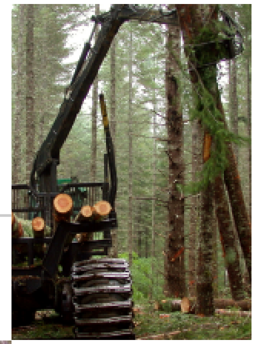
Forest Biomass Retention and Harvesting Guidelines for the Pacific Northwest



by the Forest Guild Pacific Northwest Biomass Working Group

forest GUILD

April 2013

Forest Guild Northwest Biomass Work Group helped draft this report. The group included the members listed below. Individual participation does not indicate organizational endorsement.

Chad Davis, Oregon
Steve Dettman, Ecosystem Restoration Associates, Oregon
Sarah Deumling, Zena Forest LLC, Oregon
Matt Fehrenbacher, Trout Mountain Forestry, Oregon
Marcus Kauffman, Oregon
Amy LaBarge, Seattle Public Utilities, Washington
Darcie Mahoney, California
George McKinley, Mountain Millworks, Oregon
Kyle Meister, Scientific Certification Systems, Oregon
Mark Miller, Trout Mountain Forestry, Oregon
Eric O'Kelley, Collins Pine, California
Jake Robinson, Yankee Creek Forestry, Oregon
Kara Whittaker, Washington Forest Law Center, Washington
Jean Shaffer, Nisqually Tree Art Forestry Consulting, Washington
Patrick Shannon, Sustainable Northwest, Oregon
Nils Christofferson, Wallowa Resources, Washington

Staff:

Mike DeBonis, Forest Guild, New Mexico
Alexander Evans, Forest Guild, New Mexico

This report was made possible by generous support from the Weyerhaeuser Family Fund. We also thank Debbie Page-Dumroese, Mark Harmon, and Kim Mellen-McLean for their review of these guidelines.

Front cover photo of stump by Zander Evans and harvester from Bureau of Land Management, Oregon www.flickr.com/photos/blmoregon/6871712301/.

This report is available online at:
www.forestguild.org/publications/research/2013/FG_Biomass_Guidelines_PNW.pdf

The Forest Guild practices and promotes ecologically, economically, and socially responsible forestry as a means of sustaining the integrity of forest ecosystems and the human communities dependent upon them.

*forest***GUILD** PO Box 519 Santa Fe, NM 87504 505-983-8992 www.forestguild.org

Forest Biomass Retention and Harvesting Guidelines for the Pacific Northwest

Contents

1. Executive Summary: Biomass Retention and Harvesting Guidelines

The Forest Guild developed these biomass retention and harvesting guidelines for foresters who put the highest priority on maintenance and enhancement of the entire forest ecosystem. Where economic objectives are paramount, we hope these guidelines also add value, because maintenance of ecosystem function through retention of dead wood is important for long-term forest health. Our focus is not the destination of the wood or biomass removed, but the condition of the forest after harvest. The following bullet points summarize our main guidelines on biomass retention and harvesting in the Pacific Northwest. The body of the report contains more details about these guidelines.

Forest Guild

- Manage forests based on social, economic, and ecological goals and not solely to supply biomass.
- Account for biomass harvests during landscape-level planning to minimize the potential for negative cumulative impacts.
- Protect rare ecosystems and sensitive sites. Biomass harvesting can be appropriate on sensitive sites to control invasive species, enhance critical habitat, or restore fire ecosystem processes.
- Retain and recruit snags of a variety of species to promote healthy wildlife populations—the larger the better.
- The following are average numbers of snags measured in different types of unmanaged forests in the PNW. While these levels may not necessarily apply to managed forests, we present them here as a guide to forest managers.
  - 11 per acre in westside lowland conifer-hardwood forests in Washington
  - 10 per acre in lowland conifer-hardwood forests in coastal Washington
  - 9 per acre in westside lowland conifer-hardwood forests in Oregon
  - 8 per acre in lowland conifer-hardwood forests in coastal Oregon
  - 5 per acre in conifer-hardwood forests in southwest Oregon
  - 11 per acre in montane mixed conifer forests
  - 2 per acre in eastside mixed conifer forests

- Downed woody material (DWM) is important and should be retained on-site to maintain soil nutrients and wildlife habitat. Retain and recruit downed logs of a variety of species to promote healthy wildlife populations—the larger the better.

- Measurements of percent cover of dead wood greater than 5 inches in unmanaged plots can serve as a guide for forest managers:
    - 6% cover in westside lowland conifer-hardwood forests
    - 9% cover in lowland conifer-hardwood forests in coastal Washington
    - 5% cover in lowland conifer-hardwood forests in coastal Oregon
    - 3% cover in conifer-hardwood forests in southwest Oregon
    - 5% cover in montane mixed conifer forests
    - 3% cover in eastside mixed conifer forests in the north Cascades and Rocky Mountains
    - 1% cover in eastside mixed conifer forests in the east Cascades and Blue Mountains

  Wildlife experts recommend greater retention, 15 to 20% cover, where protection of small mammals and their predators is a management objective.

- Though percent cover is a precise and efficient means of recording DWM, it may be unfamiliar to foresters.[1] For those looking for a quick rule of thumb, we concur with Oregon State University's recommendation to retain at least 30% of the fine woody debris created by the harvest on slopes conducive to ground-based harvesting and 50% or more on steeper slopes in the Douglas-fir region.

Zander Evans

- Tailor retention of dead wood to site conditions and increase it where there is little existing dead wood, soils are nutrient poor, harvest intensity is high, or harvests are frequent, as shown in the graphic below.

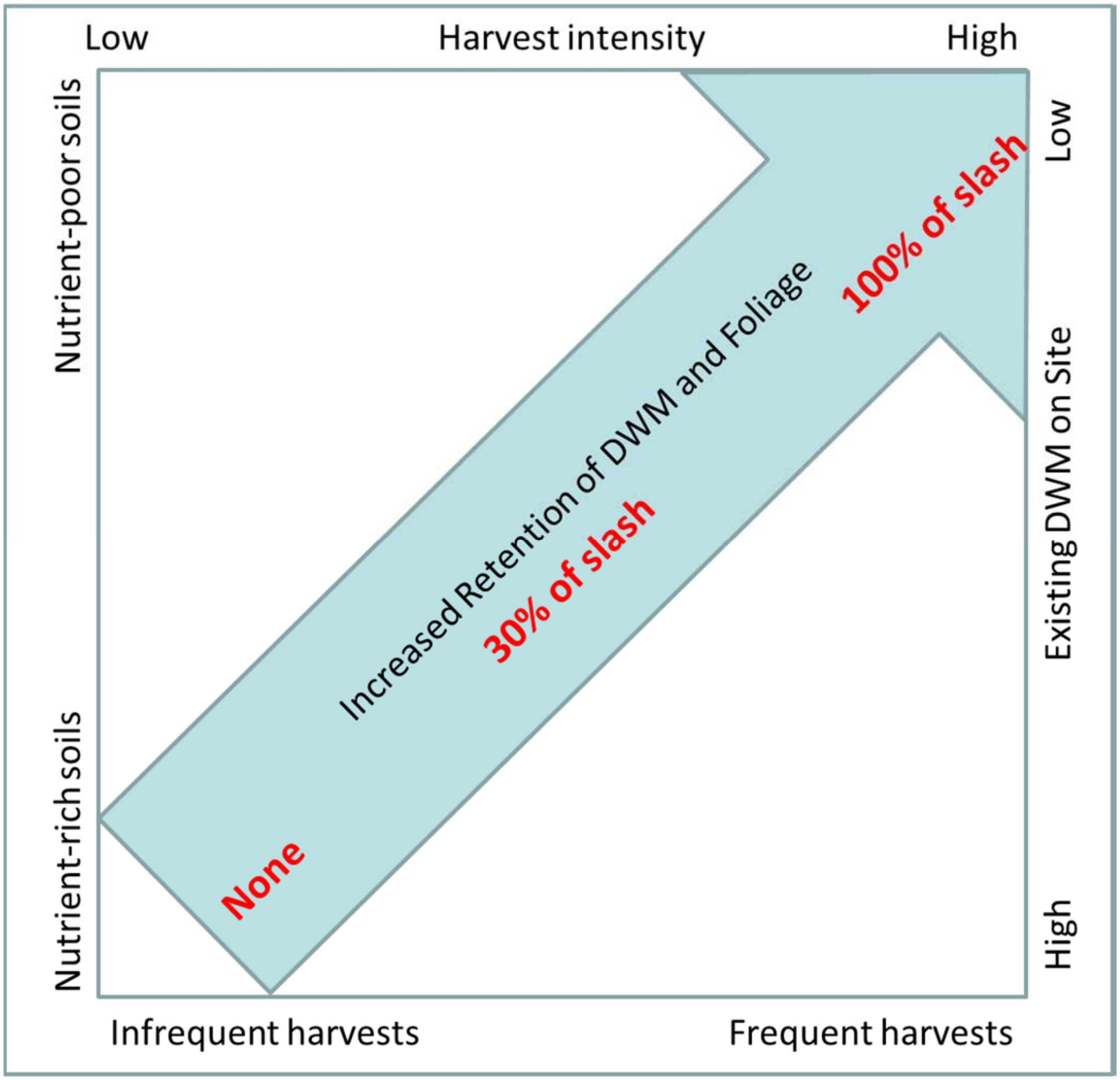


Figure 1 Relationship between retention of dead wood and site conditions

- Minimize soil and duff disturbance that is not consistent with well-defined regeneration objectives during biomass harvests.

- Focus fire threat reduction treatments on the removal of ladder fuels and small-diameter trees to help avoid potential conflicts between fuels reduction and biomass retention goals.

2. Introduction and Background

Responsible forestry sustains the integrity of forest ecosystems and the human communities dependent upon them. Growing interest in the use of wood to generate heat, power, and fuel has prompted a new focus on the potential environmental impacts of wood-energy production. Forest biomass harvests can be a source of renewable energy, boost local economies, promote the growth of higher-value trees, reduce forest fire risk, support the removal of invasive species, and offset the cost of forest restoration or timber stand improvement. At the same time, there is potential for bioenergy markets to motivate too much extraction from the forest, which would result in negative ecological impacts. We believe forests can provide a renewable source of products, energy, habitat, water, recreational opportunities, and aesthetic enjoyment if managed in a responsible manner. These guidelines are designed to provide recommendations to help forest stewards and natural resource managers do just that.

Forest Guild

These guidelines are meant to dovetail with existing state Best Management Practices (BMPs) and forest practice rules (see page 17 for links to these resources). These guidelines represent only part of a long list of criteria that should be considered for sustainable forest management, and on their own do not guarantee that a given harvest or forest management plan is sustainable. Sustainability itself is difficult to define and should include ecological, social, and economic factors. Our focus in these recommendations is on the ecological segment. Similarly, our focus is on stand- or forest-level recommendations, but biomass harvesting practices should be included in landscape-level planning to minimize the potential for negative cumulative impacts.[2]

These guidelines were designed for the forests of Washington and Oregon, though the research on which they are based is applicable to similar forests types in neighboring states and Canada. The guidelines focus on the specifics of eight major forest types, including: coastal forests; Douglas-fir–hemlock forests of the Coast Range and the Western Cascades; subalpine and fir-spruce forests; Klamath-Siskiyou mixed conifer forests; East Cascades and Okanogan Highlands mixed conifer forests; juniper woodlands and savannas; oak woodlands and savannas; and eastern ponderosa pine forests (see map on page 21). While our delineation of forest types differs from some other maps, it helped the working group focus on ecosystem specifics.

Creating the Guidelines

The Forest Guild initiated the creation of these guidelines through a working group of 24 foresters and natural resource experts. We built these guidelines on the foundation of the Forest Guild's principles for ecologically, economically, and socially responsible forestry.[3] Forest Guild stewards use nature as a model in an effort to maintain the functions, structures, and compositions that support the health of the entire forest ecosystem.[4]

Bureau of Land Management – www.flickr.com/photos/blmoregon/

Our goal was to create guidelines, based on the best available science, that could easily be comprehended and implemented in the field. Wherever possible, we based our guidelines on peer-reviewed science. However, in many cases research is inadequate to connect practices, stand-level outcomes, and ecological goals. Where the science remains inconclusive, we relied on field observation and professional experience. Since these guidelines are driven by science, they should be reviewed and updated as new information becomes available. While our working group is concerned about the carbon implications of using wood for energy and fuel, carbon accounting is beyond the scope of these guidelines. Our focus is not on the destination of the wood, but the condition of the forest after harvest.

In developing these guidelines, the working group emphasized the importance of professional judgment in practicing forestry and implementing recommendations. It may be that a recommendation is inappropriate for a particular stand because of past management history or unique site conditions. These guidelines are presented not as static targets to be maintained at all times in all places, but rather as guideposts on a path to sustainability.

Definitions

Biomass

In a scientific context, the term "biomass" includes all living or dead organic matter. In forest management, biomass usually refers to woody material that has historically had a low value and has not been considered merchantable in traditional markets. Biomass harvesting can also involve the removal of dead trees, downed logs, brush, and stumps, in addition to tops and limbs. Changing markets and regional variations determine which trees are considered sawtimber or pulpwood material and which are relegated to the biomass category. These guidelines do not discuss biomass from agricultural lands or short-rotation woody biomass plantations.

Forest Guild

In these guidelines, the term **biomass** refers to vegetation removed from the forest: usually logging slash, small-diameter trees, tops, limbs, or trees not considered merchantable in traditional markets. Similarly, we use the phrase **biomass harvesting** to refer to the removal of logging slash, small-diameter trees, tops, or limbs.

Downed Woody Material

Woody material is sometimes categorized into coarse woody material (CWM) and fine woody material (FWM). CWM has been defined as downed dead wood more than 6 inches in diameter at the large end, and FWM as less than 6 inches in diameter at the large end.[5] The USDA Forest Service defines CWM as downed dead wood with a small-end diameter of at least 3 inches and a length of at least 3 feet, and FWM as that with a diameter of less than 3 inches.[6] Large woody material (LWM) includes logs greater than 12 inches in diameter. In this report, we use the term **downed woody material** (**DWM**) to encompass all three of these size classes, but where the piece size is particularly important, we discuss a specific size of material.

3. Guidelines for Retention and Harvesting

Protecting Rare Ecosystems and Sensitive Sites
Rare ecosystems and sensitive sites, including old-growth stands, should be protected from harvesting in most cases, unless treatment is necessary to maintain structure or ecological function. For example, biomass harvesting can be appropriate in sensitive sites to control invasive species, enhance critical habitat, restore site hydrology, or return fire as an ecosystem process. It is unlikely that restored sites will contribute to long-term wood supply, because biomass removals for restoration might not be repeated at regular intervals. Any forest restoration activity should be guided by ecological principles and not designed solely to supply biomass.

Washington has an online geographic information system for identifying priority habitats and species, called Priority Habitats and Species (PHS), that may require special focus on retention or adjustment to harvest planning.[7] For example, the PHS can help identify sites where western toads have been found and may need additional retention of logs for hibernation.[8]

The state of Washington defines sensitive sites as areas near or adjacent to perennial non-fish habitat streams (type Np waters) and with one or more of the following characteristics:[9]

- Headwall seep (a seep located at the toe of a cliff with perennial water at or near the surface throughout the year)
- Side-slope seep (a seep within 100 feet of a non-fish habitat stream)
- Headwater spring (a permanent spring at the head of a perennial channel)
- Alluvial fan, excluding features that were formed under climatic or geologic conditions which are not currently present or which are no longer dynamic

In Oregon, sites that deserve special consideration include significant wetlands, sites used by threatened or endangered species, sensitive bird nesting and roosting sites, and "conservation opportunity areas" identified in the Oregon Conservation Strategy.[10] All of these sites may require additional care during planning and harvesting.

Juniper Woodlands
Western juniper may offer a significant biomass utilization opportunity, but biomass harvests should focus on removing junipers that have invaded other habitat types. Fire exclusion and removal of fine fuels by grazing livestock have allowed junipers to invade shrub-steppe and grasslands.[11] Similarly, juniper has encroached on and threatens the regeneration of some stands of pine and fir. Harvests should avoid old

juniper trees with rounded crowns and covered by light green lichen. These trees can be more than 1,000 years old. Juniper management guides are available to help identify juniper stand types, avoid old-growth stands, and select appropriate treatments.[12, 13] For example, areas of advanced juniper encroachment tend to have the greatest biomass, but they are often so degraded that removing the trees greatly increases soil erosion potential.[12, 13]

Bureau of Land Management – www.flickr.com/photos/blmoregon/

Oak Woodlands
Before Euro-American settlement, natural fires and Native American burning maintained extensive areas of oak woodland and oak savannah in the Puget Sound region and in the Willamette Valley. Because of conversion to other land uses and invasion by conifers (primarily Douglas-fir), the area of oak woodlands and savannah has drastically declined.[14] In Washington, priority oak woodlands are defined as stands of pure oak or oak-conifer associations where canopy coverage of the oak component of the stand is greater than 25%. Oak savannas include stands where total canopy coverage of the stand is less than 25%, but oak accounts for at least 50% of the canopy coverage.[15] Ninety-three different species of woodland wildlife and 47 species associated with savannas use leaf litter, snags and DWM in oak woodlands and savannahs for nesting, denning, feeding, and cover habitat.[16]

Soil Considerations
Nutrient availability and physical impacts are both important for understanding the potential impact of biomass retention and harvesting on soil in the Pacific Northwest. In most ecosystems of the Pacific Northwest, CWM contributes a large amount of organic matter to the soil and FWM and foliage contribute significantly to soil nutrient pools.[17,18] While dead wood is important for maintaining soil fertility, little scientific information exists on exactly how much biomass needs to remain on-site to protect fertility and site productivity, in part because of the site-specific nature of soil conditions.[19, 20] New mapping technology is available to help map soils sensitive to biomass removals based on chemical and physical properties.[21]

As with any harvest, biomass removal can add to soil compaction. Low-impact logging techniques, such as directional felling, careful skid trail layout, and use of slash to protect soil on skid trails, can safeguard soils from compaction, particularly when soils are wet.[22, 23] Retention of slash post-harvest can increase tree growth. For example, biomass retention slightly increased tree growth in both a coastal Washington forest at age five[24] and in study sites in the eastern Cascade Mountains of Washington.[25]

Because of the impacts of biomass removal on soils, Oregon State University recommends retention of at least 30% of the FWM on slopes conducive to ground-based harvesting and 50% or more on steeper slopes in the Douglas-fir region of Oregon and Washington.[26] The same set of recommendations suggests that it is best to wait until tops and limbs are dry before piling or removing them, so that needles and fine branches can fall off and remain distributed as uniformly as possible across the site. On the other hand, re-entry into the stand to remove biomass after a sawlog harvest can increase site impacts such as soil compaction and harm post-harvest regeneration. Some state guidelines recommend avoiding re-entering stands (to minimize soil compaction) and suggest integrating biomass removals with traditional forest operations wherever possible.[27] Professional foresters familiar with local conditions play an important role in balancing these types of tradeoffs.

In areas of juniper encroachment, removing the tree boles and leaving a light to moderate scattering of branches can reduce overland flow and increase infiltration. This type of lop-and-scatter treatment also moderates soil temperature, improves conditions for seedling establishment, and provides some protection from grazing.[12]


Forest Guild

Retention for Wildlife and Biodiversity

Throughout the Pacific Northwest, wildlife rely on dead wood and different animals prefer particular species of snags and logs.[28] For example, woodpeckers, sapsuckers, and nuthatches are highly specific in their selection of tree species for nesting and roosting. The degree and type of decay matters too, and the 93 wildlife species associated with snags in the Pacific Northwest vary in their preferences. Therefore, it is important to maintain dead wood of different tree species and in different stages of decay to benefit a variety of wildlife species. Eighty-six vertebrate wildlife species are associated with DWM, and larger downed wood (in both diameter and length) generally has more potential uses as wildlife habitat. Most snag-using wildlife species are associated with snags greater than 14 inches diameter at breast height (DBH), and about a third of these species use snags greater than 29 inches DBH.

US Forest Service researchers and managers designed the DecAID, the decayed wood advisor for managing snags, partially dead trees, and DWM for biodiversity in the forests of Washington and Oregon.[29] DecAID summarizes snags and DWM from unmanaged plots, which can help provide an estimate of how much dead wood might occur naturally. The graph below illustrates the range of snag densities found in stands of large trees (20 to 29 inches DBH). The green bars highlight the range from the number of snags found on 30% of the landscape to the number of snags found on 80% of the landscape. The average number of snags is marked within each green bar by a vertical band. For example, for unmanaged westside lowland conifer-hardwood forests in Washington with large trees, 30% of the landscape had fewer than 11 snags per acre, half the landscape had fewer than 17 snags per acre, and only 20% had more than 32 snags per acre.

Superior National Forest – www.flickr.com/superiornationalforest/

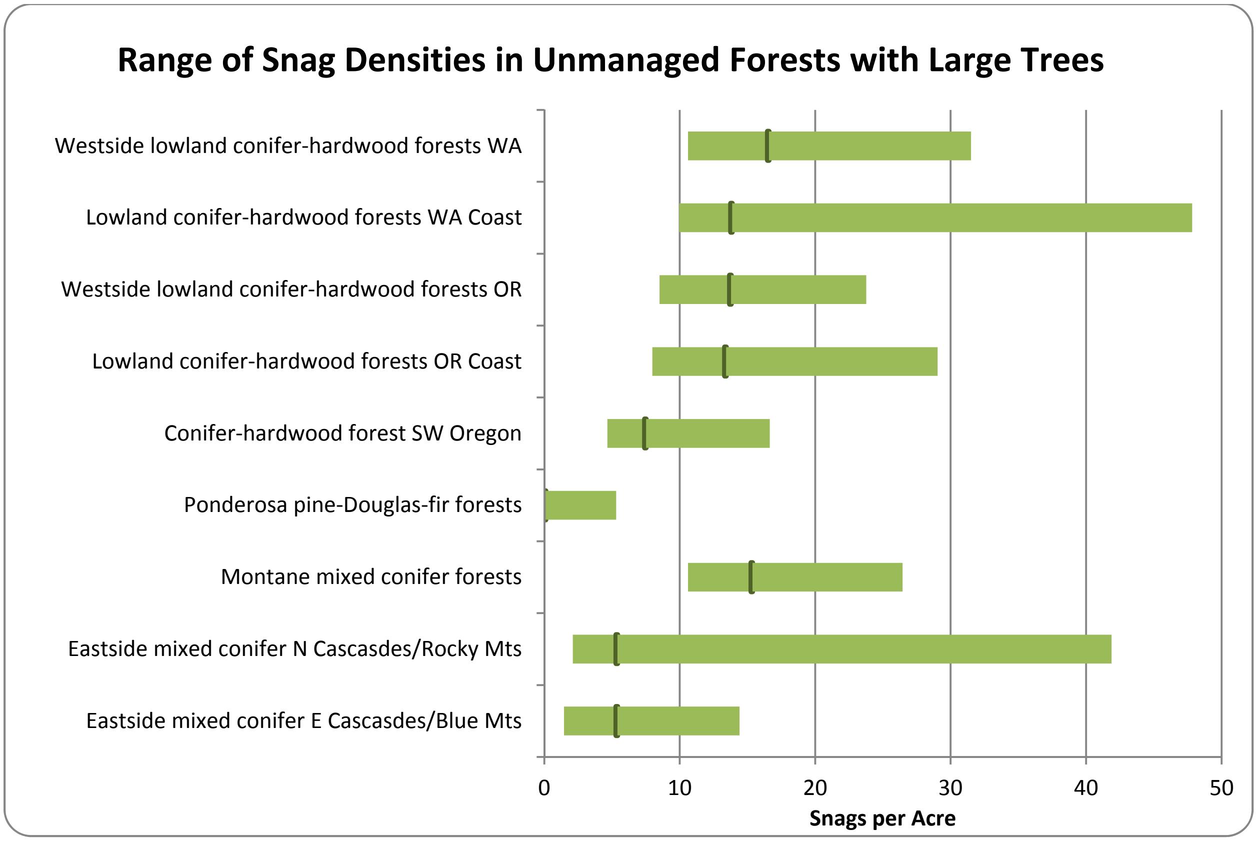


Figure 2 Snags greater than 10 inches per acre found in unmanaged, large-tree forests. Green bars show the range from 30% to 80% and dark, vertical bands indicate average number of snags. Data are from DecAID.

The lower end of the range of snags in unmanaged stands with large trees (20 to 29 inches DBH) provides a target goal for managed stands:

- 11 per acre in westside lowland conifer-hardwood forests in Washington
- 10 per acre in lowland conifer-hardwood forests in coastal Washington
- 9 per acre in westside lowland conifer-hardwood forests in Oregon
- 8 per acre in lowland conifer-hardwood forests in coastal Oregon
- 5 per acre in conifer-hardwood forests in southwest Oregon
- 11 per acre in montane mixed conifer forests
- 2 per acre in eastside mixed conifer forests

While these numbers for snag retention are unlikely in commercial harvest areas, they provide a goal that may be achievable in some areas so that, on average, managed forests can imitate unmanaged forests. Where landowner objectives include managing for particular wildlife species, we recommend consulting DecAID for more detailed recommendations on snag and DWM retention.[29] In all areas, we recommend retention of large snags wherever possible, as large snags are rare and have high habitat value.

DWM is also important and should be retained on-site to maintain soil nutrients and wildlife habitat. DecAID also provides data on the percentage of the ground covered by DWM in unmanaged stands. For example, for unmanaged westside lowland conifer-hardwood forests in Washington with large trees, data show that 50% of the landscape had at least 6% of the ground covered by DWM.

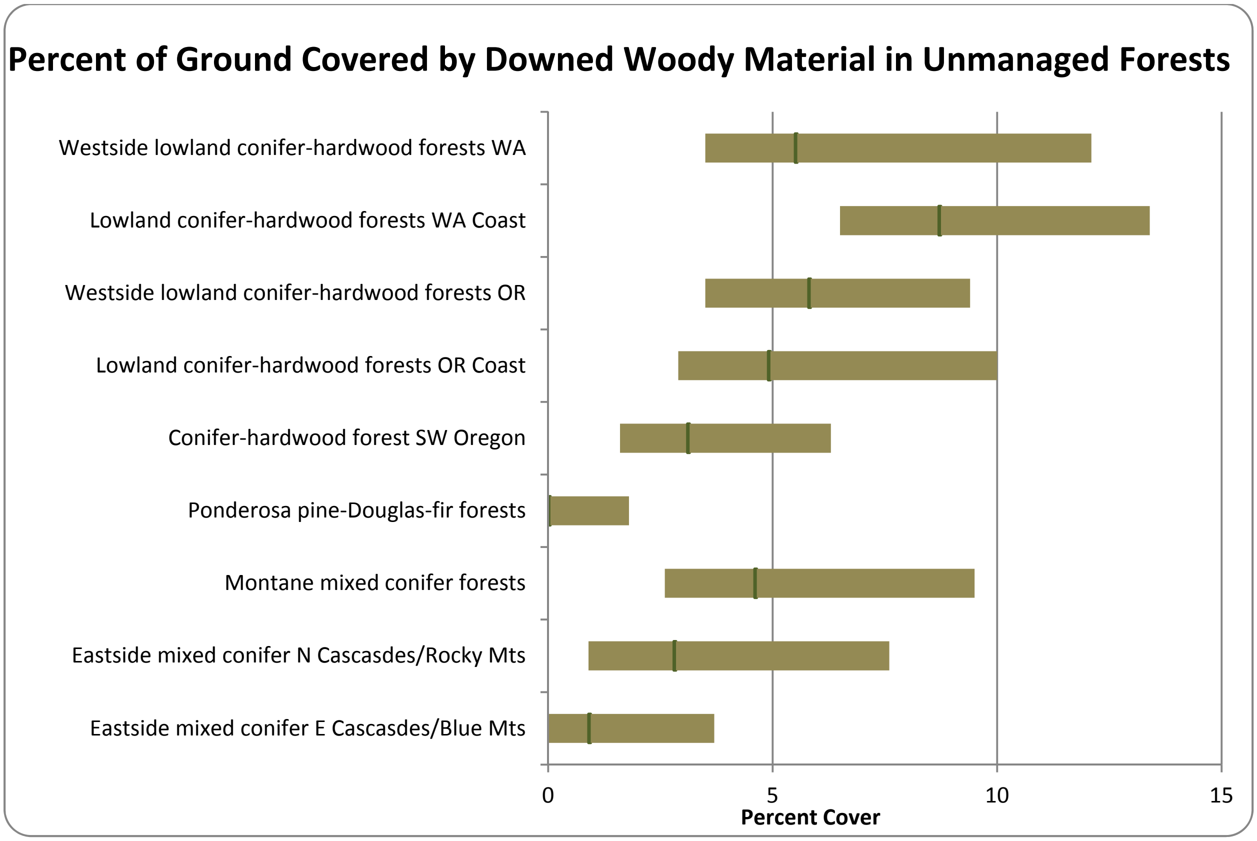


Figure 3 Percentage of ground covered by DWM (diameter greater than 5 inches) in unmanaged forests with large trees. Green bars show the range from 30% to 80% and dark, vertical bands indicate the average coverage of DWM. Data are from DecAID.

Measurements of percent cover of dead wood greater than 5 inches in unmanaged plots can serve as a guide for forest managers:

- 6% cover in westside lowland conifer-hardwood forests
- 9% cover in lowland conifer-hardwood forests in coastal Washington
- 5% cover in lowland conifer-hardwood forests in coastal Oregon
- 3% cover in conifer-hardwood forests in southwest Oregon
- 5% cover in montane mixed conifer forests
- 3% cover in eastside mixed conifer forests in the north Cascades and Rocky Mountains
- 1% cover in eastside mixed conifer forests in the east Cascades and Blue Mountains

Where protection of small mammals and their predators is a management objective, wildlife experts recommend greater retention of CWM: 15% to 20% cover in western Washington and northwestern Oregon[30] and ≥10% cover in Douglas-fir forests of southwestern Oregon.[31] Quantities of DWM vary over time as stands develop, and these goals may not be achievable at all phases of stand development; nevertheless, they can provide a long-term management goal.

Both clumped and dispersed retention can benefit wildlife and heterogeneity across the landscape. For example, wildlife such as rodents, hares, and rabbits use slash piles, and dense accumulations of logs are used extensively by American martens for hunting and for shelter.[32] Alternatively, DWM distributed throughout the stand provides cover and foraging opportunities over a wider area. Management decisions such as leaving tall stumps (3 to 6 feet high) from large trees, minimizing site preparation, extending rotations, and choosing silvicultural systems that retain more live trees (e.g., group selection or shelterwood) and logs can benefit wildlife that depends on DWM.[30]

www.nv.nrcs.usda.gov Bootstraps Program

Juniper Woodlands

Snags and DWM are important elements in old-growth juniper woodlands. Studies suggest that between 2 and 11 snags per acre and between 1 and 7 downed logs per acre are typical of old-growth juniper stands.[33-35] In areas of juniper encroachment, small mammal populations can benefit from the removal of juniper, and slash retention provides areas for vegetative reproduction and cover from predators.[36]

Oak Woodlands

The restoration of oak woodlands and savannahs is essential for the protection of unique habitats, and practitioners should consult more detailed resources specific to that topic.[15, 16] Biomass harvests could be used in oak woodland restoration as a tool to remove encroaching conifers, but care should be taken to retain snags and DWM. In fact, managers should consider creating conifer snags when thinning conifers instead of removing trees entirely. In may be necessary to prune, limb, top, or girdle encroaching conifers to ensure that they do not overshade the oaks.[15]

A survey of oak woodlands suggests that, on average, young stands have 4 snags per acre greater than 10 inches DBH while old stands have 7 snags greater than 10 inches per acre.[28] Tall, large-diameter snags (larger than 20 inches DBH) are important to retain or recruit because of their rarity and habitat value.[16] Research suggests dead wood covers about 2% of the ground in unmanaged oak woodlands,[28] while a guide to oak restoration recommends retaining up to 200 ft^3 of DWM per acre.[16]

Water Quality

Water quality and riparian concerns are important in all harvests, including those that remove biomass. As with other harvests, it is important to minimize soil and duff disturbance during biomass removal.[37] Leaving slash on-site can help prevent sheet erosion and create debris dams that slow the rate of runoff. Throughout the Northwest, retention and recruitment of snags and large downed logs in riparian areas is important because of the general scarcity of large woody material in stream channels due to past management.[38]

Forest Guild

Refer to state forest practices acts and Best management Practices (BMP) or additional measures to protect streams, wetlands, vernal pools, and other water bodies (see page 17 for a list). As with biomass guidelines, water quality BMPs need to adjust to and account for changing science and field knowledge. To be successful, state-run BMP programs should include a comprehensive monitoring system to evaluate BMP effectiveness and a periodic review to modify and improve forestry BMPs.

Fire and Fuel Considerations

In forests with historically moderate or low-severity fire regimes, land-use changes and management (particularly fire suppression) have led to overstocked conditions with uncharacteristically high fuel loadings and fire threat. For example, many eastern ponderosa pine and some mixed conifer stands are much denser than they were before settlement. Treatments designed to reduce fire severity can offer an opportunity for biomass utilization. In fact, markets for biomass removed in fuel reduction and restoration projects can expand the area treated and hence have positive ecological impact. Those forests that have departed the most from historic conditions should be prioritized for treatment.[39]

In fire adapted forests, the challenge for biomass retention guidelines is to balance fire threat reduction with the ecological values of dead wood. Wildfire threat reduction treatments tend to focus on five main elements: reducing surface fuels, reducing ladder fuels, increasing height to live crown (i.e., canopy base height), reducing canopy continuity (developing or maintaining canopy gaps), and decreasing crown density. Of these, only the reduction of surface fuels is likely to be in conflict with biomass retention goals, and this potential conflict could be mitigated in some cases by concentrating retention to create discontinuities in the fuel. In fact, since thinning can speed the development of late-successional attributes such as large-diameter trees (which can become snags and logs), fuels reduction could benefit dead wood habitat goals in the long term. In general, wildlife responses to thinning in the Northwest have been neutral or slightly positive.[40, 41]

Conclusion

The Forest Guild believes that the practice of forestry must be grounded in field observation and experience as well as the biological sciences. We also recognize that we still have more to learn about forest ecosystem function, and that responsible management requires a humble approach. These guidelines were developed to provide forest managers with the information needed to make informed decisions about removing woody biomass from forests in the Pacific Northwest. As new science becomes available and field experience evolves, biomass harvesting and retention guidelines should be revisited and revised as appropriate.

Kara Whittaker

4. Resources and References

State Best Management Practices and Forest Practice Guidance

Oregon Forest Practices Act
http://www.oregon.gov/ODF/privateforests/fpaKeys.shtml

Woodland Workbook - Oregon State University Extension
http://faculty.bus.oregonstate.edu/sullivan/woodland-workbook/

Washington Forest Practices Act
http://www.dnr.wa.gov/BusinessPermits/Topics/ForestPracticesRules/Pages/fp_rules.aspx

Washington Forest Practices Illustrated
http://www.dnr.wa.gov/BusinessPermits/Topics/ForestPracticesRules/Pages/fp_fpi.aspx

Washington Forest Practices Board Manual
www.dnr.wa.gov/BusinessPermits/Topics/ForestPracticesRules/Pages/fp_board_manual.aspx

References

1 Bate, L. J., T. R. Torgersen, E. O. Garton, and M. J. Wisdom. 1999. Accuracy and Efficiency of Methods to Sample Logs for Wildlife Research and Management. Pages 817-822 *in* W. F. Laudenslayer, Jr., B. Valentine, C. P. Weatherspoon, and T. E. Lisle, editors. *Symposium on the ecology and management of dead wood in western forests*. USDA Forest Service, Pacific Southwest Research Station. PSW-GTR-181, Reno, NV. http://www.fs.fed.us/psw/publications/documents/gtr-181/060_BateLog.pdf

2 Lindenmayer, D. B., J. F. Franklin, and J. Fischer. 2006. General Management Principles and a Checklist of Strategies to Guide Forest Biodiversity Conservation. *Biological Conservation* 131(3):433-445. http://www.sciencedirect.com/science/article/pii/S0006320706000814

3 Forest Guild. 2013. Mission and Principles. http://forestguild.org/mission.html, Santa Fe, NM.

4 Franklin, J. F., R. J. Mitchell, and B. J. Palik. 2007. Natural Disturbance and Stand Development Principles for Ecological Forestry. GTR-NRS-19, US Forest Service, Northern Research Station, Newtown Square, PA. http://www.treesearch.fs.fed.us/pubs/13293

5 MFRC. 2007. Biomass Harvest Guidelines. Minnesota Forest Resources Council, St. Paul, MN. http://www.frc.state.mn.us/FMgdline/BHGC.html

6 Woodall, C. W., and V. J. Monleon. 2008. Sampling Protocol, Estimation, and Analysis Procedures for the Down Woody Materials Indicator of the Fia Program. NRS-GTR-22, U.S. Forest Service, Newtown Square, PA. www.fs.fed.us/nrs/pubs/gtr/gtr_nrs22.pdf

7 Washington Dept of Fish and Wildlife. 2013. Priority Habitats and Species. Olympia, WA. http://wdfw.wa.gov/mapping/phs/

8 Browne, C. L., and C. A. Paszkowski. 2010. Hibernation Sites of Western Toads (*Anaxyrus Boreas*): Characterization and Management Implications. *Herpetological Conservation and Biology* 5(1):49-63.

9 Washington Administrative Code. 2013. Wac 222-16-010. http://apps.leg.wa.gov/wac/default.aspx?cite=222-16-030

10 ODFW. 2006. Oregon Conservation Strategy. Oregon Department of Fish and Wildlife, Salem, OR.

11 Miller, R. F., and J. A. Rose. 1999. Fire History and Western Juniper Encroachment in Sagebrush Steppe. *Journal of Range Management* 52(6):550-559.

12 Barrett, H. 2007. Western Juniper Management: A Field Guide. Oregon Watershed Enhancement Board, Salem, OR. www.oregon.gov/OWEB/MONITOR/docs/westernjunipermanagementfieldguide.pdf

13 Miller, R. F., J. D. Bates, T. J. Svejcar, and F. B. Pierson. 2007. Western Juniper Field Guide: Asking the Right Questions to Select Appropriate Management Actions. Circular 1321, U.S. Geological Survey, Reston, VA. http://pubs.usgs.gov/circ/1321/

14 Curtis, R. O., D. S. DeBell, R. E. Miller, M. Newton, J. B. St. Clair, and W. I. Stein. 2007. Silvicultural Research and the Evolution of Forest Practices in the Douglas-Fir Region. PNW-GTR-696, USDA Forest Service, Pacific Northwest Research Station, Portland, OR. http://www.fs.fed.us/pnw/publications/pnw_gtr696/

15 Larsen, E. M., and J. T. Morgan. 1998. Management Recommendations for Washington's Priority Habitats: Oregon White Oak Woodlands. Washington Department of Fish and Wildlife, Olympia, WA. http://wdfw.wa.gov/publications/00030/wdfw00030.pdf

16 Vesely, D., and G. Tucker. 2004. Landowner's Guide to Restoring and Managing Oregon White Oak Habitats. Bureau of Land Management, USDA Forest Service, Oregon Department of Forestry, The Nature Conservancy, Salem, OR.

17 Edmonds, R. L., and J. L. Marra. 1999. Decomposition of Woody Material: Nutrient Dynamics, Invertebrate/Fungi Relationships and Management in Northwest Forests. *Proceedings: Pacific Northwest Forest and Rangeland Soil Organism Symposium* 461:68-79.

18 Keenan, R. J., C. E. Prescott, and J. P. H. Kimmins. 1993. Mass and Nutrient Content of Woody Debris and Forest Floor in Western Red Cedar and Western Hemlock Forests on Northern Vancouver Island. *Canadian Journal of Forest Research* 23(6):1052–1059. 10.1139/x93-134

19 Jurgensen, M. F., A. E. Harvey, R. T. Graham, D. S. PageDumroese, J. R. Tonn, M. J. Larsen, and T. B. Jain. 1997. Impacts of Timber Harvesting on Soil Organic Matter, Nitrogen, Productivity, and Health of Inland Northwest Forests. *Forest Science* 43(2):234-251.

20 Page-Dumroese, D. S., M. Jurgensen, and T. Terry. 2010. Maintaining Soil Productivity During Forest or Biomass-to-Energy Thinning Harvests in the Western United States. *Western Journal of Applied Forestry* 25(1):5-11. http://www.ingentaconnect.com/content/saf/wjaf/2010/00000025/00000001/art00002

21 Kimsey, M., D. Page-Dumroese, and M. Coleman. 2011. Assessing Bioenergy Harvest Risks: Geospatially Explicit Tools for Maintaining Soil Productivity in Western Us Forests. *Forests* 2(3):797-813. http://www.mdpi.com/1999-4907/2/3/797/

22 McDonald, T. P., and F. Sexias. 1997. Effect of Slash on Forwarder Soil Compaction. *International Journal of Forest Engineering* 8(2):15-26.

23 Han, S.-K., H.-S. Han, D. S. Page-Dumroese, and L. R. Johnson. 2009. Soil Compaction Associated with Cut-to-Length and Whole-Tree Harvesting of a Coniferous Forest. *Canadian Journal of Forest Research* 39(5):976–989.

24 Ares, A., T. Terry, C. Harrington, W. Devine, D. Peter, and J. Bailey. 2007. Biomass Removal, Soil Compaction, and Vegetation Control Effects on Five-Year Growth of Douglas-Fir in Coastal Washington. *Forest Science* 53(5):600-610.

25 Zabowski, D., B. Java, G. Scherer, R. L. Everett, and R. Ottmar. 2000. Timber Harvesting Residue Treatment: Part 1. Responses of Conifer Seedlings, Soils and Microclimate. *Forest Ecology and Management* 126(1):25-34.

26 Harrison, R. B., D. A. Maguire, and D. Page-Dumroese. 2011. Maintaining Adequate Nutrient Supply - Principles, Decision-Support Tools, and Best Management Practices. Pages 33-42 *in* S. D. Angima and T. A. Terry, editors. *Best Management Practices for Maintaining Soil Productivity in the Douglas-Fir Region*. Oregon State University Extension Service, Corvallis, OR.

27 Evans, A. M., R. T. Perschel, and B. A. Kittler. 2010. Revised Assessment of Biomass Harvesting and Retention Guidelines. The Forest Guild, Santa Fe, NM. http://www.forestguild.org/publications/research/2009/biomass_guidelines.pdf

28 Rose, C. L., B. G. Marcot, T. K. Mellen, J. L. Ohmann, K. L. Waddell, D. L. Lindley, and B. Schreiber. 2001. Decaying Wood in Pacific Northwest Forests: Concepts and Tools for

Habitat Management. Pages 580-623 *in* D. H. Johnson and T. A. O'Neil, editors. *Wildlife-Habitat Relationships in Oregon and Washington*. Oregon State University Press, Corvallis, OR.

29 Mellen-McLean, K., B. G. Marcot, J. L. Ohmann, K. Waddell, S. A. Livingston, E. A. Willhite, B. B. Hostetler, C. Ogden, and T. Dreisbach. 2012. Decaid, the Decayed Wood Advisor for Managing Snags, Partially Dead Trees, and Down Wood for Biodiversity in Forests of Washington and Oregon. Version 2.20. USDA Forest Service and US Fish and Wildlife Service, Portland, OR. http://www.fs.fed.us/r6/nr/wildlife/decaid/index.shtml

30 Carey, A. B., and M. L. Johnson. 1995. Small Mammals in Managed, Naturally Young, and Old-Growth Forests. *Ecological Applications* 5(2):336-352.

31 Carey, A. B., J. Kershner, B. Biswell, and L. D. de Toledo. 1999. Ecological Scale and Forest Development: Squirrels, Dietary Fungi, and Vascular Plants in Managed and Unmanaged Forests. *Wildlife Monographs* 142:3-71.

32 Bull, E. L., C. G. Parks, and T. R. Torgersen. 1997. Trees and Logs Important to Wildlife in the Interior Columbia River Basin. GTR-PNW-391, USDA Forest Service, Pacific Northwest Research Station, Portland, OR. http://www.treesearch.fs.fed.us/pubs/3051

33 Miller, R., R. Tausch, and W. Waichler. 1997. Old-Growth Juniper and Pinyon Woodlands. Pages 375-384 *in* S. B. Monsen and R. Stevens, editors. *Ecology and management of pinyon-juniper communities within the Interior West.* USDA Forest Service, Rocky Mountain Research Station. RMRS-P-9, Provo, UT.

34 Humes, M. L., J. P. Hayes, and M. W. Collopy. 1999. Bat Activity in Thinned, Unthinned, and Old-Growth Forests in Western Oregon. *The Journal of Wildlife Management* 63(2):553-561. http://www.jstor.org/stable/3802642

35 Waichler, W. S., R. F. Miller, and P. S. Doescher. 2001. Community Characteristics of Old-Growth Western Juniper Woodlands. *Journal of Range Management* 54(5):518-527. http://www.jstor.org/stable/4003580

36 Miller, R. 2001. Managing Western Juniper for Wildlife. MISC0286, Washington State University Extension, Pullman, WA. www.woodlandfishandwildlife.org/pubs/juniper.pdf

37 Elliot, W. J. 2010. Effects of Forest Biomass Use on Watershed Processes in the Western United States. *Western Journal of Applied Forestry* 25(1):12-17. http://www.ingentaconnect.com/content/saf/wjaf/2010/00000025/00000001/art00003

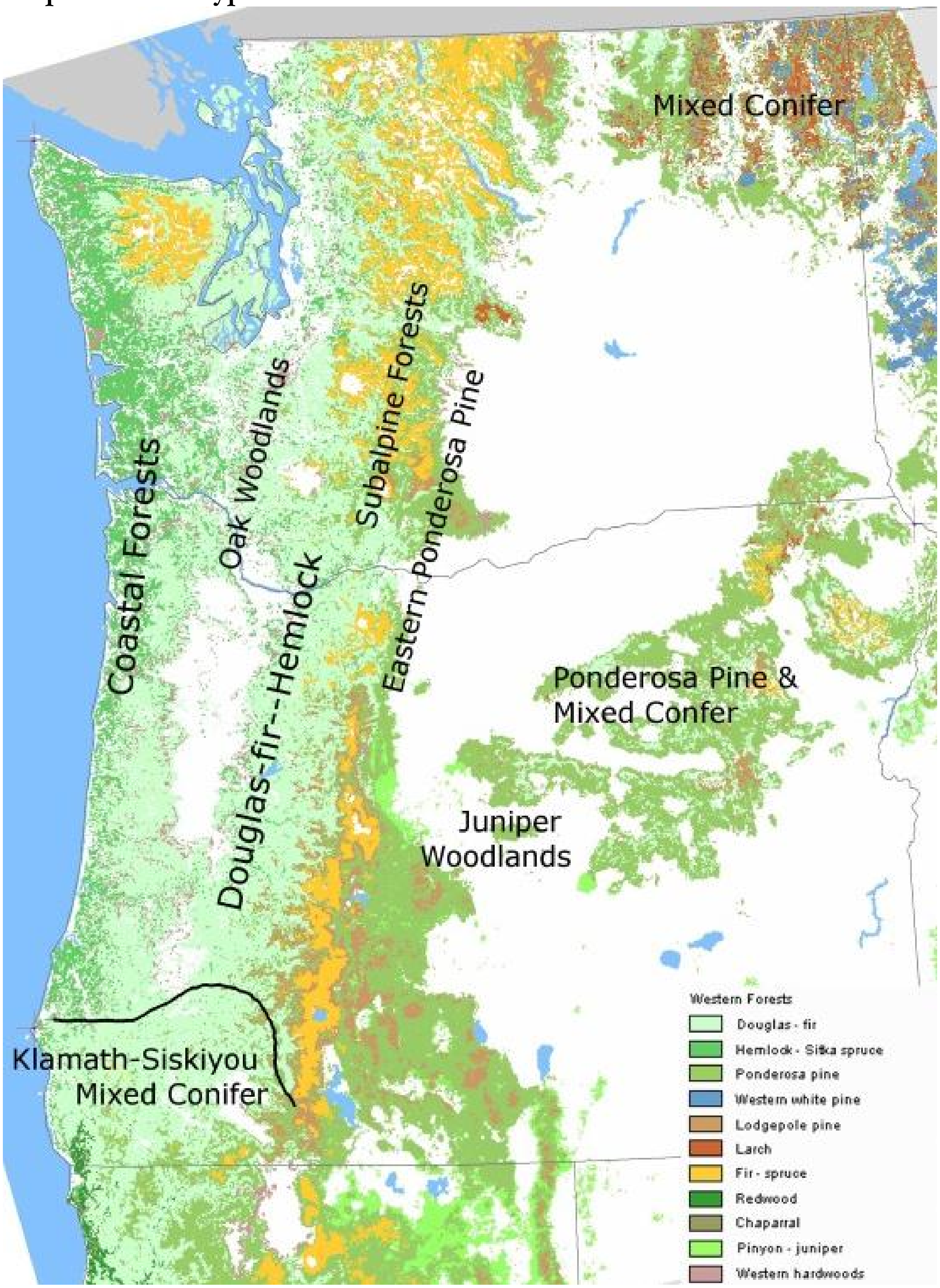
38 Everest, F. H., and G. H. Reeves. 2007. Riparian and Aquatic Habitats of the Pacific Northwest and Southeast Alaska: Ecology, Management History, and Potential Management Strategies. GTR-PNW-692, USDA Forest Service, Pacific Northwest Research Station, Portland, OR.

39 Brown, R. T., J. K. Agee, and J. F. Franklin. 2004. Forest Restoration and Fire: Principles in the Context of Place. *Conservation Biology* 18(4):903-912. http://dx.doi.org/10.1111/j.1523-1739.2004.521_1.x

40 Converse, S. J., G. C. White, K. L. Farris, and S. Zack. 2006. Small Mammals and Forest Fuel Reduction: National-Scale Responses to Fire and Fire Surrogates. *Ecological Applications* 16(5):1717-1729.

41 Verschuyl, J., S. Riffell, D. Miller, and T. B. Wigley. 2011. Biodiversity Response to Intensive Biomass Production from Forest Thinning in North American Forests – a Meta-Analysis. *Forest Ecology and Management* 261(2):221-232. http://www.sciencedirect.com/science/article/pii/S0378112710006110

Map of Forest Types



Map from: US Geological Survey and US Forest Service. 2000. Forest cover types *in* National Atlas of the United States. Reston, VA

Forest Types

Coastal Forests: Coastal forests thrive on the west side of the Coast Range from the Olympic Mountains south to, but excluding, the Klamath Mountains. This area includes Sitka spruce, red cedar–hemlock, and hemlock–silver fir forests. The disturbance regime is mostly small-scale windthrow or other gap mortality processes (though there are occasional widespread intense windstorms), with very few fires. http://www.natureserve.org/explorer/servlet/NatureServe?searchSystemUid=ELEMENT_GLOBAL.2.722833

Douglas-Fir–Hemlock Forests of the Coast Range and the Western Cascades: A large swath of the eastside of the Coast Range and west side of the Cascades is covered by productive Douglas-fir and Douglas-fir–hemlock forests. The climate is relatively mild and moist to wet. In the past, fires were typically mixed-severity or moderate-severity, with natural return intervals of a few hundred to several hundred years. Occasional stand-replacing fires were an important element in the natural fire regime.
http://www.natureserve.org/explorer/servlet/NatureServe?searchSystemUid=ELEMENT_GLOBAL.2.738967

Subalpine and Spruce-Fir Forests: The highest elevation forests in the region are dominated by a mix of high-elevation conifers, mainly subalpine fir, Engelmann spruce, mountain hemlock, and whitebark pine. Disturbances include occasional blowdown, insect outbreaks (30 to 50 years), mixed-severity fire, and stand-replacing fire (every 150 to 500 years).
http://www.natureserve.org/explorer/servlet/NatureServe?searchSystemUid=ELEMENT_GLOBAL.2.722843

Klamath-Siskiyou Mixed Conifer Forests: There is a wide range of forest communities in this area, with many stands dominated by varying mixtures of Douglas-fir and ponderosa, Jeffrey, white, and sugar pines. Fire is a major disturbance process in these forests, with fire-return intervals varying with topographic position, aspect, elevation, and species mix from low to mixed severity.
http://www.natureserve.org/explorer/servlet/NatureServe?searchSystemUid=ELEMENT_GLOBAL.2.722764

East Cascades and Okanogan Highlands Mixed Conifer Forests: This forest type is similar to the mixed conifer described for the Klamath-Siskiyou mixed conifer forest. The species mix includes Douglas-fir, grand fir, hemlock, cedar, and lodgepole

pine. Typically, stand-replacement fire-return intervals are 150 to 500 years, with moderate-severity fire-return intervals of 50 to 100 years.
http://www.natureserve.org/explorer/servlet/NatureServe?searchSystemUid=ELEMENT_GLOBAL.2.740349

Juniper Woodlands and Savannas: These woodlands are composed of two very different types. There are old-growth junipers woodlands with trees and stands often more than 1,000 years old. Old trees in these stands are fairly well-spaced with rounded crowns. There are also large areas where juniper has expanded into sagebrush steppe and bunchgrass-dominated areas, with young, pointed-crowned trees growing closely together. Fire exclusion and removal of fine fuels by grazing livestock have reduced fire frequency and allowed juniper seedlings to expand into the shrub-steppe and grasslands.
http://www.natureserve.org/explorer/servlet/NatureServe?searchSystemUid=ELEMENT_GLOBAL.2.740155

Eastern Ponderosa Pine Forests: Ponderosa pine is the dominant conifer in these eastside forests, though Douglas-fir is also present. Historically, stands were open, with a frequent fire regime (3 to 7 years).
http://www.natureserve.org/explorer/servlet/NatureServe?searchSystemUid=ELEMENT_GLOBAL.2.754393

Oak Woodlands: This forest type occurs primarily in the Puget Trough and Willamette Valley, but trickles down into the Klamath ecoregion and into California. The vegetation ranges from savanna and woodland to forest dominated by deciduous broadleaf trees, mostly Oregon white oak. Codominance by Douglas-fir is common, and Willamette and Puget Sound variants of ponderosa pine are important in some stands. In the south, common associates also include California black oak and madrone. This system is associated with dry, predominantly low-elevation sites and/or sites that experienced frequent pre-settlement fires.
http://www.natureserve.org/explorer/servlet/NatureServe?searchSystemUid=ELEMENT_GLOBAL.2.722822