are expected to occur several decades, even centuries, after harvest, not just immediately after harvest. However, we can design management and monitoring with the intent to maximize potential for learning (Bormann et al. 1994, Walters and Holling 1990). In the mean time, retrospective studies and simulation models may give insight into consequences of current and experimental forest practices.

(For additional references on history of structural retention, see Brandstrom 1933, DeBell and Curtis 1993, Gould 1965, Isaac 1940, Isaac 1956, Kirkland and Brandstrom 1936, Munger 1950).

WHAT WE THINK WE KNOW

Most application of the concept of biological legacies and most research of biological legacies have been of standing and down trees. Many data have and still are being collected on effects and effectiveness of these legacies. Many questions have yet to be asked, much less studied. This section contains a sample of current knowledge and hypotheses concerning some aspects of retention of trees.

The Next Generation of Trees. The most frequently asked questions regarding retention concern the effects on the composition, growth, and quality of the next generation of trees. While natural stands are dependent upon seed sources, most harvest areas today can be planted manually; therefore, the initial species composition of regenerating stands can be determined at least to some degree by managers on most sites. Initial spatial pattern of regeneration is also manipulated, although some areas with vigorous shrubs may defy management efforts. As seedlings grow, shading and competition from residual trees may become more important in determining which species become established. Acker and others (see Green Tree Retention and Retrospective Study) found reduced growth in regenerating conifers and an increase in proportion of western hemlock under higher densities of residual trees in natural stands in western Oregon Cascades. Simulation of different levels of overstory retention in the Augusta Creek Project (see Other Current Studies) showed similar tendencies, but stocking control in the regeneration layer allowed some manipulation of species composition (Garman pers. comm.)(see Other Current Studies). Many additional questions involve the many kinds of plants and animals that spend some or all of their life cycle in forest ecosystems.

The concept of biological legacies in ecosystem management proposes that what is left is as or more important than what is removed.

-Jerry Franklin

Structures as Biological Refugia. Franklin and Halpern (1989) described biological legacies as living trees and other organisms and chemical and physical structures retained beyond disturbance events. These structures are thought to act as refugia allowing some organisms to survive disturbances and subsequently recolonize post-disturbance sites, as well as to attract immigrating organisms (Franklin 1992).

The size, species, condition, and distribution of trees left may influence what species survive in sites and which immigrate after disturbance. For example, large old trees may act as a refuge through disturbance for unique communities of epiphytes, arthropods and vertebrates, enabling these species to persist in the regenerating forest. If residual trees are young, they may not have old-forest arthropods (Schowalter pers. comm.) and lichens (Neitlich pers. comm.) present in the canopies. However, trees develop the characteristics of old trees over time, and may be colonized by species that are able to dispurse to them. Similarly, vertebrates that require dead or defective parts of trees in their life history may not find adequate habitat in sound live trees, even if the trees are rather large. Damage or stress are necessary to bring about characteristics of trees utilized by these species. Time usually ensures formation of these attributes as the cumulative probability of disturbance and stress increases.

Live green trees remaining after harvest provide below-ground live roots which influence spatial patterns of soil invertebrates and physical characteristics of soils (Torgerson et al. 1995). Mycorrhizal fungi form an often mutually beneficial connection with roots of plants (Ingham and Molina 1991). It has been hypothesized that retention of live green trees in harvest units might help maintain presence and diversity of mycorrhizal fungi in harvest units (see Green Tree Retention and Retrospective Studies). On the other hand, live and dead trees have long been known to pass on several forms of root rot, such as *Armillaria sp.*

and *Phellinus sp.*, and lower bole rot such as *Polyporus schweinitzii* (Bega 1978).

In a study of canopy arthropods in four stand types in the west-central Cascades of Oregon (see Other Current Studies), Schowalter and Zhang found that old-growth forests sampled contained all canopy arthropod species found in the four other stand types studied, and so were considered "source" habitats for canopy arthropods. In their study, large residual green trees in 3 to 20 year old shelterwoods contained 80% of those species found in old-growth forests. It is unknown how long arthropods associated with old forest might persist on remnant trees, or how viable their populations might be. Schowalter (pers. comm.) suggests that small patches of old forest may retain more species and more stable populations through time than scattered individual trees.

No studies have yet been done to determine how long epiphytes persist on post-disturbance residual trees in harvest units or natural stands. However, field observations and related studies seem to give some insight. Sillett (1995) found little difference between epiphyte assemblages on old-growth Douglas-fir crowns in the interior and on the edge of a 20-year old clearcut. One species, *Pseudocyphellaria rainierensis*, appeared to have acclimated to exposure at the clearcut edge (Sillett 1994). There did appear to be some expansion of the upper-canopy lichen species to lower canopy levels in the edge-exposed trees, indicating a change in microclimate in the tree canopy. McCune (pers. comm.) hypothesizes that lichens more negatively affected by microclimatic changes may survive in more central and protected locations within the canopies of remnant trees in harvest units. Sillett (pers. comm.) has climbed four 500-700 year old trees growing in a stand that burned about 100 years ago. Most of the old forest lichen species were present in these remnant trees. Whether these lichens persisted or re-invaded is unknown; however, since some of these have poor dispersal capabilities, it is likely they persisted on the residual trees.

Steller's Jay

Vertebrates associated with mid- and late-successional forests, such as spotted owls and brown creepers, have not been found to breed in recent harvest units containing low densities of remnant trees. Low densities of remnant trees, however, have been associated with increases in densities of other species such as western tanagers, purple finches, and Steller's jays (Hansen et al. in press, McComb and Hunter unpubl., Chambers unpubl.). Snags left in harvest units allow nesting by species such as the hairy woodpecker, northern flicker, western bluebird, house wren, and tree and violet-green swallows (Schreiber 1987, McComb and Hunter unpubl., many others). In harvest units with little other vegetation structure, low densities of remnant trees do not provide enough canopy for forest-dwelling cavity-nesters, such as the red-breasted nuthatch and chestnut-backed chickadee. Townsend's chipmunks can be found in harvest units with few or no trees, while the Douglas squirrel (a tree-dwelling squirrel) is rarely found in these units (pers. obs.).

Hansen et al (in press) and Vega (1993) indicated that in the west-central Cascades some open-area bird species, such as white-crowned sparrow and lazuli bunting are inhibited even by low densities of remnant overstory trees such as those found in shelterwoods. Vega (1993) in the Cascades and McComb et. al. (1994) in the east Coast Range found higher rates of predation of artificially placed nests in green tree retention stands than in either clearcut or forest. Nichols and Wood (1993) found similar results with natural nests of neotropical migrants on the Monongahela NF in West Virginia. Researchers from all three studies have hypothesized that remnant trees provide perches and "lookouts" for jays, ravens, and crows, which are known predators of bird nests.

A portion of residual trees are blown down by wind, contributing to down wood. Down wood influences ground-level and soil organisms and physical soil characteristics (Harmon et al. 1993). While fine litter, such as leaves, twigs, and epiphytes contribute nutrients to soil at higher rates than logs, logs contribute nutrients over a longer period of time (Harmon and Chen 1991). Down wood also serves as habitat and probably refugia through disturbance for some fungi (Maser et al. 1988). Many small mammals and amphibians are associated with down wood (Brown 1985). Hayes and Cross (1987) captured more red-backed voles near large logs than smaller logs. Several terrestrial salamanders, such as ensatina, and clouded salamanders seem to depend more on down wood material for cover than tree canopy (Aubry et al. 1988, Bury and Corn 1988). No studies thus far have investigated relationships between density or biomass of logs and densities of vertebrates in harvest units.

Recolonization of Sites with Remnant Structure. Another function provided by retained structures is the potential for immigration and colonization by plants and animals from nearby populations. Therefore, even if some organisms associated with remnant structures are lost through disturbance, immigrants from nearby populations may be able to colonize existing structures. Key questions associated with this broader hypothesis are: At what rates do species disperse and recolonize areas? When in the successional process are suitable habitats recreated?


Lobaria oregana

Some arthropods and lichens associated with old trees may not colonize regenerating young conifers, even if a source population is present (Schowalter per. comm., McCune pers. comm., Neitlich 1993, Sillett pers. comm.). Just as the spotted owl requires specific structures found in older trees for nesting, some arthropods and lichens require structures and microclimates most often found in canopies of large old trees. Even if old-forest lichens do survive in protected microsites on remnant trees, colonization of the surrounding regenerating forest may not occur until microsites and substrates are favorable within the regenerating forest. Some species appear to prefer large horizontal limbs covered with moss

(Sillett 1995) which usually are not present in coniferous stands until 200+ or even 400+ years of age. Even if thalli from these species did lodge and begin to grow on limbs of younger trees, the canopy will move up, shading and killing lower limbs over the next few decades. It is unknown when regenerating forests are capable of supporting epiphytes associated with large old trees. It is also unknown how some of these epiphytes disperse to and colonize forests once they are suitable.

Some cyanolichens (nitrogen-fixing, leaf-like lichens) appear to colonize quicker on hardwoods and shrubs (such as vine maple, ocean spray, and dogwood) than on young conifers (Neitlich and McCune 1995). Some mature stands have been observed to have cyanolichens common in understory shrubs, but virtually nonexistent in the conifer overstory. These shrubs and hardwoods may be important in maintaining lichen diversity throughout a landscape.

It is unknown how soon large standing and down trees might act as nesting or denning habitat in regenerating stands for vertebrates such as the American marten, spotted owl, and pileated woodpecker. Neither is it known how productive these species might be in younger forests. Spotted owls found in younger stands are typically located in areas with some type of remnant structure (Forsman 1988, Irwin 1991). However, reproductive rates appear to be very low in these sites. In a study on Vancouver Island, relatively high densities of American marten were observed in young (10-40 year old) stands containing high amounts of large down wood, remnant from the previous stand (Baker 1992, in Ruggiero et al. 1994). These results are unprecedented, and examinations should be made in similar habitat elsewhere. **Figure 1** illustrates hypothesized relative timing of return of species associated with old forest structures depending on type of retention. There may, however, be some trade-off between amount of structure left, and rate of growth of the next generation of conifers. For example, Hansen et al. (in press) simulated bird response to various levels of retention (see Other Current Studies). Their simulation showed brown creeper being more abundant in the long term in the scenario with zero retention. The reason was that in the absence of shading by residual trees, regeneration trees were simulated to attain large sizes more quickly. Whether such a scenario would actually produce suitable habitat for the brown creeper is unknown.

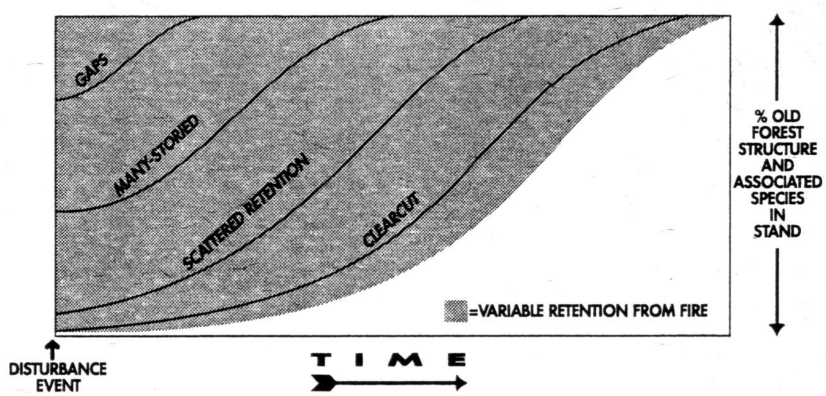

Figure 1. Hypothesized relative timing of return of species associated with old forest structures depending on four harvest regimes and fire disturbance.

Similarities With "Natural" Disturbances. One theme of ecosystem management is to manage within the range of "natural" or historic variability (Swanson et. al. 1993). This approach is based on the hypothesis that existing species and associated processes have adapted to the natural disturbance regimes (a difficult hypothesis to test). A corollary is that natural, historical patterns and processes can be used as a general guide for managing future disturbance resulting from timber harvest. Managers have some flexibility in choosing condition, density, and distribution of live trees retained in cutting units. Trees can be chosen specifically for retention in different locations within landscapes and within stands, at high or low densities, in a dispersed, clumped, or mosaic pattern. Therefore, managers can leave live trees in a variety of naturally-occuring patterns and densities. Initial similarities in overstory between natural disturbances and timber harvest are limited primarily to characteristics of the live component left. Natural disturbances and timber harvest are fundamentally different in many ways, the most obvious of which being the fate of the "mortality." Timing, intensity and frequency of fire are also different. Stands simulated to regenerate under remnant green trees and snags appear to share some vegetative and structural similarities with "old-growth" stands at about 100 years (McComb et. al. 1993, Garman pers. comm.). It would be difficult to determine how ecosystem processes were functioning in these simulated 100-year old stands.

Unharvested stand regenerating after wild fire under light canopy of live trees and snags.

Windthrow. Windthrow is an endemic phenomenon in forests of western Oregon and Washington. It is well-known that trees exposed by timber harvest have increased likelihood of being blown down. Previous studies indicate that exposed trees which remain standing experience rapid physiological adaptations including thickening of trunks and increased root growth (see review in Adler 1994). Therefore, wind conditions within the first year or two of exposure, while adaptations are occurring, may be the most critical in determining long-term densities of windfirm trees. While it is difficult to accurately predict levels of windthrow, several factors have been found important to consider in estimating potential of windthrow: tree height/diameter ratio, crown size and shape, rooting depth and strength, lower bole strength, soil characteristics, and exposure due to spatial arrangement of trees and topographic location.

The environment in which trees develop, influences their structural characteristics and thus their ability to withstand the forces of wind (Tappeiner, pers. comm.). Trees grown in tight, well-stocked stands grow tall and slender, with relatively weak root systems. When exposed by removal of surrounding trees, these trees are very susceptible to windthrow. In contrast, most old-growth trees, some of which have had surrounding trees removed by fire more than once, are relatively stable compared to these young trees. It may be possible in actively managed forest stands to use thinning to increase wind-firmness of trees (Emmingham, pers. comm.).

Stathers et. al. (1994) give excellent explanations and illustrations of the mechanics of windthrow and windthrow risks. Adler (1994) and Isaac (1940) report results of windthrow studies from their work in the Cascades. Schreiber (1991, 1994) and Ruth and Yoder (1953) report results of windthrow studies from work in the Coast Range.

Genetic Composition of Trees. Some have expressed concern that wood production and quality may decline over time if only "defective" and "less-desirable" trees are left to reproduce on site. The fear is that regeneration from seeds of these trees could pass those qualities to future generations. However, it is difficult to determine whether tree attributes at old ages are consequences of genetic traits, environmental conditions, or both. In either case, Douglas-fir pollen travels long distances, allowing quite a bit of genetic mixing and high variability in Douglas-fir (Tom Adams, pers. comm.). Also, in this era of forestry we are still planting most harvest units, rather than waiting on natural regeneration (see also Other Current Studies by Shimizu & Adams).

The environment in which trees develop, influences their structural characteristics and thus their ability to withstand the forces of wind.

-John Tappeiner

Wood Quality. Definitions of wood quality continue to change as societal values and technology change (Jamie Barbour, pers. comm.). Popular styles and looks of wood continually change. Some of the reasons and methods used to harvest timber may become important in future markets (see section on aesthetics). Therefore, it is nearly impossible to predict what types of wood and wood products will be valuable to society in 40, 60, or 200 years. For structural uses of wood, high quality is currently associated with uniformity within the bole, e.g. few changes from pith to bark or root to crown, and small knots. For paper, cell dimension and chemical composition are important. For other applications, decay resistance or aesthetic characteristics are important. However, developing technology may change what characteristics are valuable in the future. Advances in technology have already allowed removal of defects (e.g. cutting out knots), and using composites to manufacture wood with uniform qualities (e.g. laminating many layers to average out individual variations) (David Baker, Barb Gartner, pers. comm.). Nonetheless, solid wood will probably remain important for many uses.

Regardless of market and technological uncertainties, it will be important to consider how retention of trees affects wood characteristics in both residual and regenerating trees. Older residual trees may be a future source of traditional quality wood (tight grain, few knots). However, epicormic branching may occur on some trees, increasing the incidence of knots. Dominant trees from mature, rather than old-growth stands, often respond and grow quite rapidly after partial harvest (Emmingham, pers. comm.). Residual canopy will influence species composition and growth rates of regenerating trees. Douglas-fir will likely experience reduced growth rates under a residual canopy, even if the stocking level of regeneration is controlled. Under higher densities of remnants, shade-tolerant species such as western hemlock and western redcedar may be the best growing species. Rose (1993) proposed utilizing microsites created by residual trees in distributing plantation stock: planting hemlock in the shady areas and Douglas-fir in the less shady areas. Rose suggested this might increase overall stand growth rates and reduce limbiness in Douglas-fir stems compared to traditional planting schemes.

Logging Operations and Safety. Leaving stable material at low densities is operationally feasible in most cases. Green trees have been left for years for the purposes of sheltering sites from frost or insolation (shelterwood), or to provide natural seed sources (seed tree). Logging becomes more difficult when higher densities of trees are to be left scattered across a unit, and sometimes more dangerous if dead and defective trees are targeted for retention. Leaving trees in clumps or patches may reduce hazards and increase efficiency of logging operations. See Kellogg et al. (1991), Weigand and Burditt (1992).

Economics. Retention of green trees, snags, and down logs has both immediate and long-term effects. Planning, marking, and administration costs are generally higher. High-value timber is often left on site and less wood per acre is removed. Harvesting efficiency is generally less whenever standing material is left. It is possible that some harvest of residual trees at subsequent entries could provide a high value product (but see previous discussion of wood quality). See Weigand and Burditt (1992), Hansen et al. (in press), McComb et al. (1994), Shaw et al. (1993), Edwards et al. (1992), Kellogg et al. (1991).

> *People judge natural settings not only by what is there, but also why it is there.*
> **-Mark Brunson**

Aesthetics, Social Values. While at first glance it makes sense that certain stand structures might be more socially acceptable than others, Brunson (1993) reported that "acceptability" of particular forest conditions had less to do with the actual condition and more to do with what caused it. "People judge natural settings not only by what is there, but also why it is there." (Brunson 1993) Forest conditions are also judged in relation to the alternatives available. Perception of higher risk in regard to a particular value decreases the desirability of a condition or practice. Acceptability is also a function of setting. A practice acceptable in one setting may not be acceptable in another setting. Individuals' views are frequently influenced by others around them. Harvest units with trees, snags, and logs retained appear more acceptable than clearcuts without these structures for many people, but there continues to be a wide range of opinion (see Brunson 1993).

Aggregated Versus Dispersed Green Trees. Aggregations of green remnant trees probably provide better refugia for old-forest invertebrates and lichens (Neitlich 1993, Sillett pers. comm., Schowalter pers. comm.), and better protection around special habitats because of greater amelioration of microclimate. Aggregation can sometimes reduce the difficulty of logging as mentioned previously. Dispersed green trees may provide better hunting habitat than clearcuts for some perching predators, e.g. great-horned owl, red-tailed hawk, and Steller's jay. When considering snags, clumped trees may provide more foraging substrate within the vicinity of a nesting snag for species with small home ranges such as the red-breasted nuthatch. Scattered snags may benefit secondary cavity-nesting species, which often forage in or over nearby vegetation, because snags are dispersed through more potential territories.

An aggregation of remnant trees may not function the same as a small patch of forest left intact. Within clumps of trees left in harvest units, intermediate canopy and understory trees are usually felled, and shrubs, logs and soils disturbed. In an intact patch, understory trees, shrubs, logs, and soil are also relatively undisturbed. An intact patch may act as a refugia for more species than simply a clump of overstory trees.

CONSIDERATIONS FOR DECISION-MAKING

Setting objectives. Will objectives be based on characteristics of historic landscapes or specific resource objectives? Both approaches have value, and are probably best implemented together. "Managers can look to the natural landscape and its disturbance regime as one guide to the appropriate design of managed landscapes for a particular area," (Franklin 1992). Natural examples within the current landscape, or one nearby, can give indications of stand structures, patch sizes, and disturbance frequencies that might be most appropriate for a particular area. The Augusta Creek Project used a disturbance history approach to develop rationale for prescribing varying amounts of material retention on the landscape (Cissel et. al. 1994, Cissel et. al. in prep). Areas on the landscape that apparently differed by amount of material left standing after fire, size of disturbance, and frequency of disturbance were identified. This translated into management objectives for different amounts of leave material, sizes of harvest units, and frequency of harvest. (Also see Swanson et al. 1993).

Results of mid-century harvest above a tributary of Quartz Creek near Blue River Reservoir, Blue River R.D., Willamette N.F. Coarse-textured areas are old trees which were left during harvest. Fine-textured areas are young conifer regrowth.

Specific objectives can be developed within the range of natural variability. Specific resource objectives often used by managers include: percent suitable habitat for identified species, amount of timber volume, amount of stream shade,bank and slope stability, and aesthetics.

If diversity is an objective, several scales should be considered. Leaving green trees throughout a landscape, whether scattered or in patches (within a stand), promotes within-stand diversity, but may decrease between-stand diversity if a similar prescription is applied everywhere in the landscape. Leaving no structure on site reduces within-stand diversity, but may increase between-stand diversity. Natural landscapes tend to have both within-stand and between-stand diversity.

Anticipate Mortality. If your objective is to have trees standing at the end of a particular growth cycle, you will need to account for blowdown and other sources of mortality. If windthrow is anticipated, objectives for both standing trees and down logs are more likely to be met. To decrease likelihood of blowdown, some managers have partially topped live green trees, thus reducing wind resistance. This may be unnecessary for large diameter trees, and more necessary for trees with greater height/diameter ratios. (see Stathers et. al. 1994 for many ideas for dealing with windthrow).

Choose trees to meet objectives. Retained trees should be selected based on their potential to accomplish specific objectives. For example, if particular seed sources are desired, then mature windfirm specimens of those species can be chosen. If large trees with broken tops or other specific structures are desired, trees meeting those needs can be chosen. If windfirm trees are especially important, shorter, larger-diameter trees with good root systems on drier soil might be given priority. If it is desired to grow a few trees through the next cycle in order to have large trees with high-quality wood, straight trees with high potential for survival could be chosen. If it is desired to leave trees as future down wood material, choose trees of the size desired that are likely to blow down.

Clumps. Locations for clumps of trees should be based on operational constraints and on-site characteristics. For example, particular logging systems often constrain placement of clumps of trees. Trees can also be clumped in particular areas to reduce risks of mass soil movements, or to protect small seeps, wet areas, or other unique habitats.

Northern spotted owl

Intact Patches. Patches of intact forest pass on more components of forest ecosystems than clumps of trees with highly disturbed understories. Intact patches will usually have more mid-level canopy and understory cover, which may provide additional nesting and denning habitat not found in disturbed clumps of trees. Intact patches may also be used to maintain individuals or clumps of natural snags that would be safety hazards if left within a zone of operation.

Artificially created snags. If snags are desired, but none are available or are feasible to leave from the existing stand, live trees can be left and then killed after the logging is completed. Trees can be topped by saw, explosives, or by girdling the tree high on the bole. Another way to create snags from live trees is to burn slash underneath the trees killing them with heat or partial scorching. All these methods could apply to trees that are scattered or in clumps. Frequently some mortality of retained trees occurs in the first few years after harvest. In areas with little windthrow potential, it may be unnecessary to top trees immediately. Tree mortality can be monitored, and supplemented by topping or other methods if other forms of mortality do not provide desired numbers of snags.

Leave same trees through multiple rotations. Some species of plants and animals appear to be associated with structures that are present in very old forests. For example, some rare old-forest lichens, such as *Pseudocyphellaria rainierensis*, and nests of the marbled murrelet, seem to be most frequent on large, old, moss-covered limbs in very old trees. Other species, such as spotted owls, Vaux's swifts, and some mammals, require or frequently use large hollow boles in otherwise live trees for nesting or denning (or crevices in large snags in the case of some bats). These habitats are not found on solid, "healthy" trees, but are developed over long periods of time. Leaving some trees specifically for this purpose through successive rotations might allow formation of these habitats.