AN ABSTRACT OF THE THESIS OF

Kristina N. Kline for the degree of Master of Science in Forest Ecosystems and Society presented on May 11, 2016.

Title: A Multi-Spatial Scale Economic Analysis of the Impacts of Bear Damage to Douglas-fir on Private Timberlands in the Pacific Northwest

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Jimmy D. Taylor Anita T. Morzillo

Black bears (*Ursus americanus*) in western Oregon and Washington peel bark from conifers in early spring to forage on the sugar-rich phloem and cambial tissues. This provides important energy at a time when similarly attractive forage is scarce. Bears often damage Douglas-fir (*Pseudotsuga menziesii*) trees in stands that are intensively managed for timber production, as management activities including thinning and fertilization increase productivity. Fully girdled trees result in a complete economic loss while partial girdling reduces survival rates as well as merchantable volume. Previous studies on economic impacts have assessed only those losses to fully girdled trees, but not additional impacts from wounded trees. We surveyed four severely damaged stands to assess economic impacts at the stand-level, and surveyed 122 randomly selected vulnerable stands to assess economic impacts at the landscape-level. Two damage scenarios were considered. Scenario one accounted for the additional mortality and volume losses from partially girdled trees, whereas scenario two assumed that all bear-peeled trees resulted in a complete loss. Stand volumes were estimated using the Forest Vegetation Simulator growth and yield model. Economic losses were estimated using the Fuel Reduction

Cost Simulator and present value models. At the stand-level, economic losses to severe bear damage in scenario one ranged from $6,100 to $24,500. Economic losses in scenario two ranged from $19,500 to $74,700. Undamaged stands were valued from $43K-$250K. At the landscape-level, economic losses to vulnerable stands in scenario one ranged from $44,500 to $726,000. Economic losses in scenario two ranged from $169,000 to $2.8M. Undamaged stands were valued from $48M-$780.5M. Root disease was a more prevalent damage agent than black bear damage. The majority of bear damage observed (92%) was older (>2 yrs) and existed at a low frequency (1.5 bear damaged trees/ha) and severity across the landscape. Our results suggest that bear damage management over the last two decades may have reached a level of efficiency at reducing damage, and if continued, bear damage may remain at low levels across the landscape. On-the-ground monitoring of the status of bear damage frequency and severity across western Oregon and Washington at both the stand and landscape levels will provide an understanding of these changes over time as a result of management decisions.

A Multi-Spatial Scale Economic Analysis of the Impacts of Bear Damage to Douglas-fir on Private Timberlands in the Pacific Northwest

by

Kristina N. Kline

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APPROVED:

Co-Major Professor, representing Forest Ecosystems and Society

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Co-Major Professor, representing Forest Ecosystems and Society

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Head of the Department of Forest Ecosystems and Society

Dean of the Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Kristina N. Kline, Author

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CHAPTER 1: INTRODUCTION

Damage to conifers as a result of bear (*Ursus spp.*) foraging was first reported in the United States in the early 1900's (Pierson 1966). Bear species attributed to foraging damage vary geographically. On the Kenai Peninsula of Alaska, in northern Maine, northern California, western Oregon, western Washington, British Columbia, and northwestern Montana, damage is attributed to the American black bear (*Ursus americanus;* Childs and Worthington 1955, Glover 1955, Landenberger 1960, Lutz 1951, Mason and Adams 1989, Pierson 1966, Sullivan 1993, Zeedyk 1957). In southeast Alaska and British Columbia, damage is attributed to brown bears (*Ursus arctos;* Hennon et al. 1990, Sullivan 1993). Outside of North America, conifer foraging damage also occurs in Japan, and is attributed to the Japanese black bear (*Ursus thibetanus japonicas*; Watanabe 1977).

Particular conifer species affected by foraging damage also varies geographically. In northern Maine, balsam fir (*Abies balsamea*), red spruce (*Picea rubens*), and northern white cedar (*Thuja occidentalis*) are damaged (Zeedyk 1957). On the Kenai Peninsula of Alaska, white spruce (*Picea glauca*) is the most common species foraged (Lutz 1951). Damage occurs on redwoods (*Sequoia sempervirens*) in northern California (Glover 1955, Landenberger 1960) and on Douglas-fir (*Pseudotsuga menziesii*) in western Oregon (Childs and Worthington 1955) and Washington (Pierson 1966). In the Kootenai National Forest of Montana, damage has been observed on lodgepole pine (*Pinus contorta*), Engelmann spruce (*Picea engelmannii*) and western larch (*Larix occidentalis,* Mason and Adams 1989, Schmidt 1989). Additionally, damage has been observed on western white pine (*Pinus monticola*) and western redcedar (*Thuja plicata*) in British Columbia (Molnar and McMinn 1960, Sullivan 1993), and on 17 species of conifers in Japan (Watanabe 1977). Although bear damage has been reported since the early 1900's, it was not until the 1940's, with the increase in intensive forest management, that bear damage was identified as a problem for timber production (Pierson 1966).

Why Do Bears Damage Trees?

There are two types of damage to trees caused by bears: marking damage and foraging damage. It has been hypothesized that marking may be a method of communication, and is used to delineate territories or defended areas (Pierson 1966). A marked tree is often the result of a few swipes of the bark with the claws or teeth (Pierson 1966). A foraged tree has the bark stripped away and the exposed tissues are scraped and consumed (Pierson 1966). Bears peel away bark with their claws and scrape the phloem and cambial tissues (hereafter vascular tissues) with their incisors. It is suspected that peeling is a learned behavior passed from sow to cub (Schmidt and Gourley 1992). Bears exhibit this behavior in early spring at a time that coincides with the start of sap flow in the phloem, new cambial activity, and a relatively low abundance of similarly attractive forage items (Collins et al. 2002). In spring, the phloem may contain up to 3.5% soluble sugars (Kimball et al. 1998a), providing fructose, sucrose and glucose (Kimball et al. 1998b, Radwan 1969), which help bears meet their energy needs following winter dormancy (Ziegltrum 2004). In Washington, a study of the stomach contents of black bears showed that wood fibers constituted an average of 15% of their diet for the year (Poelker and Hartwell 1973), revealing the importance of this seasonal source of energy.

Bears may use the presence of carbohydrates as chemical cues for the energetic value of vascular tissues (Kimball et al. 1998a). As a result, they seem to exhibit a preference for light to moderately stocked stands that have been thinned or fertilized (Mason and Adams 1989, Nelson

1989). These practices increase growth and volume, thereby increasing sugar concentrations in vascular tissues (Kimball et al. 1998b). Management activities that increase productivity, coupled with naturally higher sugar concentrations in the spring (Radwan 1969), make certain stands vastly appealing to bears.

Characteristics of Damage

Foraging damage by bears can be identified by several features. On white spruce in Alaska, rapidly growing medium-sized trees 25-45 cm in diameter with smooth, thin bark were more commonly damaged (Lutz 1951). On Alaska yellow cedar (*Chamaecyparis nootkatensis*) scars from damage generally faced upslope and were most common on the best-drained, most productive sites (Hennon et al. 1990). In the redwoods of California, damage ranged from 19-36 trees/ha and was more severe in lightly stocked stands aged 10-30 years (Glover 1955). In Japan, damage tended to be more frequent among trees 15-30 years old and larger than 20 cm diameter (Watanabe 1977). In British Columbia, the most severely damaged western red cedars were in diameter class 12-22 cm, and ranged in age from 30-33 years (Sullivan 1993).

In western Oregon and Washington, damage primarily occurs among Douglas-fir 12-25 cm in diameter (Schmidt and Gourley 1992), ranging in age from 15-40 years (Flowers 1987). Trees are peeled at the base, as well as further up the bole. On larger trees, bark is thinner in the upper third of the tree, so peeling is easier for smaller, younger bears (Schmidt and Gourley 1992). Moreover, secondary metabolites are less concentrated in the upper one-third of the tree (Kimball et al. 1998c). In some cases, bears will remove all of the bark from trees that are nearly 15 meters tall, climbing and peeling as high as the tree can support their body weight (Giusti 1990), and a single foraging bear can peel the bark of several trees per day (Hartwell and

Johnson 1988). However, bears appear to be selective in the trees that they peel. Not all stands are selected and one tree in a stand may be stripped while its neighbor is left alone or is only marginally peeled (Kimball et al. 1998a).

Impacts of Damage

Bear damage occurs at varying severities, which result in a range of impacts. A fully girdled tree will eventually die. Partial girdling reduces wood quality and provides opportunities for insect infestations (Kanaskie et al. 1990), fungal decay, and windfall (Witmer et al. 2000), thereby reducing the likelihood of survival to harvest age. Larger wounds are more likely to become infected, and even minor decay in the lower bole can be significant as this is where the majority of the tree's wood volume and value is concentrated (Schmidt and Gourley 1992).

Damage is usually distributed in random pockets across the landscape, which leave a patchy network of openings in the canopy (Schmidt and Gourley 1992). Brush often invades and occupies these openings, inhibiting tree regeneration (Schmidt and Gourley 1992). Consequently, surrounding trees begin to grow more vigorously with the greater availability of sunlight and space, and therefore become more susceptible to future damage by bears.

The loss of bear-killed trees and subsequent changes to the homogenous plantation structure desired by forest managers are unfavorable for timber production. Yet, the changes created by bears can provide some benefits to the overall health of a forest ecosystem (Spies et al. 1990, Takahashi and Takahashi 2013). For example, bear-killed trees leave behind gaps in the canopy and snags. Canopy gaps and snags add horizontal and vertical complexity, with snags providing important foraging and nesting habitat for cavity-dependent birds and small mammals. However, when bear damage exists on private land where timber production is the primary goal, losses due to bear damage become a management issue.

To date, estimates of economic loss from black bear damage have been inferred (Nolte and Dykzeul 2002), but an in-depth, on-the-ground analysis that evaluates the magnitude of losses at multiple spatial scales has not yet been conducted (Taylor et al. 2014). Bear damage estimates at various spatial scales are important because the decisions made regarding management strategies will vary based on the scale of damage observed (Engeman 2002). For example, average bear damage throughout a region could be inconsequential resulting in little need for a large-scale damage control effort (Engeman 2002). Conversely, an individual landowner within a region could experience severe damage, resulting in the need to identify the most cost-effective damage management strategy (Engeman 2002).

Damage summaries for western Oregon historically have been based on annual aerial damage surveys (Kanaskie et al. 2001, 1990). With the use of annual aerial survey data, Nolte and Dykzeul (2002) estimated an annual timber loss as a result of bear damage at approximately $11.5 million across 25,900 hectares in western Oregon. Although informative, this estimate relied on broad assumptions of stocking densities, value per tree, and average tree age to obtain estimates. Additionally, the techniques used accounted for economic loss associated with only trees completely lost to bear damage, and did not assess the additional economic impacts of trees wounded from bear damage, or potential compensatory growth in undamaged residual trees.

Quantifying Bear Damage

The US Forest Service (USFS) and Oregon Department of Forestry (ODF) have conducted aerial surveys documenting bear-caused tree mortality in Oregon annually since 1987

(Kanaskie et al. 1990). Between 1998 and 2000, aerial surveys estimated approximately 12,000 hectares as having recent tree mortality from bears. However, the ground survey that followed confirmed approximately 7,800 of those 12,000 hectares as actually having mortality or tree damage from bears (Kanaskie et al. 2001). Thus, ground verification revealed multiple shortcomings of the aerial surveys, including imprecision due to mountainous terrain. The location of polygons drawn by observers could be misaligned spatially up to 1.2 kilometers from true damage locations (Kanaskie et al. 2001). Additionally, identification of bear damage was based only on the crowns of trees exhibiting changes in foliar color. As a result, the surveys did not account for trees that were damaged but not killed. The most recent ground-verification of aerial surveys found that two wounded trees existed for every fully girdled tree (Kanaskie et al. 2001). Limitations with aerial survey data also included misclassification with other mortality agents such as root disease. It was found that 63% of areas designated as bear damage in the 2000 aerial surveys were in fact damage caused by root disease (Kanaskie et al. 2001).

Bear Damage Management

Currently, both lethal and non-lethal methods for managing bear damage throughout Oregon and Washington are in practice. Lethal control includes hot-spot depredation hunts approved by the Oregon Department of Fish and Wildlife (ODFW) and the Washington Department of Fish and Wildlife (WDFW), and public harvest. However, public harvest to aide in bear damage management often removes an inaccurate and biased demographic of bears. A study conducted in Washington (Stewart et al. 2002) found that female bears cause the majority of damage, yet male bears were more frequently removed through public harvest (ODFW 2012).

Non-lethal approaches to reduce bear damage include both silvicultural practices and supplemental feeding. Ziegltrum (2004) showed that supplemental feeding initially reduced conifer damage in western Washington, and damage increased by a factor of nearly seven when feeding stations were removed. Moreover, supplemental feeding was found to be a cost effective tool (Ziegltrum 2006). While effective, like other supplemental feeding programs for wildlife, potential issues exist. For example, supplemental feeding tends to concentrate wildlife into small areas (Fersterer et al. 2001, ODFW 2012). These concentrations can lead to an increased risk of disease transmission (Dunkley and Cattet 2003, Schmitt et al. 1997, Williams et al. 2002), an increased rate of illegal harvest (Dunkley and Cattet 2003), habitat degradation in surrounding areas (Doenier et al. 1997, Cooper and Ginnett 2000), and dependence on feeding stations (Doman and Rasmussen 1944, Schmidt and Hoi 2002). Non-lethal methods such as repellents, fences and scare devices are impractical for protecting timber stands, as stands generally cover large expanses of land and because these methods could disturb non-target wildlife species (Nolte 2003). The option to relocate nuisance bears is also impractical due to their exceptional homing behavior (Landriault et al. 2009), and because relocated animals have high mortality rates. It is also difficult to locate sites where resource managers want additional bears (Nolte 2003).

Silvicultural practices can be effective means for damage management. For example, Kimball et al. (1998c) found that black bears were four times more likely to forage unpruned versus pruned Douglas-fir, as pruning results in reduced growth and decreased carbohydrate content of vascular tissue. Others suggest cultivating trees at higher stand densities (Nolte et al. 1998), managing for greater species diversity (Schmidt and Gourley 1992), or using wider initial spacing to delay thinning until damage subsides (Barnes and Engeman 1995, Schmidt and Gourley 1992).

Study Objectives

Given that there are both lethal and non-lethal methods to manage bear damage, and various costs associated with each method, it is important to accurately estimate damage frequency and economic loss. Accurate estimates of damage frequency and severity at the landscape level will allow for a better understanding of the status of bear damage across the landscape. With this knowledge, the effectiveness of current management methods can then be assessed. Accurate estimates of economic loss based on ground-verified sampling will allow for a better understanding of the most cost-effective means to continue managing bear damage on private lands across spatial scales.

Our research objectives were to: 1) explore the impacts of severe bear damage at the stand level for trees that are both wounded and killed, 2) validate the black bear damage portion of the USFS/ODF aerial forest health surveys through ground verification, and 3) use validated damage frequency and severity data to inform economic models and estimate economic loss at the landscape level.

In Chapter 2, we use on-the-ground damage frequency and severity data coupled with the Forest Vegetation Simulator (FVS) growth model (Dixon 2002) and economic models to address Objective 1. In Chapter 3, we use annual aerial survey data, along with stand-level data, high-resolution aerial imagery, on-the-ground damage frequency and severity data, and the FVS growth model to address Objectives 2 and 3. We conclude with management implications and future research needs in the Chapter 4.

LITERATURE CITED

Barnes, V.G. and R.M. Engeman. 1995. Black bear damage to lodgepole pine in central Oregon. Northwestern Naturalist 76:127-129.

Collins, G.H., R.B. Wielgus, and G.M. Koehler. 2002. Effects of sex and age of American black bear on conifer damage and control. Ursus 13:231-236.

Childs, T.W. and N.P. Worthington. 1955. Bear damage to young Douglas-fir. USDA. Pacific Northwest Forest & Range Exp. Stn. Res. Note No. 113, Portland, OR. 4 p.

Cooper, S.M., and T.F. Ginnett. 2000. Potential effects of supplemental feeding of deer on nest predation. Wildlife Society Bulletin 28:660-666.

Dixon, G.E. 2002. Essential FVS: A users guide to the forest vegetation simulator. USDA Forest Service, Internal Report, Forest Management Service Center, Fort Collins, CO. 246 p.

Doenier, P.B., G.D. DelGiudice, and M.R. Riggs. 1997. Effects of winter supplemental feeding on browse consumption by white-tailed deer. Wildlife Society Bulletin 25:235-243.

Doman, E.R., and D.I. Rasmussen. 1944. Supplemental winter feeding of mule deer in northern Utah. Journal of Wildlife Management 8:317-338.

Dunkley, L., and M.R.L. Cattet. 2003. A comprehensive review of the ecological and human social effects of artificial feeding and baiting of wildlife. Canadian Cooperative Wildlife Health Centre. University of Saskatchewan, Saskatoon, Canada. 70 p.

Engeman, R.M. 2002. Economic considerations of damage assessment. In: Clark, L., J. Hone, J.A. Shivik, R.A. Watkins, K.C. VerCauteren, and J.K. Yoder, eds. Human conflicts with wildlife: economic considerations. Proceedings, 3rd National wildlife research center special symposium; 2000 August 1-3; Fort Collins, CO. U.S. Department of Agriculture, Wildlife Services, National Wildlife Research Center: 36-41.

Fersterer, P., D.L. Nolte, G.J. Ziegltrum, and H. Gossow. 2001. Effect of feeding stations on the home ranges of American black bears in western Washington. Ursus 12:51-54.

Flowers, R.H. 1987. Supplemental feeding of black bear in tree-damaged areas of western Washington. In: Baumgartner, D.M., R.L. Mahoney, J. Evans, J. Caslick, and D.W. Breuer, eds. Animal damage management in Pacific Northwest forestry. Cooperative Extension, Washington State University Press, Pullman, WA. 147-148.

Giusti, G. 1990. Black bear feeding on second growth redwoods: a critical assessment. Proceedings of the Vertebrate Pest Conference. 14:214-217.

Glover, F.A. 1955. Black bear damage to redwood reproduction. Journal of Wildlife Management 19:437-443.

Hartwell, H.D., and L.E. Johnson. 1987. Silvicultural effects of basal girdling by black bear in a young Douglas-fir plantation. Washington State Department of Natural Resources Technical Report. 31 p.

Hennon, P.E., E.M. Hansen, and C.G. Shaw III. 1990. Causes of basal scars on Chamaecyparis nootkatensis in Southeast Alaska. Northwest Science 64:45-54.

Kanaskie, A., M. McWilliams, D. Overhulser, and R. Christian. 2001. Black bear damage to forest trees in northwest Oregon, aerial and ground surveys 2000. Oregon Department of Forestry, Salem, OR. 29 p.

Kanaskie, A., G. Irwin, J. Chetock, and D. Overhulser. 1990. Black bear damage to forest trees in northwest Oregon 1988-1989. Pest Management Report 90-1. Oregon Department of Forestry, Salem, OR. 37 p.

Kimball, B.A., D.L. Nolte, R.M. Engeman, J.J. Johnston, and F.R. Stermitz. 1998a. Chemically mediated foraging preference of black bear (Ursus americanus). Journal of Mammalogy 79:448-456.

Kimball, B.A., E.C. Turnblom, D.L. Nolte, D.L. Griffin, and R.M. Engeman. 1998b. Effects of thinning and nitrogen fertilization on sugars and terpenes in Douglas-fir vascular tissues: implications for black bear foraging. Forest Science 44:599-602.

Kimball, B.A., D.L. Nolte, D.L. Griffin, S.M. Dutton, and S. Ferguson. 1998c. Impacts of live canopy pruning on the chemical constituents of Douglas-fir vascular tissues: implications for black bear foraging. Forest Ecology and Management 109:51-56.

Landenberger, F. 1960. Bear damage to young-growth trees. California Redwood Association Research Project No. 1. 36123, International Report H. San Francisco, CA. 4 p.

Landriault, L.J., G. S. Brown, J. Hamr, and F.F. Mallory. 2009. Age, sex and relocation distance as predictors of return for relocated nuisance black bears *Ursus americanus* in Ontario, Canada. Wildlife Biology 15:155-164.

Lutz, H.J. 1951. Damage to trees by black bears in Alaska. Journal of Forestry 49:522-552.

Mason, A.C. and D.L. Adams. 1989. Black bear damage to thinned stands in northwest Montana. Western Journal of Applied Forestry 4:10-13.

Molnar, A.C., and R.G. McMinn. 1960. The origin of basal scars in the B.C. interior white pine type. Forestry Chronicles 36:50-60.

Nelson, E.E. 1989. Bears prefer urea fertilized trees. Western Journal of Applied Forestry 4:13-15.

Nolte, D.L. 2003. Bears prefer trees in the spring. USDA National Wildlife Research Center-Staff Publications. Paper 263:8-9.

Nolte, D.L., Dykzeul, M. 2002. Wildlife impacts on forest resources. In: Clark, L., J. Hone, J.A. Shivik, R.A. Watkins, K.C. VerCauteren, and J.K. Yoder, eds. Human conflicts with wildlife: economic considerations. Proceedings, 3rd National wildlife research center special symposium; 2000 August 1-3; Fort Collins, CO. U.S. Department of Agriculture, Wildlife Services, National Wildlife Research Center:163-168.

Nolte, D.L., B.A. Kimball, and G.J. Ziegltrum. 1998. The impact of timber management on the phytochemicals associated with black bear damage. Proceedings of the Vertebrate Pest Conference. 18:111-117.

Oregon Department of Fish and Wildlife (ODFW). 2012. Oregon black bear management plan. Oregon Department of Fish and Wildlife, Portland, Oregon. 61 p.

Pierson, D.J. 1966. Washington's black bear problem. Western Asscociation of Game and Fish Commissioners. 46: 96-100.

Poelker, R.J., and H.D. Hartwell. 1973. Black bear of Washington. Washington State Game Department. Biology Bulletin 14.180 p.

Radwan, M.A. 1969. Chemical composition of vascular tissue of four tree species in relation to feeding by black bear. Forest Science 15:11-16.

Schmidt, K.T., and H. Hoi. 2002. Supplemental feeding reduces natural selection in juvenile red deer. Ecography 25:265-272.

Schmidt, W.C. 1989. Management of young Larix occidentalis forests in the northern Rocky Mountains of the United States. Int. Union For. Res. Organ. Working Party S 1.05-03:246- 253.

Schmidt, W., and M. Gourley. 1992. Black bear. In: H. Black, editor. Silvicultural approaches to animal damage management in Pacific Northwest forests. USDA Forest Service General Technical Report PNW-GTR-287. Portland, Oregon. 309-311.

Schmitt, S.M., S.D. Fitzgerald, T.M. Cooley, C.S. Bruning-Fann, L. Sullivan, D. Berry, T. Carlson, R.B. Minnis, J.B. Payeur, and J. Sikarskie. 1997. Bovine tuberculosis in free-ranging white-tailed deer from Michigan. Journal of Wildlife Diseases 33:749-758.

Spies, T.A., J.F. Franklin, and M. Klopsch. 1990. Canopy gaps in Douglas-fir forests of the Cascade Mountains. Canadian Journal of Forest Research 20:649-658.

Stewart, W.B., G.W. Witmer, G.M. Koehler, and M. Norton. 2002. Incisor analysis technique to predict the gender of black bears damaging trees. International Biodeterioration and Biodegradation 49:209-212.

Sullivan, T.P. 1993. Feeding damage by bears in managed forests of western hemlock-western redcedar in midcoastal British Columbia. Canadian Journal of Forest Research 23:49-54.

Takahashi, K. and K. Takahashi. 2013. Spatial distribution and size of small canopy gaps created by Japanese black bears: estimating gap size using dropped branch measurements. BMC Ecology 13:1-12.

Taylor, J., Morzillo, A., and A. Anderson. 2014. Estimating the total economic impact of black bear peeling in western Oregon using GIS and REMI. Vertebrate Pest Conference 26:419-422.

Watanabe, H. 1977. Damage to conifers by the Japanese black bear. International Conference of Bear Research and Management. International Union for Conservation of Nature and Natural Resources. Morges, Switzerland. 3:67-70.

Williams, E.S., M.W. Miller, T.J. Kreeger, R.H. Kahn, and E.T. Thorne. 2002. Chronic wasting disease in deer and elk: a review with recommendations for management. Journal of Wildlife Management 66:551-567.

Witmer, G., D. Nolte, and W. Stewart. 2000. Integrated pest management of black bear reforestation damage. USDA National Wildlife Research Center-Staff Publications. Paper 824:228-235.

Zeedyk, W.D. 1957. Why do bears girdle balsam fir in Maine? Journal of Forestry 55:731-732.

Ziegltrum, G.J. 2006. Cost-effectiveness of the black bear supplemental feeding program in western Washington. Wildlife Society Bulletin 34:375-379.

Ziegltrum, G.J. 2004. Efficacy of black bear supplemental feeding to reduce conifer damage in western Washington. Journal of Wildlife Management 68:470-474.

CHAPTER 2: STAND-LEVEL ECONOMIC IMPACTS OF BEAR-DAMAGE TO DOUGLAS-FIR: A CASE STUDY IN OREGON AND WASHINGTON

Kristina N. Kline, *Department of Forest Ecosystems and Society, Oregon State University, Corvallis, Oregon 97331*

Jimmy D. Taylor, *USDA APHIS, Wildlife Services, National Wildlife Research Center, Corvallis, Oregon 97331*

Anita T. Morzillo, *Department of Natural Resources and the Environment, University of Connecticut, Storrs, Connecticut 06269*

Doug A. Maguire, *Department of Forest Engineering, Resources and Management, Oregon State University, Corvallis, OR 97330*

As opportunistic omnivores, black bears (*Ursus americanus*) peel the bark from conifers in early spring to forage on phloem and cambial tissues (hereafter vascular tissues). These tissues provide energy-rich soluble sugars for bears at a time of the year when similarly attractive energy sources such as salmonberry (*Rubus spectabilis*), red huckleberry (*Vaccinium parvifolium*), and blackberry (*Rubus ursinus*) are scarce. The presence of up to 3.5% soluble sugars in the phloem of trees at this time of year (Kimball et al. 1998a) provide fructose, sucrose and glucose (Kimball et al. 1998b, Radwan 1969), which help bears meet their energy needs following winter dormancy (Ziegltrum 2004). Bears peel away bark with their claws and scrape the vascular tissues with their incisors. It is suspected that peeling is a learned behavior passed from sow to cub (Schmidt and Gourley 1992). Bear foraging damage was first reported in the early 1900's (Pierson 1966). However, it was not until the increase in intensive forest management in the 1940's, that bear peeling was identified as a problem for timber production (Pierson 1966).

In western Oregon and Washington, bears typically damage Douglas-fir (*Pseudotsuga menziesii*) trees in stands that are intensively managed for timber production (Schmidt and Gourley 1992). Management activities such as thinning and fertilization increase tree growth and volume, which in turn increases sugar concentrations in vascular tissues (Kimball et al. 1998b). This makes trees more susceptible to peeling by bears. Peeling occurs at varying severities, which result in a variety of damage impacts. When a tree is fully girdled, with the entire circumference of the trunk peeled, the tree will eventually die. A tree that is partially girdled, or wounded, becomes more susceptible to insect infestations, fungal decay (Kanaskie et al. 1990), and windfall (Witmer et al. 2000), thereby reducing the likelihood of surviving to harvest age. Miller et al. (2007) evaluated survival of bear damaged trees in Washington, and reported mortality rates for wounded trees at 17% over a 16-year period. A more recent study of simulated bole damage in Capitol Forest, Washington reported mortality rates of between 5-28% for wounded trees, with mortality rates dependent on the percentage of the bole circumference damaged (Harrington et al. 2015). Additionally, wounded trees that survive to harvest age may experience a reduction in the volume of merchantable timber produced (Lowell et al. 2010, Pierson 1966).

Currently, management to reduce bear damage includes both lethal and non-lethal techniques. Non-lethal approaches include silvicultural practices and supplemental feeding, whereas lethal control includes hot-spot depredation hunts approved by the Oregon Department of Fish and Wildlife (ODFW) and Washington Department of Fish and Wildlife (WDFW). Both Oregon and Washington also provide sport-hunting opportunities for black bears during spring and fall seasons. Although sport-hunting and bear damage management is currently maintaining bear damage at reasonable levels overall, stands still exist with severe damage regardless of bear management efforts.

Just two studies have quantified volume losses due to bear damage. In a survey of bear-damaged trees sent to mill in Washington, Lowell et al. (2010) found a 6.4% loss in volume on average for trees wounded as a result of bear damage. Additionally, Lowell et al. (2010) found the value of trees wounded from bear damage was 5% less than undamaged trees. In another study, Pierson (1966) reported average volume losses from a survey of 100 Douglas-fir trees with varying damage severities. Trees with bark removed from less than 50% of the trunk circumference lost an average of 7% merchantable volume, while trees with bark removed from more than 50% of the trunk circumference lost an average of 10% merchantable volume (Pierson 1966).

Both studies that quantified volume lost were focused on the scale of individual trees. Previous studies on economic impacts of bear damage focused at the regional level and accounted only for trees completely lost to damage (Nolte and Dykzeul 2002). Thus, there remains a key gap in the knowledge regarding volume losses to bear damage over larger areas (i.e., at the stand-level), as well as the additional economic impacts of wounded trees and the possibility of compensatory growth on adjacent unwounded trees. To fill in these knowledge gaps, our objective was to estimate stand-level volume losses and economic losses from severe bear damage. We further improved upon existing loss estimates in three ways: 1) including the additional impacts of wounded trees, 2) accounting for loss based on the severity of individual tree damage, and 3) accounting for potential growth release on undamaged trees.

STUDY AREA

The study area consisted of four intensively managed Douglas-fir stands on private land within the Coast Range and the western Cascades of Oregon and Washington (Figure 2.1, Table 2.1). The two Washington sites were located nine miles southeast of Morton and eight miles southwest of Oakville. The Coast Range site (CR-WA) was on a southwest-facing slope with an ephemeral drainage on the southwest edge and was located approximately one kilometer south of the Lower Chehalis State Forest. The western Cascades site (WC-WA) was on a benching north-facing slope just above Riff Lake and was located approximately one kilometer north of the Gifford Pinchot National Forest.

The Oregon sites were located three miles east of Lowell and 12 miles southeast of Toledo. The Coast Range site (CR-OR) was situated on a northeast-facing slope with an ephemeral drainage on the northeast edge that fed into Ayers Lake, and was located approximately one kilometer east of the Siuslaw National Forest. The western Cascades site (WC-OR) was on a north-facing slope just above Fall Creek Lake. It had an ephemeral drainage running north through the center of the stand that fed into the lake, and was located approximately one kilometer north of Oregon Department of Forestry (ODF) land.

The western Cascades ecoregion consists of a mild maritime climate with cool, wet winters, and hot, dry summers (Immell et al. 2013). Average annual rainfall ranges from 107-226 cm and average annual snowfall ranges from 18-592 cm occurring above 1,220 meters (ODFW 2006). Stands were dominated by Douglas-fir, with co-dominants including western hemlock (*Tsuga heterophylla*), western redcedar (*Thuja plicata*), and red alder (*Alnus rubra*). Understory vegetation was comprised of salmonberry (*Rubus spectabilis*), vine maple (*Acer circinatum*), swordfern (*Polystichum munitum*), foxglove (*Digitalis purpurea*), Oxalis (*Oxalis oregana*), Oregon grape (*Mahonia nervosa*), snowberry (*Symphoricarpos albus*), devil's club (*Oplopanax horridus*), stinging nettle (*Urtica dioica*), Trillium (*Trillium ovatum*), lady fern (*Athyrium filix-femina*), pacific bleeding heart (*Dicentra formosa*), and miner's lettuce (*Claytonia perfoliata*).

The Coast Range ecoregion consists of a maritime climate, with mild, wet winters and warm, dry summers, (Cushman and McGarigal 2003). Average annual precipitation ranges from 152-249 cm (ODFW 2006). Stands are dominated by Douglas-fir, with co-dominants including western hemlock, western redcedar, and red alder. Understory vegetation was comprised of salmonberry, salal (*Gaultheria shallon*), vine maple, swordfern, foxglove, Oxalis, Oregon grape and snowberry.

The four stands included in this study were even-aged plantations and managed for timber production using intensive silvicultural practices. Stands were chosen based on their close proximity to adjacent public land and availability of information regarding bear damage severity from local foresters. Because it was essential to capture stands that contained high levels of bear damage, we relied on private landowners to inform us of stands on their property that met these criteria.

METHODS

Data collection

Data were collected in June 2015, with each stand sampled at 10% intensity. It is common in forest inventory to use belt transects for measuring timber. When surveying with belt transects, the observer remains on a center-line and makes observations by scanning both directions perpendicular to the center-line. With this method, damage on the side of trees opposite the observer may not be detected. For this reason, we used fixed 0.04 ha circular plots to survey each stand. With fixed circular plots, the full circumference of each tree was observed, ensuring all damage was captured regardless of where damage occurred on the tree.

Plots were evenly spaced throughout the stand in a grid-like arrangement (Figure 2.2). Within each plot, we measured diameter at breast height (dbh) of every tree and height and height-to-live-crown-base of every tenth tree as well as every bear-damaged tree. Trees measured and recorded were limited to those greater than 10 cm dbh. For trees damaged by bear we noted the condition of the crown (red, yellow, green, or no needles), and measured the percentage of the circumference peeled and the age of damage at the base of the tree. Age of damage was determined using a pulaski to peel back the bark surrounding the damaged area and counting the layers of new bark since damage. Additionally, we noted if damage occurred further up the tree bole from a climbing bear. For trees damaged due to root disease, the type of disease was identified and recorded using a pulaski to expose roots and peel back bark. Damage from other animals and unknown sources were also recorded.

Imputation of tree-level attributes

Imputation of values for certain tree-level attributes, such as height, is a necessary component of forest inventory (Garber et al. 2009). Measuring heights of all individual trees is a time consuming task (Wang and Hann 1988) and imputation greatly increases the efficiency at which a stand can be sampled. Height imputations involve the use of both dbh and height variables, as a strong relationship exists between the two within a stand. For each stand, we used the following height-diameter equation, which is commonly used in the Pacific Northwest (Curtis 1967) to relate tree height to dbh:

$$H = 1.37 + \beta_1 * e^{(\beta 2/\mathrm{dbh})} + \varepsilon_1$$

where H is the height of the tree in meters, 1.37 is the height in meters above ground at which dbh is measured, e is the base of the natural logarithm, dbh is the diameter at breast height of the tree in centimeters, β_1 and β_2 are parameters to be estimated from the data, and ε_1 is the residual error with $\varepsilon_1 \sim N(0,\sigma_1^2)$. This equation was log transformed in order to obtain initial parameter estimates through simple linear regression. Due to differences in tree density and stand structure that result in unique height-diameter relationships, equations were fit separately for each stand.

Because recorded height measurements included both bear-damaged and undamaged trees, we used a modified version of the non-linear equation that included an indicator variable "I" to distinguish damaged trees (I=1) from undamaged trees (I=0) in each stand. This allowed us to test if there was a significant difference in β_1 and β_2 between bear-damaged and undamaged trees. The parameter β_1 was the upper asymptote for predicted heights, while the β_2 parameter determined the shape of the approach to this upper asymptote. Understanding whether β_1 and β_2 differed between damaged and undamaged trees was important for testing whether the relationship between dbh and height differed. If the relationships were the same, missing heights could be imputed using a height-diameter equation developed from the combined sample of both damaged and undamaged trees. If the relationships differed, only undamaged trees should be used to develop the equation for predicting undamaged tree heights. The modified equation was as follows:

$$H=1.37 + [\beta_{11} + \beta_{12}*I]e^{[\beta 21+ \beta 22*I]/dbh} + \varepsilon_2$$

where β_{11}, β_{12} , β_{21}, and β_{22} are parameters to be estimated from the data, ε_2 is the residual error with $\varepsilon_2 \sim N(0,\sigma_2^2)$, and all other variables are defined above.

For our CR-WA stand, both the β_1 and β_2 parameters for bear damaged and undamaged trees differed, resulting in use of the following model for height imputations of undamaged trees:

$$H=1.37 + 19.2835*e^{-11.1880/dbh}$$

For our CR-OR stand, the β_2 parameter for damaged and undamaged trees was the same, while the β_1 parameter differed, resulting in use of the following reduced model for height imputations of undamaged trees:

$$H=1.37+ 35.1395*e^{-13.5911/dbh}$$

For our WC-OR stand, both the β_1 and β_2 parameters for damaged and undamaged trees were the same, resulting in use of the following model for height imputations of undamaged trees:

$$H=1.37 + 21.305*e^{-14.24278/dbh}$$

For our WC-WA stand, the β_1 parameter for damaged and undamaged trees was the same, while the β_2 parameter differed, resulting in use of the following model for height imputations of undamaged trees:

$$H=1.37+ 32.2209*e^{-17.9388/dbh}$$

To impute missing height-to-live-crown-base (HCB) measurements we used the following equations for each stand:

CR-WA: $HCB= 15.2013*e^{-12.88327/dbh}$

CR-OR: $HCB= 26.2462*e^{-22.1546/dbh}$

WC-OR: $HCB= 16.97871*e^{-12.65584/dbh}$

WC-WA: $HCB= 14.13212*e^{-14.47310/dbh}$

where *HCB* is the height from the base of the trunk to the base of live crown measured in meters, *e* is the base of the natural logarithm and *dbh* is the diameter at breast height of the tree in centimeters. Data used to fit the models were limited to living trees only, as dead trees had no HCB values. For all stands, the β_1 and β_2 parameters for damaged and undamaged trees were the same. All analyses were completed using SAS software, Version 9.2 (2011 SAS Institute, Cary NC).

Estimating volume loss and economic loss

To estimate standing timber volume and simulate the impacts of bear damage over time in each stand, tree-level data were transformed into tree lists for stand projection in a growth model. Tree lists consisted of the following tree-level variables: tree number, species, dbh, height, crown ratio, and expansion factor. Tree lists for each stand were input into the Forest Vegetation Simulator (FVS) growth model (Dixon 2002) with the Landscape Management System (LMS) interface, Version 2.1 (Nelson et al. 1999). FVS is an individual-tree, distance-independent growth and yield model (Dixon 2002) that has been calibrated to produce variants for specific geographic areas of the United States (USDA 2014). It is capable of simulating a wide range of silvicultural treatments for most tree species, forest types, and stand conditions (USDA 2014). The Pacific Northwest Coast (PN) variant was used for Coast Range sites, and the West Cascades (WC) variant was used for western Cascades sites.

Two scenarios were developed to explore estimated loss in timber volume due to bear damage in each stand. Employing alternative scenarios in ecological and economic modeling is useful for exploring the range in plausible outcomes in the face of uncertainty. Each scenario reflects a different landowner perception of bear damage impacts. The first scenario was based on the findings of Harrington et al. (2015), Lowell et al. (2010), and Pierson (1966) as described earlier. In this first scenario, a percentage of bear-wounded trees were assumed to die, conditional on the severity of damage. For those that survived, a percentage of volume was assumed to be lost, also conditional on the severity of damage. The second scenario was based on anecdotal observations by some of the cooperating landowners that provided study sites and stand data for this study. In this second scenario, any bear damage resulted in a complete loss of the damaged tree's volume, regardless of whether the tree was wounded or killed. It was assumed that additional costs required to salvage a bear-damaged tree at harvest offset any profit that would be made from the tree, resulting in zero value gain and, hence, equivalent to assuming mortality after any bear damage.

Scenario one

To consider the presence of bear damage in each stand in the growth model under scenario one, we used Harrington et al.'s (2015) estimates of percent mortality coupled with Pierson's (1966) estimates of volume lost at the tree level. Harrington et al.'s (2015) estimates were derived from five different severity levels of bole circumference damage: 20, 40, 60, 80 and 90% of circumference. For trees in the 20, 40, and 60% damage categories, mortality rates leveled off around 6% after six years. We assumed that mortality rates for these three categories (20, 40, and 60) would remain at 6% in the future, and designated this as a single damage category, further referred to as the low-damage category. For trees in the 80 and 90% categories Harrington et al. (2015) showed that mortality rates increased linearly over time. We assumed that mortality rates in these categories would continue on their linear trajectories into the future. With this assumption, we fit a linear model for each category in order to estimate mortality rates past eight years. This was necessary as stands were to be projected in the growth model 15-45 years into the future.

The equation fit for the 90% category was:

$$m = -17.9750 + 3.6083*yr$$

The equation fit for the 80% category was:

$$m = -8.4028 + 1.4583*yr$$

where m= % mortality at harvest age and yr= the number of years since damage occurred. The "yr" value was obtained by adding the number of years since damage occurred on average in each stand at present to the number of years each stand was to be projected in the growth model.

Further modifications were made to the data. Our categories of damage severity from field data ranged from 10-100% in 5% increments, and were re-categorized to match those used by Harrington et al. (2015). We assigned all trees with observed damage $\leq$ 60% of the circumference peeled to the low-damage category. We assigned all trees with observed damage between 60-80% circumference peeled to the 80% category. We assigned all trees with observed damage between 80-99% circumference peeled, to the 90% category.

To estimate each stand's volume we implemented two thinning treatments in the growth model. The first thinning involved removal of all observed bear-killed trees before growing the stand to harvest age. Each stand was then grown to harvest age in the model, and an additional thinning was implemented. To implement this second thinning, we calculated the proportion of wounded trees in each stand that fell into each of the three damage categories (low-damage, 80%, and 90%). We then removed the percentage of trees in each damage category that would have died over time from bear damage. Percentages were based on mortality rates derived from the linear models that were fit for each stand (Table 2.2). Thinned trees were identified by species (Douglas-fir) and dbh (trees with the mean dbh of bear-damaged trees).

To compute losses in volume of surviving wounded trees, we calculated the standing volume of all trees remaining at harvest with ≤50% of their circumference damaged, and then multiplied it by 7% to obtain the first volume reduction value. Then, we calculated the standing volume of all trees remaining at harvest with >50% of their circumference damaged and multiplied it by 10% to obtain the second volume reduction value. These two volume reductions were added together and then subtracted from the total stand volume at harvest to obtain a recoverable stand volume after accounting for bear damage.

Scenario two

To simulate scenario two in the growth model, we implemented two thinning treatments in each stand. In the first thinning, all observed bear-killed trees were removed. Each stand was then projected to harvest age, and a second thinning was implemented. In this second thinning, all remaining bear-wounded trees were removed from each stand. Thinned trees were selected by species (Douglas-fir) and by dbh (trees with the mean dbh of bear damaged trees). Wounded trees were removed after each stand was projected to harvest because they are usually left to grow until harvest. In this scenario, they become a complete loss at harvest because the value of recoverable volume is assumed equal to harvesting costs.

Undamaged scenario

We developed an "undamaged" scenario for each stand to serve as a control for comparison of the other two scenarios. To simulate undamaged stands bear-killed trees were treated as undamaged living trees. Bear-killed trees were originally assigned crown ratios of zero. To include them as living trees, their crown ratios were imputed from the HCB equations described above specific to each stand. Stands were then projected to harvest age in the growth model and volume of surviving trees at harvest was calculated.

Present stand value

Present value of each stand was calculated to translate volume losses into economic losses. Present value estimations require knowledge of volume at harvest and the value of logs delivered to the mill (pond value). These estimations also require knowledge of the logging and hauling costs that are subtracted from the value of logs delivered to the mill. To estimate logging and hauling costs associated with each stand at harvest, volume at harvest values for each stand under all scenarios were input into the Fuel Reduction Cost Simulator (FRCS) (Fight et al. 2006), specifically the FRCS-West variant. Data inputs included stand slope, average yarding distance from the stand to a roadside landing, stand area, elevation, harvesting system used, number of large trees/ha, and mean volume/large tree. Large trees/ha and mean volume/large tree values were derived from growth model outputs by dividing total volume/ha by trees/ha. Average yarding distance was derived by measuring the distance from the center of each stand to the nearest road in GIS. Slope values were derived from digital elevation model layers in GIS using the Spatial Analyst Slope Tool.

The FRCS simulation was performed using the Special "Billion-Ton" Processing Rules. These rules designated a harvesting method based on each stand's slope and volume/ha. If the slope was $\leq$ 40% then two alternatives of a ground-based logging system were considered: mechanical whole-tree harvesting with feller-bunchers and skidders used to transport bunches, or manual whole-tree harvesting with chainsaws and skidders used to transport whole trees

(Dykstra 2010, Fight et al. 2006). FRCS completes calculations for both possible alternatives and selects the lower-cost alternative (Dykstra 2010). If the slope was >40% the simulator used manual felling and cable yarding as the harvesting system (Dykstra 2010). Based on stand slopes, CR-WA and WC-WA were harvested in the simulation using a ground-based mechanical system, and CR-OR and WC-OR were harvested in the simulation using a system of manual felling with chainsaws and cable yarding. All stands were simulated as clear-cuts and loading costs were included.

The present value of each stand under all scenarios was estimated using the following Land Expectation Value (LEV) Equation:

$$PV = \frac{Vh * SP}{(1+i)^y}$$

where PV= the present value of the stand in dollars, Vh= the total volume of the stand at harvest age, SP= the stumpage price which is the pond value (i.e., log value) minus logging and hauling costs, i= the discount interest rate, and y= the number of years from present to harvest age (years projected). To determine an average log value per thousand board feet (MBF) we used output from the growth model to calculate a distribution of volumes by log grade at harvest in each stand. We then calculated a weighted mean log value per MBF based on this distribution for each stand (Table 2.3). Stand volume was distributed among the following six log grades: special mill, #2 sawmill, #3 sawmill, #4 sawmill, chip-and-saw, and pulp logs. The most current market value for each grade was used in the calculation of weighted mean price per Douglas-fir MBF. We used a discount interest rate of 5%, because the most common interest rates used in these calculations are 4-6% (Darius Adams, Oregon State University, personal communication).

Mean dbh of bear damaged trees

Various studies have reported that bears tend to damage the largest, most vigorously growing trees in a stand (Childs and Worthington 1955, Giusti 1990, Hosack and Fulgham 1996, Kanaskie et al. 1990). We tested the hypothesis that mean dbh was greater for damaged trees using a t-test. We performed a separate analysis for each stand using the statistical package R (R Development Core Team 2010).

RESULTS

The WC-OR stand contained the highest levels of bear damage with 42.4% of the stand damaged. The CR-WA stand contained 16.2% damage, WC-WA contained 13.5% damage, and CR-OR contained 8.5% damage. Each stand contained root disease as well, although minimal (Figure 2.3). Volume losses in scenario one ranged from 4-15% and in scenario two ranged from 16-43% (Table 2.4, Figure 2.4). Volume losses in scenario two were on average four times greater than volume losses in scenario one. Economic losses in scenario one ranged from $472/ha to $1,635/ha while economic losses in scenario two ranged from $2,416/ha to $4,978/ha (Table 2.5). Mean dbh of damaged trees was greater than mean dbh of undamaged trees in all four stands (Table 2.6, Figure 2.6).

DISCUSSION

Accurate estimates of loss as a result of severe bear damage on private lands are important when making management decisions for both bears and timber resources. Our estimates of economic loss at the stand level improved upon existing estimates by including the additional impacts of wounded trees and accounting for loss based on the severity of individual tree damage. Our two damage scenarios reflected how different landowners might perceive the losses they incur from severe bear damage on their lands. In scenario one, damaged stands retained 84-96% of the value of undamaged stands. In scenario two, losses were on average four times greater, and bear damaged stands retained 54-83% of the value of undamaged stands (Table 2.5). These economic losses can be put into perspective with regards to average timber management costs (Table 2.7). In scenario one, losses from bear damage equaled the costs for landowners to prep and plant 5-22 ha of industrial timberland. In scenario two, losses from bear damage equaled the costs for landowners to prep and plant 17-66 ha of industrial timberland. Scenario two losses were also equivalent to the costs required to pre-commercially thin 51-195 ha of industrial timberland. For small landowners, the profits from harvesting timber are likely used toward the management of other timber stands on their lands. If landowners are relying on harvest profits to fund intensive management of other areas, and bear damage decreases these profits, they may not be able to intensively manage other stands. Moreover, if landowners have already expended funds on managing bears to prevent damage, and their timber stand still experiences severe damage, then the losses are even greater. The landowner loses out on the money they spent on bear damage management (because it was not successful), and they also lose out on the profits they would make from the stand because it is damaged.

Our growth models and economic models relied on several assumptions. The first assumption was that our estimates represented a snapshot in time of bear damage observed in a single year of the timber rotation. We do not currently have the ability to accurately predict what levels of new damage, if any, will occur in these stands over the next 15-45 years. Additionally, we were solely interested in understanding losses in these stands in their current state. Therefore, our models only account for bear damage that has occurred in these stands between stand initiation (i.e., time of planting) and 2015. Any additional damage that may occur in these stands between 2015 and harvest is not accounted for. If these stands experience additional damage in the future, economic losses will likely be much different.

The second assumption of our models was that bear damage is analogous to a thinning treatment. When removing bear-killed trees, the model treated these trees as if killed that year, which in turn affects the predicted growth of adjacent surviving trees in the model. However, in reality, the majority of the bear-killed trees had been dead or dying for multiple years. As a result, the remaining surviving trees had likely already responded to relinquished resources and growing space around them. Additionally, the model thins trees uniformly across the stand, whereas bear damage imposes a more clustered thinning. The pockets of dead trees caused by bear damage can cause a different response in the future growth of the stand than uniformly spaced mortality.

The third assumption of our models was that height and diameter growth for bear-wounded trees and undamaged trees was the same. In order to have a control (undamaged scenario) we had to simulate undamaged stands from stands that contained bear damage. To do so, we treated the bear-killed trees in each stand as if they were alive, but did not change the bear-wounded trees in any way. Bear-wounded trees and undamaged trees were projected to harvest age in the same way. Miller et al.'s (2007) study of the growth of bear damaged trees found that wounded trees averaged 29-33% faster diameter growth than nearby undamaged trees. Additionally, Harrington et al.'s (2015) study of tree growth eight years following simulated bole damage showed an increase in diameter growth of wounded trees as well as initial decreases in height growth. We chose not to account for changes in height or diameter growth of damaged trees in the model because we felt the eight years of reported values were not enough to project 15-45 years. Instead, we found it more imperative to account for tree mortality over time from bear damage wounds.

The fourth assumption of our models was that the bare land value for each stand was not affected by bear damage. In other words, the land that each damaged stand exists on today is not always likely to contain bear damaged timber in the future. Due to this assumption, our present stand value calculations are ratios of the timber values at the end of the current rotation and do not consider bare land values. From an economic standpoint, it would only be necessary to include bare land values if we suspected that some stands are inherently predisposed to repeated bear damage in perpetuity.

The four stands we sampled contained what is considered severe bear damage (greater than 25 bear damaged trees/ha) but they covered a range of severities, from 8.5% damage to 42% damage. Understanding the economic losses associated with a range of severities will be important for landowners when making more economically favorable decisions for managing both bears and timberlands to prevent severe bear damage in the future.

LITERATURE CITED

Childs, T.W., and N.P. Worthington. 1955. Bear damage to young Douglas-fir. USDA. Pacific Northwest For. & Range Exp. Stn. Res. Note No. 113, Portland, OR. 4 p.

Curtis, R.O. 1967. Height-diameter and height-diameter-age equations for second-growth Douglas-fir. Forest Science 13:365-375.

Cushman, S.A. and Kevin McGarigal. 2003. Landscape-level patterns of avian diversity in the Oregon Coast Range. Ecological Monographs 73:259-281.

Dixon, G.E. 2002. Essential FVS: A users guide to the forest vegetation simulator. USDA Forest Service, Internal Rep., Forest Management Service Center, Fort Collins, CO. 246 p.

Dykstra, D. 2010. Batch processing in FRCS. User's guide for FRCS fact sheet. USDA Forest Service, Pacific Northwest Research Station. Portland, OR. 10 p.

Fight, R.D., B.R. Hartsough, and P. Noordijk. 2006. Users guide for FRCS: fuel reduction cost simulator software. USDA Forest Service General Technical Report PNW-GTR-668. Portland, OR. 30 p.

Garber, S.M., H. Temesgen, V.J. Monleon, and D.W. Hann. 2009. Effects of height imputation strategies on stand volume estimation. Canadian Journal of Forest Resources 39:681-690.

Giusti, G. 1990. Black bear feeding on second growth redwoods: a critical assessment. Proceedings of the Vertebrate Pest Conference 14:214-217.

Harrington, C., P. Gould, and D. Marshall. 2015. Effect of artificial damage on survival, growth, and wound occlusion of Douglas-fir. USFS Pacific Northwest Research Station, Unpublished report.

Hosack, D.A. and K.A. Fulgham. 1996. Black bear damage to regenerating conifers in northwestern California. Journal of Wildlife Research 1:32-37.

Immell, D., D.H. Jackson, and M.C. Boulay. 2013. Denning ecology of American black bears in the Cascade Mountains of Oregon. Ursus 24:1-12.

Kanaskie, A., G. Irwin, J. Chetock, and D. Overhulser. 1990. Black bear damage to forest trees in northwest Oregon 1988-1989. Pest Management Report 90-1. Oregon Department of Forestry, Salem, OR. 37 p.

Kimball, B.A., D.L.Nolte, R.M. Engeman, J.J. Johnston, and F.R. Stermitz. 1998a. Chemically mediated foraging preference of black bear (Ursus americanus). Journal of Mammalogy 79:448-456.

Kimball, B.A., E.C. Turnblom, D.L. Nolte, D.L. Griffin, and R.M. Engeman. 1998b. Effects of thinning and nitrogen fertilization on sugars and terpenes in Douglas-fir vascular tissues: implications for black bear foraging. Forest Science 44:599-602.

Lowell, E.C., D. Dykstra, and G. McFadden. 2010. Effects of bear damage on Douglas-fir lumber recovery. Western Journal of Applied Forestry 25:73-80.

Miller, R.E., H.W. Anderson, D.L. Reukema, and T.A. Max. 2007. Growth of bear-damaged trees in a mixed plantation of Douglas-fir and red alder. USDA Forest Service, Pacific Northwest Research Station Research Paper PNW-RP-571. 40 p.

Nelson, C.E., J.B. McCarter, J. Wilson, P.J. Baker, J.S. Hall, and C.D. Oliver. 1999. Landscape Management System User's Manual. University of Washington, College of Forest Resources, Internal Rep., Silviculture Laboratory, Seattle, WA. 100 p.

Nolte, D.L., Dykzeul, M. 2002. Wildlife impacts on forest resources. In: Clark, L., J. Hone, J.A. Shivik, R.A. Watkins, K.C. Vercauteren, and J.K. Yoder, eds. Human conflicts with wildlife: economic considerations. Proceedings, 3rd National wildlife research center special symposium; 2000 August 1-3; Fort Collins, CO. U.S. Department of Agriculture, Wildlife Services, National Wildlife Research Center:163-168.

Oregon Department of Fish and Wildlife. 2006. Oregon conservation strategy. Oregon Department of Fish and Wildlife, Portland, Oregon. 12 p.

Pierson, D.J. 1966. Washington's black bear problem. Western Association of Game and Fish Commissioners. 46:96-100.

R Development Core Team. 2010. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Radwan, M.A. 1969. Chemical composition of vascular tissue of four tree species in relation to feeding by black bear. Forest Science 15:11-16.

SAS Institute Inc. 2011. Base SAS® 9.2 Procedures Guide. Cary, NC: SAS Institute Inc.

Schmidt, W., and M. Gourley. 1992. Black bear. In: H. Black, editor. Silvicultural approaches to animal damage management in Pacific Northwest forests. USDA Forest Service General Technical Report PNW-GTR-287. Portland, Oregon. Pages 309-311.

U.S. Department of Agriculture (USDA) Forest Service. "What is FVS?". US Forest Service Forest Management Service Center. Web. 24 June 2014.

Wang, C. and D.W. Hann. 1988. Height-diameter equations for sixteen tree species in the central western Willamette Valley of Oregon. Oregon State University College of Forestry, Forest Research Lab. Research paper 51. 14 p.

Witmer, G., D. Nolte, and W. Stewart. 2000. Integrated pest management of black bear reforestation damage. USDA National Wildlife Research Center-Staff Publications. Paper 824:228-235.

Ziegltrum, G.J. 2004. Efficacy of black bear supplemental feeding to reduce conifer damage in western Washington. Journal of Wildlife Management 68:470-474.

Table 2.1. Stand level-details for each study site in western Oregon and Washington, 2015.

Stand	Age	Size (ha)	Elev (m)	TPH[a]	Plots[b]
CR-WA	17	15	170-280	936	37
CR-OR	29	8	380-520	642	20
WC-OR	15	6	380-1750	724	15
WC-WA	33	13	790-920	684	32

[a] Stand density in trees/ha

[b] Number of 0.04 ha sample plots surveyed in each stand

Table 2.2. Percent mortality values used for each stand at harvest age, as derived from the percent mortality linear models fit from Harrington et al. (2015).

Stand	Years Projected	Percent Mortality for 80%[a]	Percent Mortality for 90%[b]	Percent Mortality for Low Damage[c]
CR-WA	45	65	100	6
CR-OR	15	21	54	6
WC-OR	40	54	100	6
WC-WA	30	40	100	6

[a] Percent of bear wounded trees with between 60 and 80% of their circumference peeled that would die in each stand after being projected to harvest age. Value derived from the following linear regression equation: m= -8.4028 + 1.4583*yr where m= % mortality at harvest age and yr= the number of years since damage occurred.

[b] Percent of bear wounded trees with between 80 and 99% of their circumference peeled that would die in each stand after being projected to harvest age. Value derived from the following linear regression equation: m= -17.9750 + 3.6083*yr.

[c] Percent of bear wounded trees with less than 60% of their circumference peeled that would die in each stand after being projected to harvest age.

Table 2.3. Distribution of volume by different log grades at harvest, and weighted mean log values per Douglas-fir MBF used in present value calculations.

Stand	Log Grade	Log Value/MBF	% of Total Volume	Weighted Mean Value/MBF
CR-WA	chip-and-saw	$187	2	$599
	special mill	$700	30	
	pulp logs	$107	1	
	#2 sawmill	$605	35	
	#3 sawmill	$550	24	
	#4 sawmill	$525	8	
CR-OR	chip-and-saw	$187	4	$533
	pulp logs	$107	2	
	#2 sawmill	$605	26	
	#3 sawmill	$550	48	
	#4 sawmill	$525	20	
WC-OR	chip-and-saw	$187	5	$517
	pulp logs	$107	2	
	#2 sawmill	$605	1	
	#3 sawmill	$550	69	
	#4 sawmill	$525	23	
WC-WA	chip-and-saw	$187	6	$517
	pulp logs	$107	2	
	#2 sawmill	$605	6	
	#3 sawmill	$550	63	
	#4 sawmill	$525	24	

Table 2.4. Volume at harvest and present stand values for each of four sample stands under two bear damage scenarios and an undamaged scenario.

		Undamaged		*Damage Scenario 1*		*Damage Scenario 2*	
Stand	Harvest Age	Total Vol at Harvest (m^3)	Present Value of Stand	Total Vol at Harvest (m^3)	Present Value of Stand	Total Vol at Harvest (m^3)	Present Value of Stand
CR-WA	62	23536	$250,072	21309	$225,542	16720	$175,407
CR-OR	44	5307	$181,854	5091	$174,533	4440	$150,049
WC-OR	55	4335	$42,659	3686	$35,812	2486	$23,131
WC-WA	63	7117	$124,280	6794	$118,142	5375	$92,867

Table 2.5. Economic losses to bear damage for each of four sample stands under two bear damage scenarios.

			Damage Scenario 1			*Damage Scenario 2*		
Stand	% Damaged	TPH Damaged	Economic Loss	Loss/ha	% Value of Undamaged Stand	Economic Loss	Loss/ha	% Value of Undamaged Stand
CR-WA	16.2	148	$24,530	$1,635	90	$74,666	$4,978	70
CR-OR	8.5	55	$7,321	$915	96	$31,805	$3,976	83
WC-OR	42.4	310	$6,846	$1,141	84	$19,528	$3,255	54
WC-WA	13.5	93	$6,138	$472	95	$31,413	$2,416	75

Table 2.6. Results of t-test for presence of bear damage against dbh for each sample stand in western Oregon and Washington, 2015.

Stand	T-Statistic	Degrees of Freedom	P-Value	Mean for Damaged[a]	Mean for Undamaged[b]
CR-WA	-6.034	1372	<0.01	19.71	17.99
CR-OR	-5.584	517	<0.01	33.16	27.04
WC-OR	-10.571	437	<0.01	18.84	16.31
WC-WA	-6.716	170	<0.01	27.96	23.56

[a] Mean dbh of bear-damaged trees in cm.

[b] Mean dbh of undamaged trees in cm.

Table 2.7. Average cost/ha for common timber management activities in western Oregon and Washington, 2015.

Management Activity	Cost per Hectare
Site preparation	$644.94
Site planting	$480.13
Decadal management	$156.43
Precommercial-thin	$383.26
Fertilization	$179.18

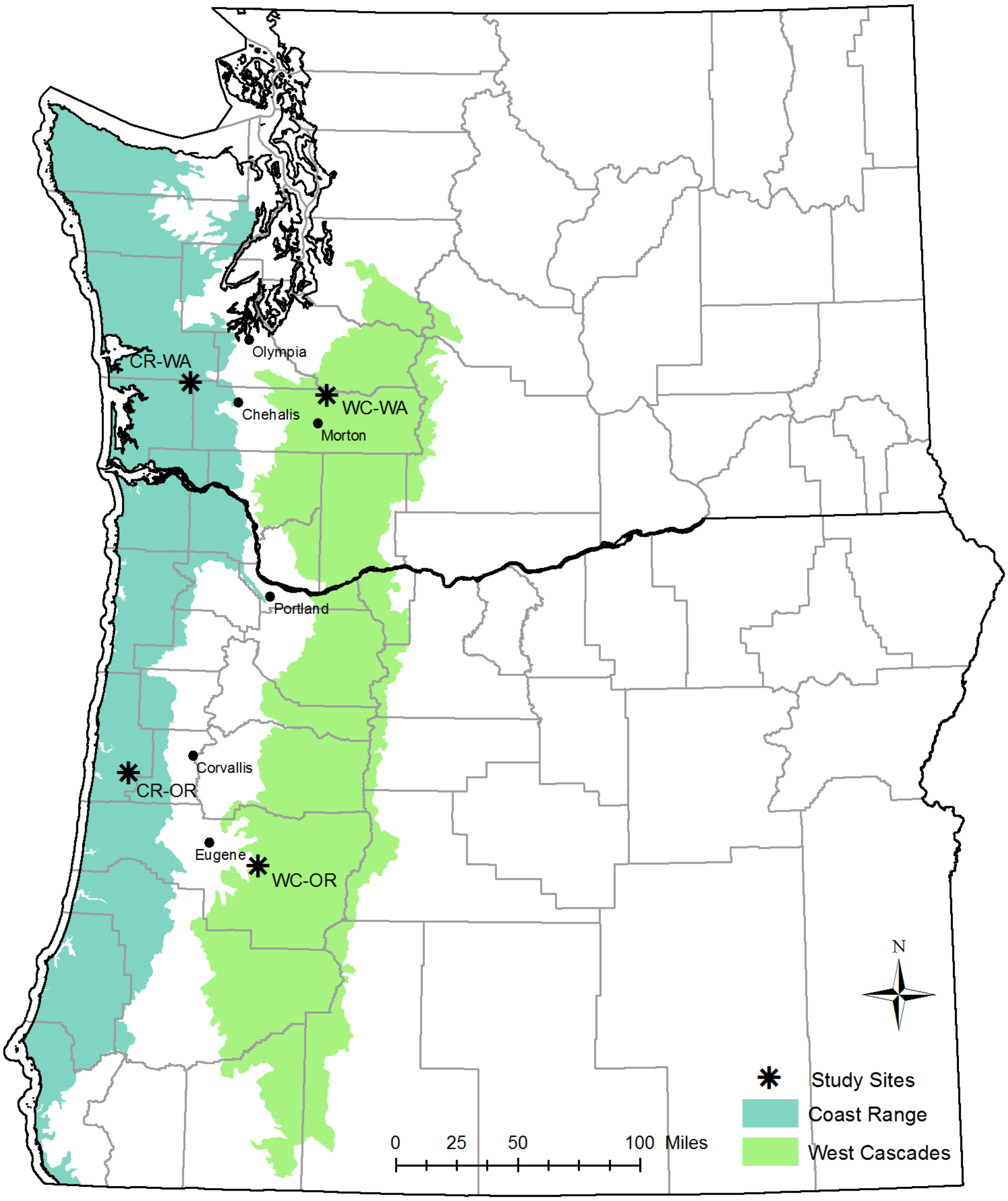

Figure 2.1. Locations of the four study sites in the western Cascades and Coast Range of Oregon (CR-OR and WC-OR) and Washington (WC-WA and CR-WA).

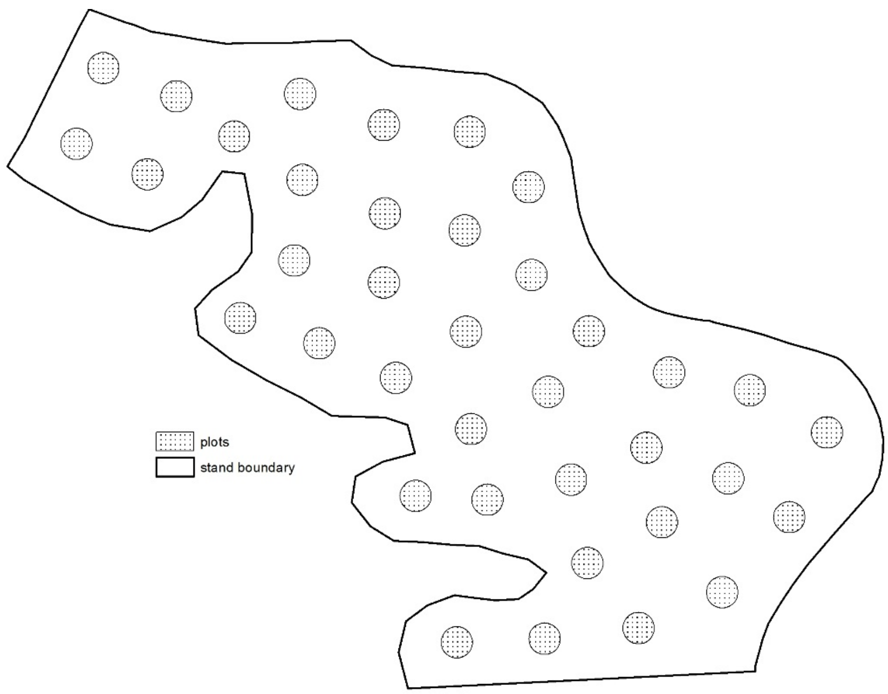

Figure 2.2. Illustration of arrangement of 0.04 ha circular plots. Plots were evenly spaced across each stand in a grid-like system.

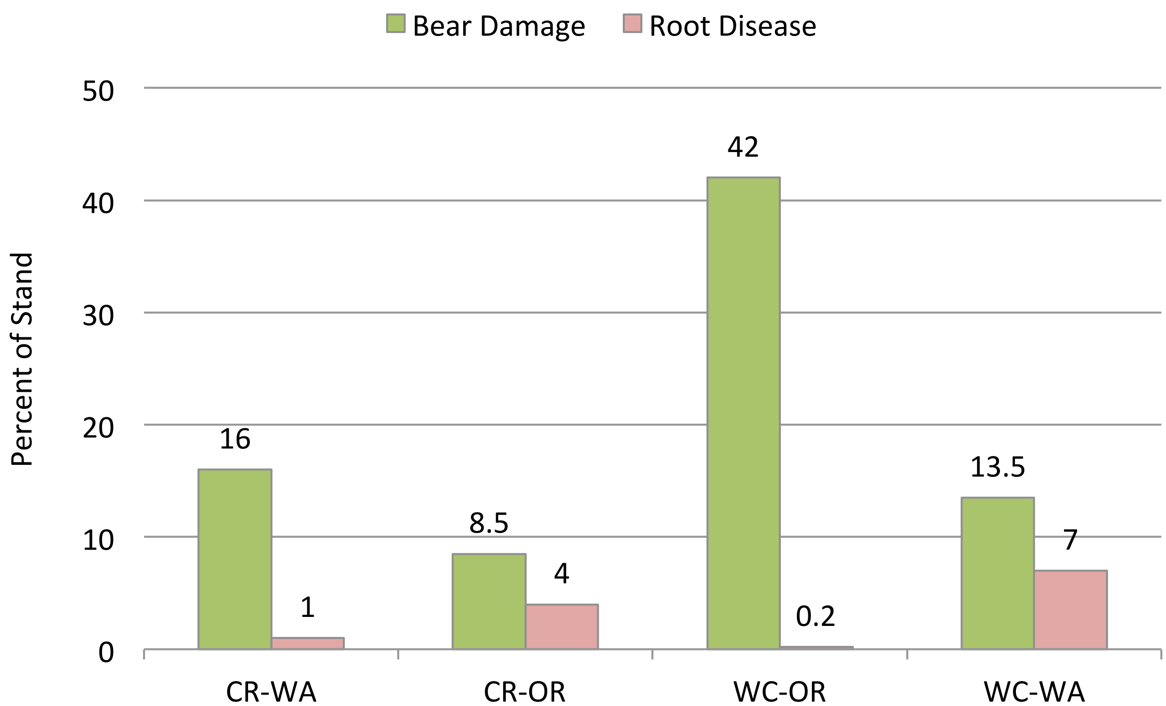

Figure 2.3. Overview of the extent of damage occurring in each of four sample stands in western Oregon and Washington, 2015.

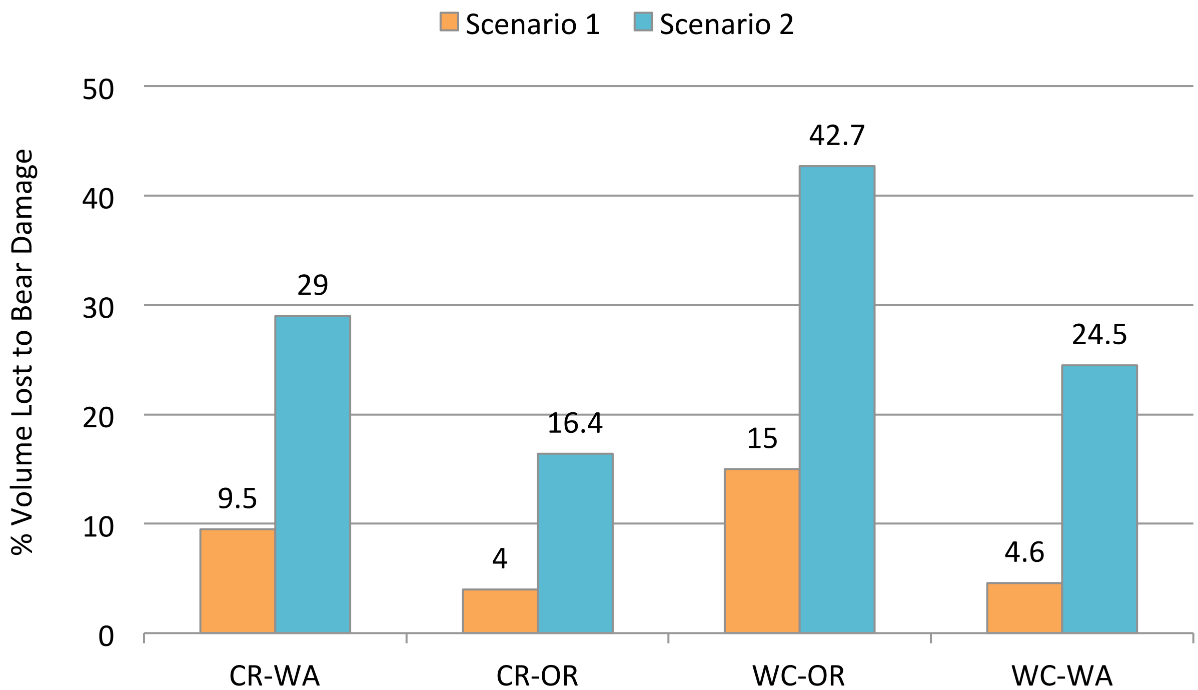

Figure 2.4. Volume losses to severe bear damage across two bear damage scenarios in four sample stands in western Oregon and Washington, 2015.

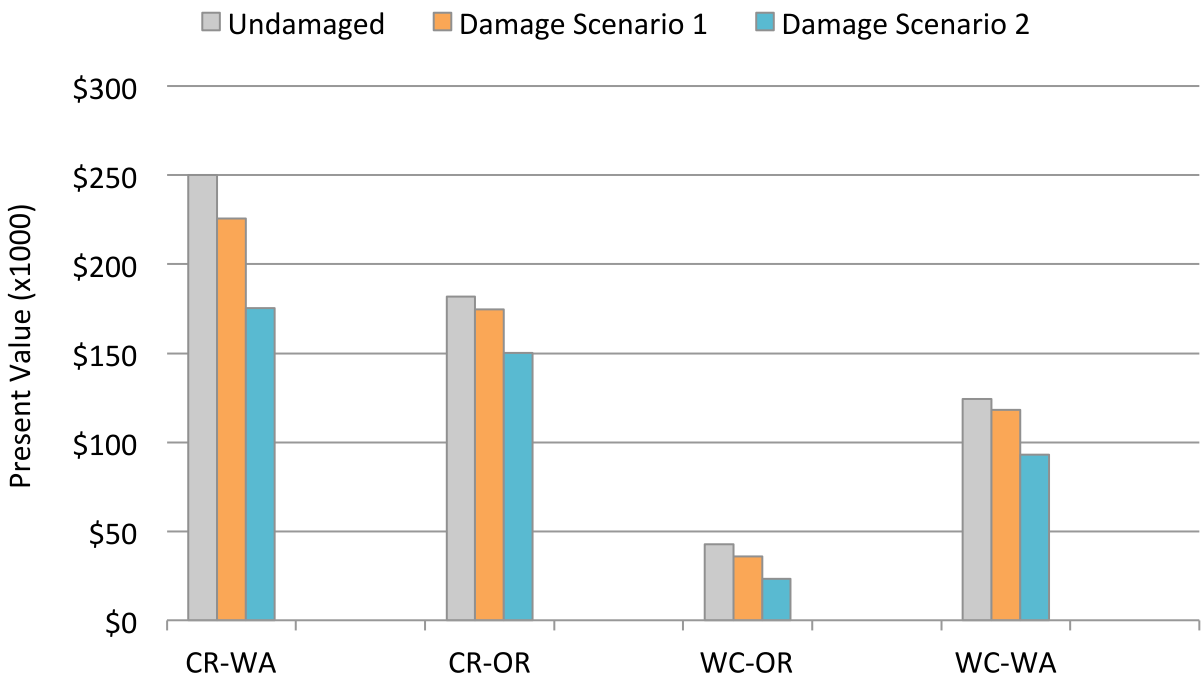

Figure 2.5. Present values of each of four sample stands under two bear damage scenarios shown against an undamaged scenario in western Oregon and Washington, 2015.

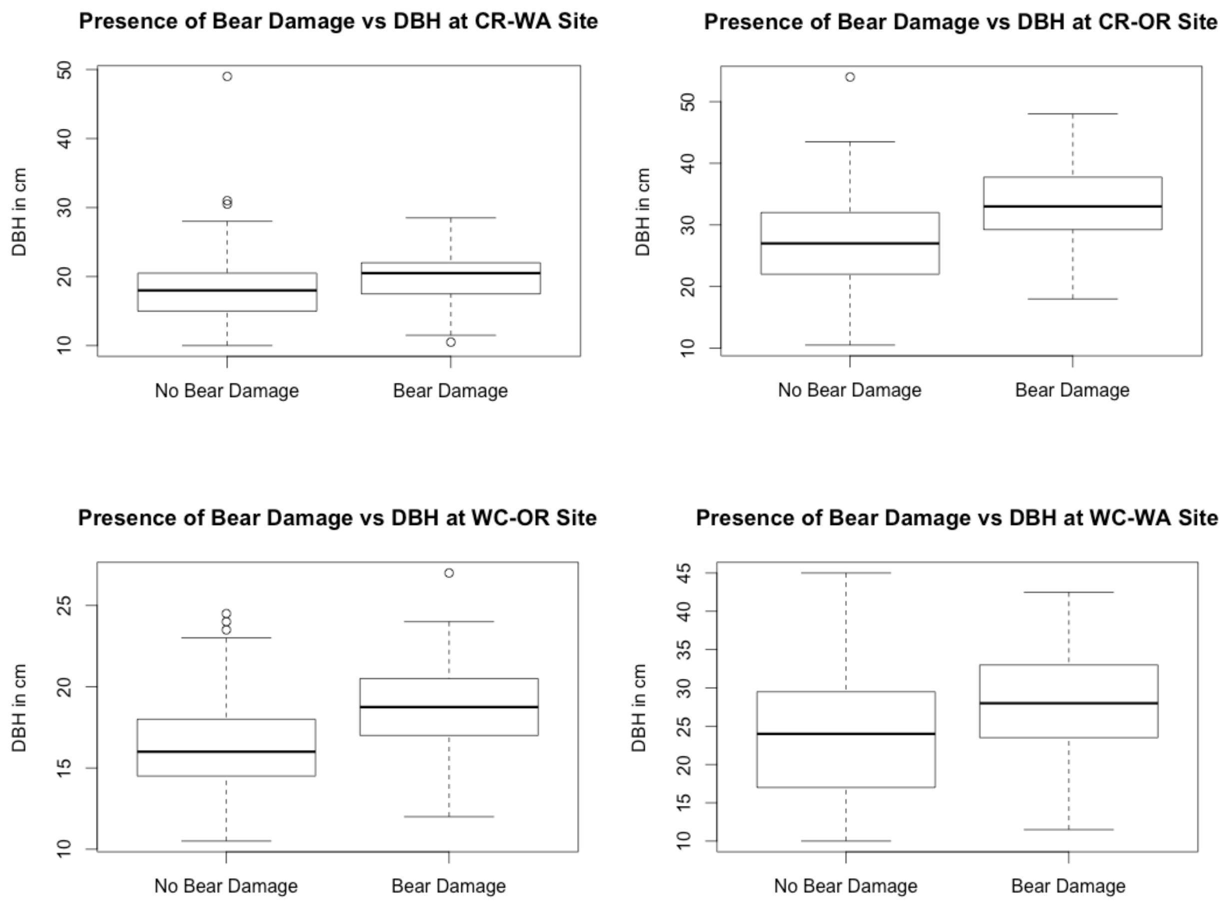

Figure 2.6. Presence of bear damage against dbh for each sample stand in western Oregon and Washington, 2015.

CHAPTER 3: LANDSCAPE-LEVEL ECONOMIC IMPACTS OF BEAR DAMAGE TO DOUGLAS-FIR ON PRIVATE TIMBERLANDS ACROSS WESTERN OREGON

Kristina N. Kline, *Department of Forest Ecosystems and Society, Oregon State University, Corvallis, Oregon 97331*

Jimmy D. Taylor, *USDA APHIS, Wildlife Services, National Wildlife Research Center, Corvallis, Oregon 97331*

Anita T. Morzillo, *Department of Natural Resources and the Environment, University of Connecticut, Storrs, Connecticut 06269*

Doug A. Maguire, *Department of Forest Engineering, Resources and Management, Oregon State University, Corvallis, OR 97330*

Economic losses due to wildlife damage in the United States have been estimated in excess of $22 billion annually (Conover 2002). These estimates include measures of direct loss and costs associated with measures used to prevent wildlife damage. Common sources of wildlife damage generally fall within the following categories: automobile collisions, aircraft collisions, metropolitan households, rural households, agriculture, and timber (Conover 2002). Typical economic assessments of wildlife damage involve estimating the costs of damage by quantifying the amount of product damaged and assessing its reduced economic value (Reidinger and Miller 2013).

The costs of wildlife damage can be direct, indirect, or induced. Direct costs represent the loss in actual consumptive value of the product (Reidinger and Miller 2013), whereas indirect and induced costs represent how the economy responds to the loss of that product (Taylor et al. 2014). Most wildlife damage can be assessed over a short timescale (e.g., a single strike event or percent loss of an annual crop). However, quantifying economic loss to timber production is much more complex given long rotation lengths and the susceptibility to multiple sources of wildlife damage over time.

Ecologically, wildlife damage to seedlings, saplings, and mature trees is a normal consequence of the search for food and habitat in forests (McDonald and Radosevich 1992). However, from the perspective of forest production and economics, animal damage to forests has been recognized as an issue since artificial regeneration efforts began (Black and Lawrence 1992). For example, newly regenerating tree plantations can experience extensive damage to saplings from ungulate browsing of terminal leaders (Black et al. 1979), as well as rodent foraging of roots and stems (Askham 1992). Once plantations mature past stand initiation, young trees become susceptible to bole damage by mountain beaver (*Aplodontia rufa*), porcupines (*Erethizon dorsatum*), and black bears (*Ursus americanus*). Intensive silvicultural practices that promote tree vigor and stand health (e.g., site preparation, vegetation management, fertilization, and thinning) may also promote tree damage by wildlife through foraging.

Of all wildlife species, black bears are perceived to have the greatest economic impact to young western conifers because bears usually damage the largest, most vigorously growing trees within the most productive stands (Kimball et al. 1998a, Schmidt and Gourley 1992). Following winter dormancy, common food sources for bears such as salmonberry, huckleberry, and blackberry are scarce, requiring them to find additional sources of energy (Ziegltrum 2004). In early spring, this energy can be found in the sugar-rich phloem and cambial tissues (hereafter vascular tissues) of vigorously growing plantation conifers (Radwan 1969). Bears peel away bark with their claws and consume vascular tissues by scraping them with their incisors. In the Pacific Northwest, the most common conifer foraged is young Douglas-fir (*Pseudotsuga menziesii*), particularly within the 15-40 year age range (Flowers 1987). Damage is typically concentrated at the most valuable basal log of trees where the quality of wood tends to be higher, and where the majority of the tree's wood volume is concentrated (Schmidt and Gourley 1992). However, some bears climb and peel trees where secondary metabolites are less concentrated (Kimball et al. 1998c), and bark is thinner and easier to peel (Schmidt and Gourley 1992). The result of full girdling of a tree is mortality, while partially girdled trees are more susceptible to disease, insect infestation (Kanaskie et al.1990), and windfall (Witmer 2000). Thus, impacts to timber stands from bear damage can be substantial, especially since many stands are damaged by bears for multiple years in a rotation.

Forest growth and yield models forecast stand dynamics through simulating the increase in tree growth over a given period of time as well as the total amount of tree volume available for harvest (yield) at a given time (Avery and Burkhart 1983). Thus, growth and yield models can be used to evaluate timber volume outputs under various management scenarios, and to assess economic impacts of wildlife damage (Brodie et al. 1979). Present value models, also called Land Expectation Value (LEV) calculations, underlie all of modern financial economics (Geltner and Mei 1995). These models operate by forecasting timberland value at harvest and then discounting that value at a constant discount rate, or interest rate (Geltner and Mei 1995). The term discount rate is used rather than interest rate because the present value, a smaller number, is calculated from the future value, a larger number (Baker 2008). Along with discount rate, inputs of present value models include merchantable volume, harvesting costs, and stumpage prices. Outputs of growth and yield models become inputs for calculations within present value models. For example, growth and yield models output timber volume at harvest, which is required to estimate how much a stand of timber is worth at present. Therefore, the combination of both models becomes a useful tool for estimating economic losses to wildlife damage in forested landscapes.

Currently, bear damage in commercial timber stands is assumed to result in substantial economic loss. However, no on-the-ground, in-depth analysis of damage frequency and severity has evaluated this economic loss at regional levels (Taylor et al. 2014). To date, the only estimate of economic loss to bear damage at the landscape level is Nolte and Dykzeul's (2002) estimate of approximately $11.5 million across 25,900 hectares in western Oregon. Although informative, that estimate (Nolte and Dykzeul 2002) did not include growth, yield, and present value models. Rather, it was derived from aerial survey estimates using broad assumptions of average tree age, economic value per tree, and tree density.

Costs associated with preventing and managing wildlife damage to timber resources are another measure of the potential economic consequences of wildlife damage (Nolte and Dykzeul 2002). Timber managers in western Oregon spend approximately $1.69/ha (adjusted to 2015 dollars) for wildlife damage management, 25% of which is spent on bear damage management (Nolte and Dykzeul 2002). Loss of lethal control measures to prevent bear damage to timber resources has been projected to increase management costs 332-400% (Nolte and Dykzeul 2002). With various methods of bear damage prevention and management tactics available, as well as various costs associated with these methods, accurate estimates of bear damage frequency and severity at the landscape level will be helpful in informing management decisions.

Current damage frequency estimates at the landscape level rely on detection of damage through aerial surveying. Trees that die as a result of bear damage will typically experience a change in foliar color from green to red by the following spring. Trees with discolored foliage, or red crowns, can be detected remotely from the air or distant viewpoints on the ground. This method is used extensively for determining the occurrence of bear damage on the landscape (Hartwell and Johnson 1987). Trees with red crowns are also recognized as a potential index for extrapolating the total amount of bear damage and economic impact of damage in designated areas at a specific period in time (Hartwell and Johnson 1987).

Aerial surveys to detect red crowns and document tree mortality from black bears in western Oregon have been conducted annually by Oregon Department of Forestry (ODF) and the U.S. Forest Service (USFS) since 1987. These surveys are currently the only estimate of damage amounts over a large geographic area (Kanaskie et al. 2001), covering approximately 3.1 million hectares each year (Flowers et al. 2012). Because aerial surveys for bear damage are focused on detecting red crowns, they are an annual estimate of the number of trees completely girdled by bears the previous year, and do not estimate partial peeling or cumulative damage. Additionally, the aerial damage surveys have been ground verified twice since they began, and various weaknesses in their accuracy were revealed, including misclassification with other mortality agents (Kanaskie et al. 1990, 2001).

Lack of extensive ground-verification efforts in western Oregon created the need to assess the accuracy of aerial surveys for continued bear damage estimation. This also provided the opportunity to develop new techniques for simulating bear damage impacts over time and assess economic loss. Therefore, objectives of this study were to 1) validate the black bear damage portion of the USFS/ODF aerial forest health surveys, and 2) to combine growth, yield, and present value models to estimate economic loss at regional levels using validated damage frequency and severity data. Improved damage estimation will lead to improved estimates of economic loss, which in turn will lead to improved decisions for bear damage management in industrial forests.

STUDY AREA

The study was conducted across 122 intensively managed Douglas-fir stands on private land in the western Cascades and Coast Range of Oregon (Figure 3.1). The Western Cascades ecoregion extends from just east of the Cascade Mountains summit to the foothills of the Willamette, Umpqua, and Rogue valleys, and spans the entire length of the state of Oregon, from the Columbia River to the California border (ODFW 2006). The mild maritime climate is characterized by cool, wet winters and hot, dry summers (Immell et al. 2013). Elevation ranges from sea level to 3,500 meters. Average annual rainfall is 107-226 cm and average snowfall above 1,220 meters is 18-592 cm (ODFW 2006). This ecoregion is almost entirely forested by conifers. Douglas-fir is the most common tree below 1,220 meters, often mixed with western hemlock (*Tsuga heterophylla*) as a co-dominant. At higher elevations, dominant tree species include Pacific silver fir (*Abies amabilis*), mountain hemlock (*Tsuga mertensiana*), or subalpine fir (*Abies lasiocarpa*). Other common conifers include western redcedar (*Thuja plicata*), grand fir (*Abies grandis*), and noble fir (*Abies procera*) (ODFW 2006). Understory vegetation is comprised of vine maple (*Acer circinatum*), salal (*Gaultheria shallon*), rhododendron (*Rhododendron macrophyllum*), swordfern (*Polystichum munitum*), vanilla leaf (*Achlys triphylla*), Oregon oxalis (*Oxalis oregano*), and twin flower (*Linnaea borealis*, Immell et al. 2013).

The Coast Range ecoregion extends from the Pacific coast eastward through coastal forest to the border of the Willamette Valley and Klamath Mountains. The area is comprised of rugged, mountainous terrain with steep slopes and deep river and creek drainages. Elevation ranges from sea level to 1250 meters. Climate is maritime with mild, wet winters and cool, dry summers (Cushman and McGarigal 2003), and an average annual precipitation of 152-249 cm (ODFW 2006). The forest overstory is dominated by Douglas-fir, western hemlock, and red alder (*Alnus rubra*). Western redcedar and bigleaf maple (*Acer macrophyllum*) are also common. Common understory vegetation include salmonberry (*Rubus spectabilis*), salal, vine maple, Oregon grape (*Berberis spp*.), huckleberry (*Vaccinium sp*.), and swordfern (Cushman and McGarigal 2003).

Approximately 45% of western Oregon forestland is managed by federal agencies (OFRI 2013). Approximately 30% falls under large private ownership, and 18% falls under small private ownership (OFRI 2013). The remaining seven percent is managed by ODF and other nonfederal public entities (OFRI 2013). Resource management is primarily for timber production.

METHODS

Data collection

We accessed bear damage data from ODF and USFS aerial forest health surveys conducted in 2014-2015 (http://www.oregon.gov/ODF/ForestBenefits/Pages/ForestHealth.aspx). For these surveys, observers recorded damage from fixed-wing aircraft in early summer, as this is the optimal time to detect changes in foliar color among injured western conifers (Flowers et al. 2012). Flights followed a grid pattern 300-500 meters above the ground with flight lines 6.5 kilometers apart (Flowers et al. 2012). Observers used a digital sketch mapping system to record damaged areas in the form of polygon figures (Flowers et al. 2012). The resulting polygons designated approximate damage boundaries and were coded with suspected damage agent and an estimate of number of trees affected. Areas of mature (>30 cm dbh), dead Douglas-fir in tight groups were coded as Douglas-fir beetle mortality, while all other mortality was coded as bear damage unless an obvious alternative cause was evident (Kanaskie et al. 2001).

We obtained stand-level spatial and relational data from cooperating landowners, and integrated those data into a geographic information system (GIS) with aerial survey data of bear damage for 2014-2015. We randomly selected 35 stands in the western Cascades and 35 stands in the Coast Range (70 stands each year for two years; 140 stands total) that overlapped with a surveyed bear damage polygon and were within the most common age range of vulnerability for bear damage (11-34 years). Eight of the selected stands were not sampled for reasons including closed or decommissioned roads, locked private gates with no access permission, and downed trees across roads. After accounting for access issues and removing stands with aerial images that contained no red crowns to verify on the ground, 122 of the 140 sample stands were surveyed.

We acquired high-resolution, geo-referenced aerial images of sample stands each year (2014-2015) just prior to ground sampling, to obtain more precise and accurate estimates of red crown locations. The sampling scheme used to assess wildlife damage influences extrapolation of damage estimates to the larger area (Engeman 2002). Because we needed to maximize the efficiency of establishing the ratio of actual bear peeling frequency (i.e., partial and full girdling) to frequency of red crowns (i.e., full girdling causing mortality) in order to extrapolate damage estimates, our sampling design was based on surveying a smaller proportion of each stand that contained red crowns. Therefore, we used 0.4 ha circular plots to survey each stand. A single plot was positioned around the largest group of red crowns within each stand's boundary, and within, or as close as possible to, a bear damage polygon designated from aerial surveys (Figure 3.2). We assumed that the proportion of identified red crowns that were actually bear peeled, as opposed to those red crowns caused by other agents, was the same for clusters of red crowns versus individually scattered red crowns.

We used handheld global positioning systems to navigate to plot locations, and systematically surveyed plots between July and October 2014-2015 to identify each tree as damaged or not damaged. Two observers walked rows of trees back and forth across each plot while visually scanning trees from base to top for damage. One observer scanned one side of the row of trees, while the other observer scanned the opposite side. Depending on tree density in each plot, observers were at times several tree rows apart. Binoculars were used as necessary to scan for damage occurring higher up in the tree canopy (i.e., climb-and-peel). Various data were recorded for trees identified as bear-damaged. This included tree species, severity of damage (percent of circumference peeled), age of damage, and crown condition (red, green, no needles). Age of peeling damage was determined using a pulaski to peel back bark surrounding the damaged area and count layers of new bark since damage. We also noted if damage occurred further up the tree bole from a climbing bear. Damage from other agents and unknown sources were also recorded. For trees damaged due to root disease, the type of disease was identified using a pulaski to expose roots and peel back bark.

Annual forest health survey validation

To validate the accuracy of the bear damage portion of the ODF and USFS annual forest health survey, we compared estimates of on-the-ground damage frequency (bear-damaged trees/ha) with aerial survey estimates of damage frequency using a chi-square test of accuracy (Freese 1960). We evaluated only those plots that fell within a bear damage polygon designated from the aerial survey. Analysis was completed using the statistical package R (R Development Core Team 2010).

To assess the accuracy of the location of aerial survey polygons, we measured the distance between polygons and the nearest red crowns on aerial imagery in GIS. Differences were examined using descriptive statistics. This assessment only indicated how efficient the aerial survey was at designating polygons around true locations of *red crowns*. It did *not* indicate how efficient the aerial survey was at detecting true bear damage locations. We were unable to assess this because it would have required sampling a much greater proportion of each stand in order to verify all red crowns both inside and outside of bear damage polygons.

Extrapolating damage estimates from plot-level to stand-level

To assess volume losses at the landscape level, we created a method to expand plot-level frequency and severity data to the stand level, referred to as red crown-to-damage ratios. First, we calculated a ratio of the number of bear damaged (both killed and wounded) trees and root disease killed trees per observed red crown in each plot. Then, we calculated the mean of this ratio across all stands. We also calculated separate ratios for the number of trees peeled at severities of 100%, 5-50% and 55-95% of their circumference per red crown.

To estimate stand-level damage amounts, we counted the number of red crowns present within each stand using high-resolution aerial imagery. We used the alpha band in GIS to create a transparency mask on the images, which allowed red colors to contrast more intensely against the rest of the image. This enabled greater accuracy and ability to count red crowns in each image manually. We evaluated observer bias in detection of red crowns with a group of seven observers who counted red crowns among a subsample of images. A paired t-test confirmed estimates did not differ among observers ($t_7 = 2.26$, $p = 0.06$), and the margin of error in detection ability was +/- 2.1 red crowns per image (95% confidence interval). The number of red crowns identified in each stand was then multiplied by red crown-to-damage ratios to obtain a total estimate of bear damaged trees (wounded and killed) and root diseased trees in each stand.

Model construction

Growth and yield model

To estimate standing timber volume and simulate impacts of damage over time, we used the Forest Vegetation Simulator (FVS) growth model (Dixon 2002). FVS is an individual-tree, distance-independent growth and yield model (Dixon 2002) that has been calibrated to produce variants for specific geographic areas of the United States (USDA 2014). The model forecasts stand dynamics by simulating tree growth and suppression mortality over a given time projection and outputs the total yield, or amount of tree volume available for harvest, at a given time (Avery and Burkhart 1983). FVS is capable of simulating a wide range of silvicultural treatments for most tree species, forest types, and stand conditions (USDA 2014). We used the Pacific Northwest Coast (PN) variant for Coast Range sites, and the West Cascades (WC) variant for western Cascades sites.

FVS inputs consist of both stand-level information and tree-level information (Figure 3.3) in the form of "tree lists". Tree-level information includes dbh, height and crown ratio (ratio of live crown height to height of tree). To build tree lists for growth simulation, we used tree-level data from two previous studies in the western Cascades and Coast Range of Oregon (Maguire et al. 2011), and which covered the same general area as our study area. We selected tree-level data that had the following stand-level attributes that were similar to our sample stands: age, trees/ha, basal area, and quartile mean diameter. We used an average harvest age of 45-50 years for all projections.

Present stand value model

A present stand value model was used to translate volume losses into economic losses. Present value estimates require knowledge of volume at harvest (obtained from growth model outputs, Figure 3.3) and the value of logs delivered to the mill (pond value). These estimations also require knowledge of the logging and hauling costs that are subtracted from the value of logs delivered to the mill. To estimate logging and hauling costs associated with each stand at harvest, we used the Fuel Reduction Cost Simulator (FRCS), FRCS-West variant (Fight et al. 2006). Data input included stand slope, average yarding distance from the stand to a roadside landing, stand area, elevation, harvesting system used, the number of large trees/ha, and the mean volume/large tree. Large trees/ha and mean volume/large tree were derived from growth model output tables by dividing total volume/ha by trees/ha. We used an average yarding distance of 180 meters for all stands. Slope values were derived from digital elevation model layers in GIS using the Spatial Analyst Slope Tool.

The FRCS simulation was performed using the Special "Billion-Ton" Processing Rules. These rules designated a harvesting method based on each stand's slope and volume/ha. If slope was $\leq 40\%$ two alternatives of a ground-based logging system were considered: mechanical whole-tree harvesting with feller-bunchers and skidders used to transport bunches, or manual whole-tree harvesting with chainsaws and skidders used to transport whole trees (Dykstra 2010, Fight et al. 2006). FRCS completes calculations for both possible alternatives and selects the lower-cost alternative (Dykstra 2010). If slope was $>40\%$ the simulator used cable yarding as the harvesting system (Dykstra 2010). The simulation harvested stands as clear-cuts and loading costs were also included.

Present stand value was estimated using the following Land Expectation Value (LEV) model:

$$PV = \frac{Vh * SP}{(1+i)^y}$$

where PV= the present value of the stand in dollars, Vh= the total volume of the stand at harvest age, SP= the stumpage price and is the pond value (i.e., log value) minus logging and hauling costs, i= the discount interest rate, and y= the number of years from present to harvest age (years projected). To determine an average log value per thousand board feet (MBF) we completed a series of simulations in the growth model using 10 stands that encompassed the full range of tree densities present across all stands. We used the output from these simulations to calculate an average distribution of volumes by log grade at harvest across all stands (Table 3.1). We then calculated a weighted mean log value per MBF based on this distribution and applied it to all stands in the present value calculation. Stand volume was distributed among the following six log grades: special mill, #2 sawmill, #3 sawmill, #4 sawmill, chip-and-saw, and pulp logs. The most current market value for each grade was used in the calculation of weighted mean price per Douglas-fir MBF. We used a discount interest rate of 5%, because the most common interest rates used in calculations such as this are 4-6% (Darius Adams, Oregon State University, personal communication). For each of the following model scenarios, the present values of all 122 stands were added together for a total present value across the landscape.

Model scenarios

We developed two scenarios to explore estimated loss in timber volume due to bear damage in the growth model. Employing alternative scenarios in ecological and economic modeling is useful for exploring the range in plausible outcomes in the face of uncertainty. Each scenario reflects a different landowner perception of bear damage impacts. The first scenario was based on the findings of Harrington et al. (2015), Lowell et al. (2010), and Pierson (1966) as described in Chapter 2. In this first scenario, a percentage of bear-wounded trees were assumed to die, conditional on the severity of damage. For those that survived, a percentage of volume was assumed to be lost, also conditional on the severity of damage. The second scenario was based on anecdotal observations by some of the cooperating landowners that provided study sites and stand data for this study. In this second scenario, any bear damage resulted in a complete loss of the damaged tree's volume, regardless of whether the tree was wounded or killed. It was assumed that the additional costs required to salvage a bear-damaged tree at harvest offset any profit that would be made from selling the tree, resulting in zero net revenue. Two additional scenarios were included to account for economic losses as a result of other observed damage agents such as root disease. A third scenario included volume losses from trees killed by root disease. A fourth scenario included the combined volume losses from both trees killed by root disease and trees killed and/or damaged by bears. In all scenarios, we simulated damage in the model through implementing thinning treatments.

Scenario one

We implemented two thinning treatments in the growth model under this scenario; an initial thinning where all bear-killed trees were removed immediately, followed later by removal of a proportion of the remaining wounded trees after growing the stands to harvest age. This latter thinning was implemented to simulate the percentages of bear-damaged trees that were predicted to die over the course of the simulation. In the final step of volume estimation, we removed a percentage of cull volume from surviving wounded trees conditional on damage severity. Thinning treatments were completed by reducing trees/ha, and because bears tend to damage the larger trees in a stand, trees of larger dbh were removed.

Scenario two

To simulate scenario two in the growth model, we implemented two thinning treatments. We first immediately removed all trees that had been killed by bears at year of simulation initiation. Stands were then grown to harvest age and the remaining bear-wounded trees were thinned from the stand. Thinning was completed by reducing trees/ha, and because bears tend to damage the larger trees in a stand, trees of larger dbh were removed. We chose to remove the wounded trees after the stand was projected, because in most cases, wounded trees are left to keep growing until harvest. It is at harvest when those trees become a complete loss. We used summary table outputs from FVS to calculate volume/ha and total standing volume for each stand. We then input volume information into the FRCS simulation, and computed present stand values.

Scenario three

We implemented a single thinning treatment to simulate scenario three in the growth model. We immediately removed all root disease-killed trees and then projected to harvest age. This thinning was implemented as a reduction in trees/ha, and trees removed represented the full dbh range. We used summary table outputs from FVS to calculate volume/ha and total standing volume for each stand. We then input volume information into the FRCS simulation, and computed present stand values.

Scenario four

We implemented three thinning treatments to simulate scenario four in the growth model. We first removed all root disease-killed trees and all bear-killed trees at the start of the simulation. We projected to harvest age and then thinned out the remaining bear-wounded trees. Removal of root disease trees was conducted across the full dbh range, while removal of bear-damaged trees was restricted to those of larger dbh in each stand. We used summary tables output from FVS to calculate volume/ha and total standing volume for each stand. We then input volume information into the FRCS simulation, and computed present stand values.

Undamaged scenario

Because we were interested in the amount of volume lost to damage, we developed an “undamaged” scenario for stands to serve as a control for comparison. We projected stands to harvest age in the growth model assuming complete lack of any damage, and volume at harvest was calculated. We then input volume information into the FRCS simulation, and computed present stand values.

Characteristics of bear damaged stands

The abundance of stand level attributes for each of our sample stands paired with the knowledge of which stands contained bear damage, allowed for some exploratory analysis. We were interested in testing whether or not various physical attributes of stands with bear damage differed from stands without bear damage. We used two sample t-tests in the statistical package R (R Development Core Team 2010) to test for these differences. We stratified the data and tested the following stand variables separately for Coast Range sites and western Cascades sites: density, basal area, volume/ha, site index, age, slope, aspect, and elevation.

RESULTS

Accuracy of aerial survey

Aerial survey estimates of bear damage frequency did not provide the required accuracy in comparison to our observed estimates of damage frequency (X^2_{66} =119.20, p < .01). On average, aerial survey estimates of bear damage frequency were 5.2 trees/ha greater (SE=1.92) than our observed estimates (Figure 3.4). Furthermore, bear damage polygons from the aerial survey averaged 58.8 meters (SE=8.8) from polygon edge to nearest true red crown locations.

Plot-level damage

Seventeen percent of plots surveyed (N=122) contained bear damage as the primary damage agent, while 82% of plots surveyed contained root disease as the primary damage agent. Four percent of plots contained some ungulate damage, and one plot (<1% of all plots) contained substantial mountain beaver damage. Nineteen percent of bear damaged plots contained only trees wounded by bears. The mean ratio of fully girdled trees to wounded trees across all plots was 1 to 2.5 (SE=0.57). We observed a total of 324 red crowns across all plots, 15% of which were the result of bear damage, and 85% of which were the result of root disease. For every red crown observed in our images there were on average 1.67 bear damaged trees (SE=0.34; 1.09 killed, 0.58 wounded) and 4.64 root diseased trees (SE=0.36). This was our red crown-to-damage ratio. We observed a total of 478 bear damaged trees across all plots, of which 170 were killed. Of the 170 bear killed trees, 71% were dead with no needles, while 29% were dead with red crowns. Sixteen percent of bear damaged trees had climb-and-peel damage.

Bear-killed trees with no needles were 2.5 times more abundant than bear-killed trees with red crowns. Just two percent of bear-damaged trees had fresh damage (occurred during the year of observation), while six percent of bear-damaged trees had damage that occurred the year prior to observation. The majority of bear damage observed (65%) occurred 2-5 years prior to observation, while 27% of bear damage occurred over five years prior to observation (Figure 3.5). One and half percent of bear-damaged trees experienced damage in multiple years.

Stand-level damage

Extrapolated to the stand level, we observed a mean of 1.5 bear-damaged trees/ha (SE=0.05) and 4 root-diseased trees/ha (SE=0.25). For bear damage, the greatest amount of trees removed through thinning treatments in the growth model was 2.5 trees/ha, while most stands lost less than 2 trees/ha. For root disease, the greatest amount of trees removed through thinning treatments in the growth model was 23 trees/ha, while the majority lost 2-5 trees/ha.

Characteristics of damaged vs. undamaged stands

For our Coast Range sites, the only variable that differed between damaged and undamaged stands was mean slope. On average, stands with bear damage had less steep slopes than stands without bear damage (Table 3.2). For our western Cascades sites, three variables differed between damaged and undamaged stands. On average, volume/ha, basal area, and stand age were greater for stands containing bear damage, than for stands without bear damage (Table 3.2).

Landscape-level volume and economic losses

After extrapolating damage estimates to the stand level, the total number of bear damaged trees in each stand was too small to evaluate losses under scenario one in the growth model. The majority of initial thinning treatments for this scenario would have resulted in less than one wounded tree/ha remaining for later thinning treatments. To then remove a proportion of less than one wounded tree/ha to account for wounded tree mortality, and further remove a percentage of volume from that became impractical in the model. Thus, we focused on simulating damage impacts through our remaining three scenarios. The estimated undamaged value of the 122 stands was $47.9 million. In our second scenario where all bear damaged trees are a complete loss, 0.35% of the total volume across the 122 stands was lost to bear damage. This translates to an economic loss across all surveyed stands of $168,950. In our third scenario, which included only the impacts from trees lost to root disease, there was no volume loss and no economic loss, in fact, stands had slightly greater volume and were worth slightly more at harvest. In our fourth scenario, which included the combined effects of both bear damage and root disease, there was a loss in volume of 0.31% across all 122 stands. This translates to an economic loss across all surveyed stands of $148,855. Economic losses as a result of the combined effects of root disease and bear damage were $20,095 less than economic losses from bear damage alone.

Our study area consisted of 3,024 ha of private timberland. According to our model estimates, a loss of 1.5 bear damaged trees/ha equates to an average economic loss of $56/ha. If we assume that this level of bear damage is present across all stands within our study area, aged 11-34 and that overlapped with bear damage polygons from the 2014-2015 aerial surveys (36,236 ha valued at $574.1 million undamaged), direct economic losses to bear damage are estimated at $2.03 million. This estimate is based on our second scenario where all bear damaged trees (wounded or killed) result in a complete loss in volume. We were unable to calculate scenario one losses in the growth model, but we concluded that scenario two losses were on average four times greater than scenario one losses (see Chapter 2). If we assume the same average, that brings our scenario one estimate of economic loss to $534,004 (one-fourth of $2.03 million).

Using the same calculations, if we assume that this level of bear damage is present across all stands within our study area, aged 11-34 years and that overlapped with bear damage polygons designated from all aerial surveys conducted since 2003, that brings our total damaged area to 49,263 ha valued at $780.5 million undamaged. Scenario one losses to bear damage across western Oregon at this level are estimated at $0.73 million while scenario two losses are estimated at $2.8 million (Table 3.3, Figure 3.6).

DISCUSSION

Accurate estimates of loss due to bear damage on private lands are important when making management decisions for both bears and timber resources. Our estimates of direct economic loss to bear damage across western Oregon improve upon existing estimates by verifying the frequency and severity of damage on the ground, and by including the additional impacts of wounded trees. Our estimates across various damage scenarios and at multiple spatial scales, show a range in economic loss. In our scenarios, loss depends on how landowners perceive the impacts of bear damage on their lands, and ranged from $44,500 to $2.8 million. Although this study was limited to western Oregon, our estimates should be applicable to any similar forest type where bear damage occurs. If comparable levels of bear damage exist on similar forested landscapes, our estimated direct loss to bear damage of $56/ha can be used to estimate losses at larger spatial scales. Additionally, the conceptual framework used to simulate bear damage impacts included variables that can be applied to many other locations and forest types where bear damage occurs.

While the economic impacts of wildlife damage can be direct and indirect, we focused our assessment on direct losses as a result of bear damage. We did not assess indirect losses (how the economy responds to the loss of timber volume from bear damage) because the levels of damage observed were minimal. At the landscape level, the overall market system would act to offset any supply reductions through substitution from other owners and regions. Thus, the impacts measured at the overall market or regional level would be minuscule (Darius Adams, Oregon State University, personal communication).

Although aerial surveys are a useful tool for forest managers, their accuracy cannot be expected to equal that of a ground survey. Our estimates of bear damage frequency at the landscape level consisted of an average of 1.5 bear damaged trees/ha (including wounded and killed). The most recent aerial survey estimated an average of 3.2 bear killed trees/ha (Flowers et al. 2014). If wounded trees are included in that estimate (two wounded trees for every killed tree), the estimate is closer to 9.6 bear damaged trees/ha. This estimate is over six times greater than our estimate. The 2000 aerial survey estimated approximately 12,000 hectares as having some mortality or tree damage caused by bears. However, the ground survey that followed confirmed approximately 7,800 hectares as actually having mortality or tree damage from bears (Kanaskie et al. 2001).

Other inaccuracies of aerial surveys include misclassification with other mortality agents, and not accounting for wounded trees. In the 2000 ground-verification it was found that 63% of areas identified from the air as having bear damage actually contained root disease on the ground (Kanaskie et al. 2001). Additionally, it was found that on average, two wounded trees existed for every fully girdled tree (Kanaskie et al. 2001). Although we know that severe bear damage does occur within some private forest stands, we found that the frequency of severely bear damaged stands across the landscape is minimal. Our estimates suggest that the majority of bear damage across the landscape exists at low severities. If forest managers continue to use the annual aerial surveys as an indicator of bear damage frequency on their lands, it is important for them to understand that at the landscape level, aerial surveys likely overestimate damage amounts.

Our models accounted for the presence of other mortality agents that were observed extensively across the landscape, such as root disease. We observed three different types of root disease within our study area: laminated root rot, black stain, and Armillaria. Surprisingly, root disease was present at a higher frequency than bear damage but it resulted in no economic loss when evaluated across 3,024 ha. In fact, when trees lost to root disease were accounted for, stand values at harvest slightly increased. This result could be due to the fact that root diseased trees removed in the model were smaller than the bear damaged trees removed. When these smaller trees were removed at moderate levels, it likely simulated a pre-commercial thinning. The removal of inferior trees allowed for increased resources for the remaining larger trees, resulting in a greater volume at harvest. It is important to realize that our analysis assumes no further mortality from root disease, which is not likely given the typical expansion of laminated root rot pockets.

To date, in each ground-verification effort, the number of aerial survey polygons containing root disease has increased, while the number of polygons containing bear damage has decreased. The 1990 ground verification found that 24% of polygons contained root disease, and 76% contained bear damage (Kanaskie et al. 1990). The 2000 ground verification found that 63% of polygons contained root disease and 42% contained bear damage (Kanaskie et al. 2001).

Our 2015 ground verification found that 92% of polygons contained root disease and 25% contained bear damage. This trend may be an indication that bear damage management over the last two decades has reached a level of efficiency at reducing damage, and if continued, bear damage may remain at low levels across the landscape.

Our study design was based on using red crowns as an indicator of bear damage in a forested landscape. This is currently the most widely accepted technique to quantify damage amounts. Our observations showed that 85% of red crowns were caused by root disease. The majority of bear-killed trees were not red crowns but instead were dead trees with no needles, indicating the status of bear damage across the landscape may now be at a point where the majority of damage is old, and the frequency of new damage each year is minimal. As a result, using red crowns as an indicator of bear damage may be best served if ground verification is completed often and adjustments to red crown estimates are made.

We questioned if the low levels of bear damage we observed happened to result from a sampling design that was biased toward areas containing root disease. In the aerial damage surveys, polygons of various sizes are drawn around damaged areas. The majority of these polygons are a standard 0.8 ha circle, and are the result of a buffer created from the observer marking a single red crown from the air. It was found that these smaller polygons are less likely to contain bear damage (Kanskie et al. 2001). For this reason, polygons chosen for verification in the 2000 ground-verification effort were randomly selected with a probability proportional to their size. In other words, larger polygons were more likely to be randomly selected than smaller, 0.8 ha polygons. Conversely, our selection of stands/polygons to ground-verify was completely random. Stands were selected on the condition that they overlapped an aerial survey polygon in some way (regardless of polygon size). As a result, the majority (63%) of stands selected for our ground sample contained smaller aerial survey polygons. However, we found that 53% of the stands we sampled that contained bear damage were stands containing the smaller aerial survey polygons, and 47% of bear-damaged stands contained larger aerial survey polygons. This indicated that in our sample, it was almost equally likely for a smaller polygon to contain bear damage as it was for a larger polygon.

Nevertheless, the fact that the majority of stands contained root disease may explain why the levels of bear damage we observed were minimal. The presence of root disease implies that stands may be unhealthy, and it is well known that bears choose to damage the most productive, vigorously growing stands (Barnes and Engeman 1995, Schmidt and Gourley 1992). Bears may not have been damaging these stands more severely due to the presence of root disease. Furthermore, in Chapter 2, we observed minimal levels of root disease in stands that contained severe bear damage.

While our estimates showed losses to bear damage were minimal, they were likely overestimates due to the way we simulated mortality of bear-wounded trees in the growth models. In our first scenario, it was at final harvest that we removed the proportion of bear-wounded trees predicted to not survive. Similarly, in our second scenario it was at final harvest that we removed all bear-wounded trees. In reality, these wounded trees would die gradually over time. The mortality of wounded trees that would occur in each annual growth period would accelerate the growth of adjacent undamaged trees, resulting in a response similar to that from repeated light thinning. Consequently, adjacent trees may result in greater volume outputs, compensating for the volume lost to mortality of bear-wounded trees. Nevertheless, the majority of wounded trees were of low severity (89%), thus, overestimates are likely minimal as the majority of wounded trees would have survived to harvest.

Forest management activities that are implemented to increase economic productivity make certain timber stands more susceptible to bear foraging. Activities such as thinning and fertilization increase timber growth and volume resulting in increased sugar concentrations in vascular tissues (Kimball et al. 1998b). Stands with light to moderate stocking densities also tend to be preferred (Nelson 1989), as well as sites with less steep slopes and northerly aspects (Noble and Meslow 1998). Bears appear to be selective in the individual trees that they peel. One tree in a stand may be peeled while its neighbor is left alone or is only marginally foraged. Just two of our ground surveyed bear damaged stands had been pre-commercially thinned, and bear damaged stands ranged in density from 500-1500 TPH. There was no difference in stand density between bear damaged and undamaged stands. However, our results for Coast Range stands were consistent with previous research in that bear damaged stands tended to occur on less steep slopes. Our bear damaged stands in the western Cascades tended to have greater volume per acre, greater basal area, and older trees.

The economic losses reported from our growth models and economic models relied on several assumptions. The first assumption was that the bear damage and root disease observed in 2014-2015 represented all the damage a given stand will sustain up until harvest. Therefore, our models only account for damage that has occurred between stand initiation (i.e., time of planting) and 2015. Any additional damage that may occur between 2015 and harvest is not accounted for. Until a bear damaged stand is studied from initiation to harvest, we will not truly understand the cumulative impacts of bear damage.

The second assumption, in regards to our sampling design and estimation procedure, was that the proportion of identified red crowns that were actually bear peeled would not change with size of cluster, from relatively large clusters to individually scattered red crowns. Placing plots around the greatest number of red crowns that could be captured in a 0.4 ha circle could have biased results toward clusters of red crowns. These clusters may have been more likely to be caused by root disease. Although plots were placed in this manner, the majority of plots (60%) contained just 1-2 red crowns, and groups of red crowns greater than three were less common (25%). It was most important that plots were placed to capture the most representative 0.4 ha piece of each stand.

The third assumption of our models was that damage is analogous to a thinning treatment, which the spatially implicit FVS model is assumed to implement more or less uniformly across each stand. Bear damage is a more clustered disturbance and does not occur uniformly across stands. Root disease also typically occurs in clusters, starting with an individual tree epicenter, which spreads to adjacent trees. Any pockets of dead trees that either damage agent causes result in a different stand growth response than uniformly spaced damage that imitates operational thinning. In turn, the larger the clusters or pockets, the more adverse the effects on stand yields.

The fourth assumption of our models was that the bare land value for each stand was not affected by bear damage. In other words, the land that each damaged stand exists on today is not always likely to contain bear damaged timber in the future. Due to this assumption, our present stand value calculations are ratios of the timber values at the end of the current rotation and do not consider bare land values. From an economic standpoint, it would only be necessary to include bare land values if we suspected that some stands are inherently predisposed to repeated bear damage in perpetuity.

There are several ways that our study could be improved upon, with most improvements requiring considerably more time and resources dedicated to the study. The first improvement would be to collect tree measurements and quantify the spatial distribution of damaged trees. With this additional information and a growth model that can process spatial data, removal of damaged trees in the model would be more representative of reality. If damaged trees existed in clusters they would be removed that way in the model, rather than being removed uniformly across the stand, as would generally be the case in a spatially implicit model.

Another improvement would be to increase the number of stands surveyed and sample a larger proportion of each stand using several smaller plots. Surveying each stand at a higher intensity would allow for greater accuracy in damage frequency when extrapolating to the stand level. Using slightly smaller plots would allow for greater accuracy in damage detection within each plot. To maintain a large sample size, these improvements would require considerably more time and resources. However, they may increase the accuracy of estimates greatly, allowing for extrapolation of damage estimates to larger areas.

LITERATURE CITED

Askham, L.R. 1992. Voles. Pages 187-204 *in* C. Black (editor), Silvicultural approaches to animal damage management in Pacific Northwest forests. USDA Forest Service General Technical Report PNW-GTR-287. Portland, Oregon.

Avery, T.E. and H.E. Burkhart. 1983. Forest measurements, third edition. New York. McGraw Hill.

Baker, S.L. “Discounting future income and present value”. University of South Carolina, Norman J. Arnold School of Public Health, Department of Health and Administration, Economics Interactive Tutorials. Web. 28 January 2008.

Barnes, V.G. and R.M. Engeman. 1995. Black bear damage to lodgepole pine in central Oregon. Northwestern Naturalist 76:127-129.

Black, H. C., E. J. Dimock II, J. Evans and J.A. Rochelle. 1979. Animal damage to coniferous plantations in Oregon and Washington. Part I: a survey, 1963-1975. Research Bulletin 25. Corvallis, OR: Oregon State University, School of Forestry. 44 pages.

Black, H.C., and W.H. Lawrence. 1992. Animal damage management in Pacific Northwest forests: 1901-90. Pages 23-55 *in* A. Black (editor), Silvicultural approaches to animal damage management in Pacific Northwest forests. USDA Forest Service General Technical Report PNW-GTR-287. Portland, Oregon.

Brodie, D., H.C. Black, E.J Dimock II, J. Evans, C. Kao and J.A. Rochelle. 1979. Animal damage to coniferous plantations in Oregon and Washington. Part II: an economic evaluation. Research Bulletin 26. Corvallis, OR: Oregon State University, School of Forestry. 26 pages.

Conover, M.R. 2002. Resolving human-wildlife conflicts: the science of wildlife damage management. Boca Raton, Florida. CRC Press.

Cushman, S.A. and Kevin McGarigal. 2003. Landscape-level patterns of avian diversity in the Oregon Coast Range. Ecological Monographs 73:259-281.

Dixon, G.E. 2002. Essential FVS: A users guide to the forest vegetation simulator. USDA Forest Service, Internal Rep., Forest Management Service Center, Fort Collins, CO. 246 p.

Dykstra, D. 2010. Batch processing in FRCS. User's guide for FRCS fact sheet. USDA Forest Service, Pacific Northwest Research Station. Portland, OR. 10 p.

Engeman, R.M. 2002. Economic considerations of damage assessment. In: Clark, L., Hone, J., Shivik, J.A., Watkins, R.A., Vercauteren, K.C., Yoder, J.K., eds. Human conflicts with wildlife: economic considerations. Proceedings, 3rd National wildlife research center special symposium; 2000 August 1-3; Fort Collins, CO. [Fort Collins, CO]: U.S. Department of Agriculture, Wildlife Services, National Wildlife Research Center: 163-168.

Fight, R.D., B.R. Hartsough, and P. Noordijk. 2006. Users guide for FRCS: fuel reduction cost simulator software. USDA Forest Service General Technical Report PNW-GTR-668. Portland, OR. 30 p.

Flowers, R. H. 1987. Supplemental feeding of black bear in tree-damaged areas of western Washington. Pages 147-148 in Baumgartner, D. M., R. L. Mahoney, J. Evans, J. Caslick, and D. W. Breuer, editors. Symposium Proceedings of the Conference on Animal Damage Management in Pacific Northwest Forestry. Cooperative Extension, Washington State University Press, Pullman, WA.

Flowers, R., M. Norlander, D., and A. Kanaskie. 2014. Memorandum: 2014 aerial survey of tree mortality in northwest Oregon. Oregon Department of Forestry, Salem, OR. 7 pages.

Flowers, R., M. McWilliams, and A. Kanaskie. 2012. Memorandum: 2012 aerial survey of tree mortality in northwest Oregon. Oregon Department of Forestry, Salem, OR. 7 pages.

Freese, F. 1960. Testing accuracy. Forest Science 6:139-145.

Geltner D., and J. Mei. 1995. The present value model with time-varying discount rates: implications for commercial property valuation and investment decisions. Journal of Real Estate Finance and Economics 11:119-135.

Harrington, C., P. Gould, and D. Marshall. 2015. Effect of artificial damage on survival, growth, and wound occlusion of Douglas-fir. USFS Pacific Northwest Research Station, Unpublished report.

Hartwell, H.D., and L.E. Johnson. 1987. Silvicultural effects of basal girdling by black bear in a young Douglas-fir plantation. Washington State Department of Natural Resources Technical Report. 31 pages.

Immell, D., D.H. Jackson, and M.C. Boulay. 2013. Denning ecology of American black bears in the Cascade Mountains of Oregon. Ursus 24:1-12.

Kanaskie, A., M. McWilliams, D. Overhulser, and R. Christian. 2001. Black bear damage to forest trees in northwest Oregon, aerial and ground surveys 2000. Oregon Department of Forestry, Salem, OR. 29 pages.

Kanaskie, A., G. Irwin, J. Chetock, and D. Overhulser. 1990. Black bear damage to forest trees in northwest Oregon 1988-1989. Pest Management Report 90-1. Oregon Department of Forestry, Salem, OR. 37 pages.

Kimball, B.A., D.L.Nolte, R.M. Engeman, J.J. Johnston, and F.R. Stermitz. 1998a. Chemically mediated foraging preference of black bear (Ursus americanus). Journal of Mammalogy 79:448-456.

Kimball, B.A., E.C. Turnblom, D.L. Nolte, D.L. Griffin, and R.M. Engeman. 1998b. Effects of thinning and nitrogen fertilization on sugars and terpenes in Douglas-fir vascular tissues: implications for black bear foraging. Forest Science 44:599-602.

Kimball, B.A., D.L. Nolte, D.L. Griffin, S.M. Dutton, and S. Ferguson. 1998c. Impacts of live canopy pruning on the chemical constituents of Douglas-fir vascular tissues: implications for black bear foraging. Forest Ecology and Management 109:51-56.

Lowell, E.C., D. Dykstra, and G. McFadden. 2010. Effects of bear damage on Douglas-fir lumber recovery. Western Journal of Applied Forestry. 25:73-80.

Maguire, D.A., D.B. Mainwaring, and A. Kanaskie. 2011. Ten year growth and mortality in young Douglas-fir stands experiencing a range in Swiss needle cast severity. Canadian Journal of Forest Research. 41:2064-2076.

McDonald, P., and S.R. Radosevich. 1992. General principles of forest vegetation management. Pages 67-86 *in* A. Black (editor), Silvicultural approaches to animal damage management in Pacific Northwest forests. USDA Forest Service General Technical Report PNW-GTR-287. Portland, Oregon.

Nelson, C.E., J.B. McCarter, J. Wilson, P.J. Baker, J.S. Hall, and C.D. Oliver. 1999. Landscape Management System User's Manual. University of Washington, College of Forest Resources, Internal Rep., Silviculture Laboratory, Seattle, WA. 100 p.

Noble, W.O., and E.C. Meslow. 1998. Spring foraging and forest damage by black bears in the central Coast Ranges of Oregon. Ursus. 10:293-298.

Nolte, D.L., Dykzeul, M. 2002. Wildlife impacts on forest resources. In: Clark, L., Hone, J., Shivik, J.A., Watkins, R.A., Vercauteren, K.C., Yoder, J.K., eds. Human conflicts with wildlife: economic considerations. Proceedings, 3rd National wildlife research center special symposium; 2000 August 1-3; Fort Collins, CO. [Fort Collins, CO]: U.S. Department of Agriculture, Wildlife Services, National Wildlife Research Center: 163-168.

Oregon Department of Fish and Wildlife. 2012. Oregon black bear management plan. Oregon Department of Fish and Wildlife, Portland, OR. 61 p.

Oregon Department of Fish and Wildlife. 2006. Oregon conservation strategy. Oregon Department of Fish and Wildlife, Portland, OR. 12 p.

Oregon Forest Resources Institute. 2013. OFRI county sheets. Oregon Forest Resources Institute, Portland, OR. 36 p.

Pierson, D. J. 1966. Washington's black bear problem. Western Association of Game and Fish Commissioners. 46:96-100.

Radwan, M.A. 1969. Chemical composition of vascular tissue of four tree species in relation to feeding by black bear. Forest Science 15:11-16.

R Development Core Team. 2010. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Reidinger, R.F. and J.E. Miller. 2013. Wildlife damage management: prevention, problem solving, and conflict resolution. Baltimore, Maryland. Johns Hopkins University Press.

Schmidt, W., and M. Gourley. 1992. Black bear. Pages 309-311 *in* H. Black (editor), Silvicultural approaches to animal damage management in Pacific Northwest forests. USDA Forest Service General Technical Report PNW-GTR-287. Portland, OR.

Taylor, J., Morzillo, A., and A. Anderson. 2014. Estimating the total economic impact of black bear peeling in western Oregon using GIS and REMI. Vertebrate Pest Conference 26:419-422.

U.S. Department of Agriculture (USDA) Forest Service. "What is FVS?". US Forest Service Forest Management Service Center. Web. 24 June 2014.

Witmer, G., D. Nolte, and W. Stewart. 2000. Integrated pest management of black bear reforestation damage. USDA National Wildlife Research Center-Staff Publications. Paper 824:228-235.

Ziegltrum, G.J. 2004. Efficacy of black bear supplemental feeding to reduce conifer damage in western Washington. Journal of Wildlife Management 68:470-474.

Table 3.1. Average distribution of volume by different log grades at harvest, and weighted mean log value per Douglas-fir MBF used in present value calculations.

Log Grade	Log Value/MBF	Avg % of Total Volume	Weighted Mean Value/MBF
chip-and-saw	$187	7	
special mill	$700	10	
pulp logs	$107	2	$545
#2 sawmill	$605	13	
#3 sawmill	$550	45	
#4 sawmill	$525	22	

Table 3.2. Differences in 10 site characteristics among bear damaged and undamaged plots within the western Cascades and Coast Range of western Oregon, 2014-2015.

Mountain Range	Variable	T-Statistic	Deg. of Freedom	P-value	Mean for Damaged	Mean for Undamaged
W Cascades	Volume per acre (m3)	-2.55	17	**0.02**	56	27
W Cascades	Basal area(sq m/ha)	-2.68	18	**0.02**	35	25
W Cascades	Age	-2.66	20	**0.02**	26	21
W Cascades	Aspect	0.03	18	0.97	204	205
W Cascades	Average slope (%)	-0.61	20	0.55	29	26
W Cascades	Max slope (%)	-0.49	21	0.63	40	37
W Cascades	Average elevation (m)	-0.81	18	0.43	647	599
W Cascades	Gross TPH	1.41	22	0.17	1013	1149
W Cascades	Net TPH	-1.03	21	0.31	635	558
W Cascades	Site index	1.03	14	0.32	118	122
Coast Range	Volume per acre (m3)	-1.42	32	0.17	42	29
Coast Range	Basal area(sq m/ha)	-1.92	36	0.06	28	22
Coast Range	Age	-0.74	33	0.47	21	20
Coast Range	Aspect	-0.87	37	0.39	213	190
Coast Range	Average slope (%)	2.14	46	**0.04**	18	27
Coast Range	Max slope (%)	1.80	42	0.08	26	37
Coast Range	Average elevation (m)	0.85	26	0.40	364	405
Coast Range	Gross TPH	-0.12	37	0.91	990	978
Coast Range	Net TPH	0.27	55	0.79	643	655
Coast Range	Site index	-0.21	23	0.84	127	126

Table 3.3. Estimated economic losses due to bear damage across western Oregon under two damage scenarios, at multiple spatial scales.

Area of Impact	Ha	Undamaged Value	Scenario 1 Loss	Scenario 2 Loss
Surveyed stands[a]	3,024	$47,911,520	$44,461	$168,950
All stands 11 to 34 with BD polys 2014/2015[b]	36,236	$574,114,487	$534,004	$2,029,216
All stands 11 to 34 with BD polys since 2003[c]	49,263	$780,511,149	$725,981	$2,758,728

[a] Loss estimates reported for the 122 surveyed sample stands.

[b] Loss estimates reported for all stands within our study area aged 11-34 that overlapped with a bear damage polygon designated from the aerial surveys in 2014 and 2015.

[c] Loss estimates reported for all stands within our study area aged 11-34 that overlapped with a bear damage polygon designated from the aerial surveys between 2003 and 2015.

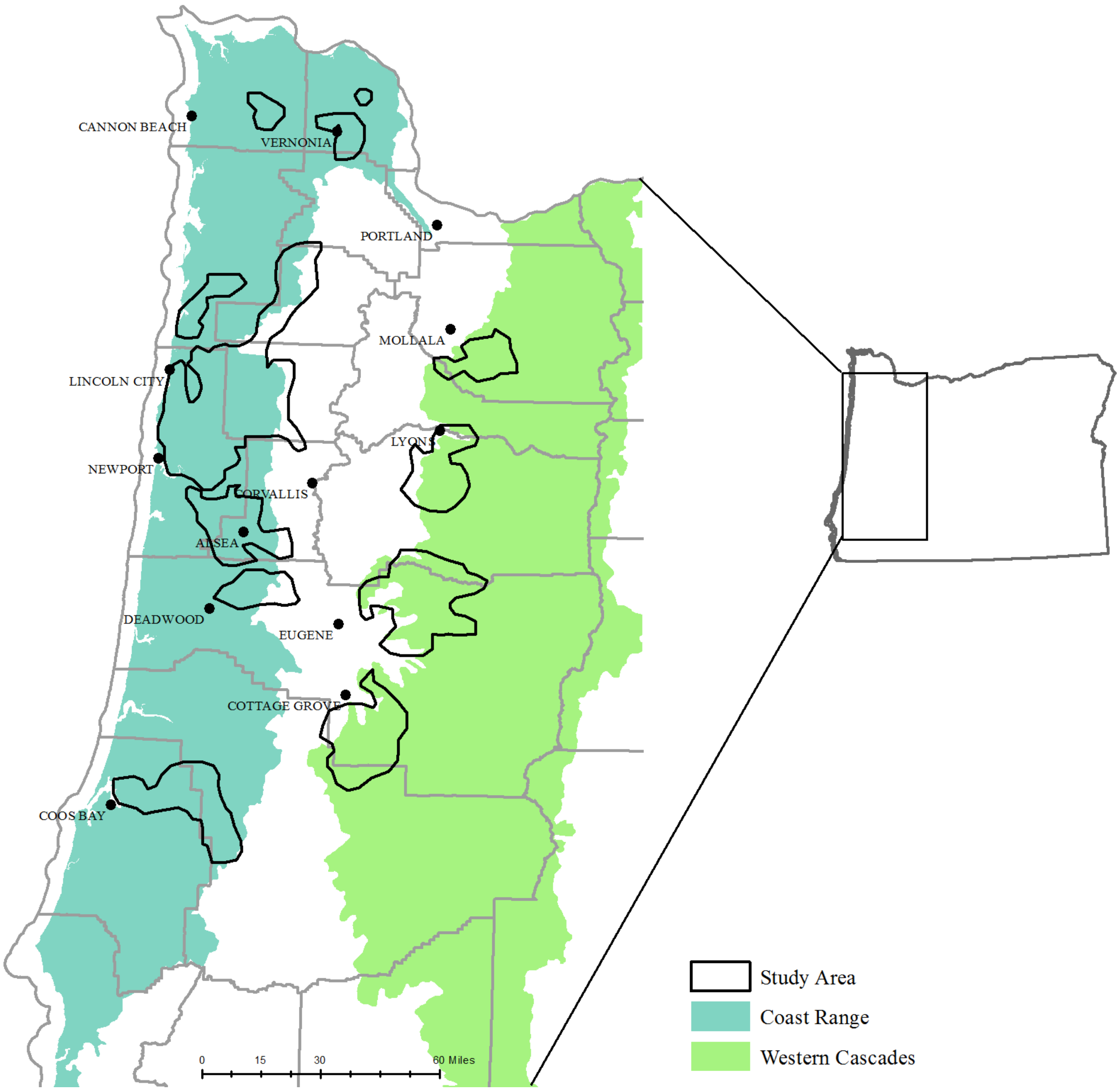

Figure 3.1. Extent of study area in the Western Cascades and Coast Range of Oregon.

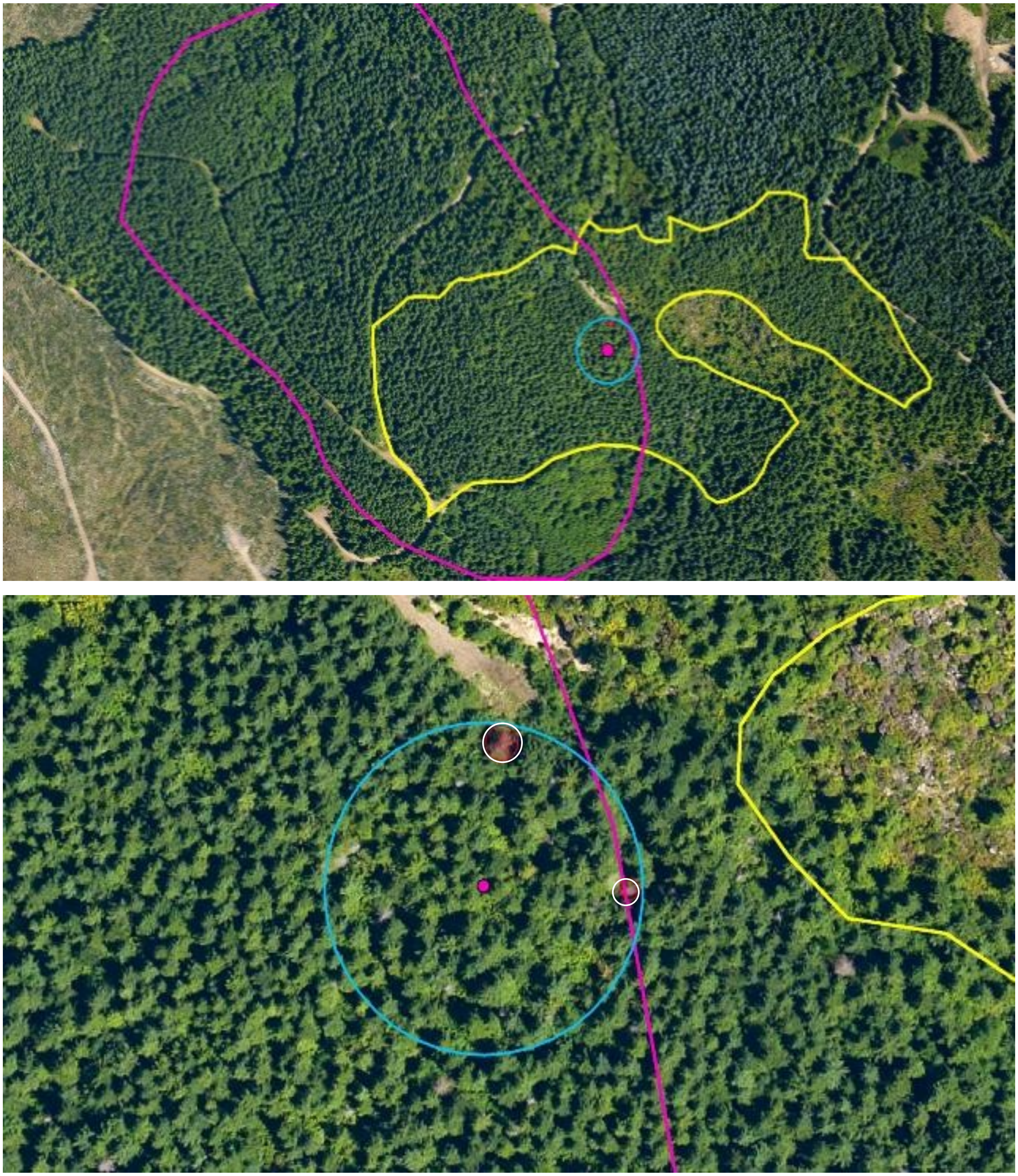

Figure 3.2. Top image shows a 0.4 ha circular plot (blue outline) situated within both a delineated timber stand boundary (yellow outline) and within a surveyed bear damage polygon (purple outline). Bottom image shows arrangement of 0.4 ha circular plot situated around red crowns identified on the image (circled in white).

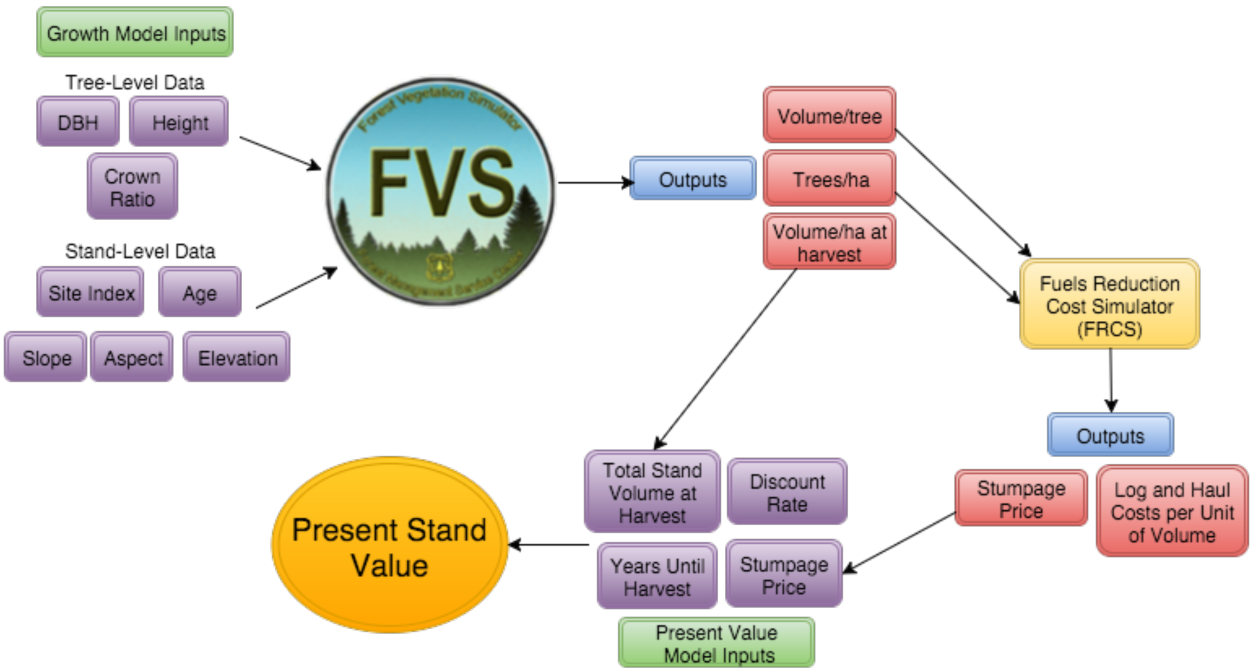

Figure 3.3. Flowchart illustrating various growth model and economic model inputs and outputs for simulating impacts of bear damage to private timberlands in western Oregon.

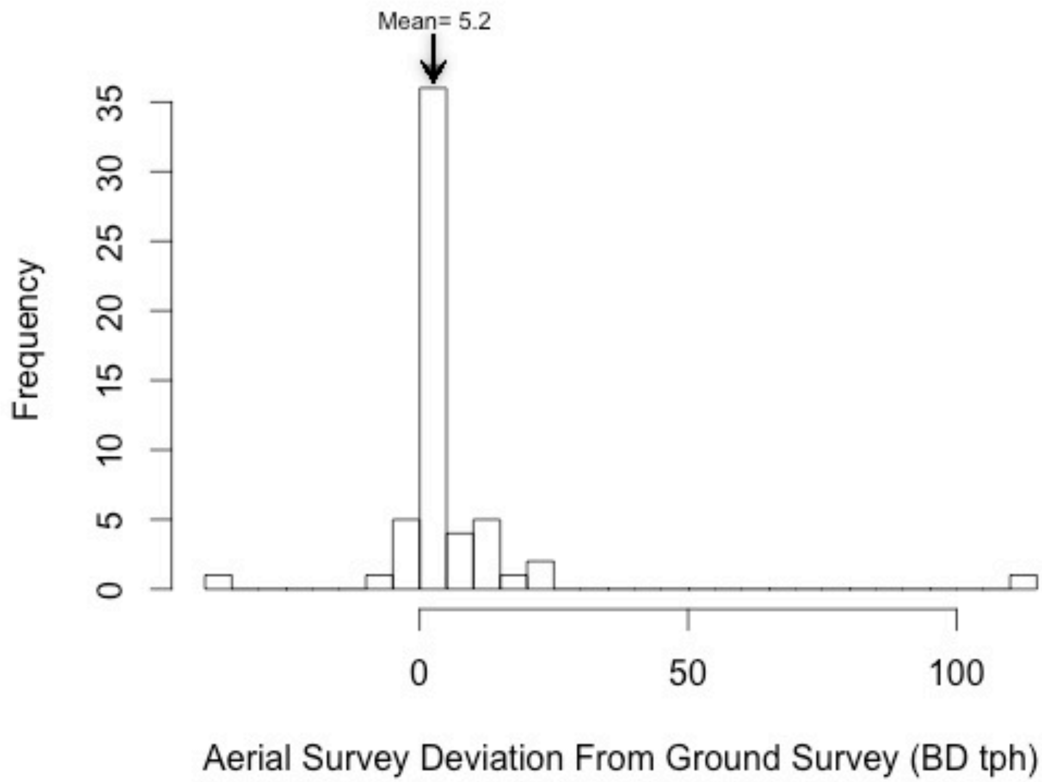

Figure 3.4. Histogram showing deviations of aerial surveyed bear damage estimates from ground verified bear damage estimates in western Oregon, 2014-2015.

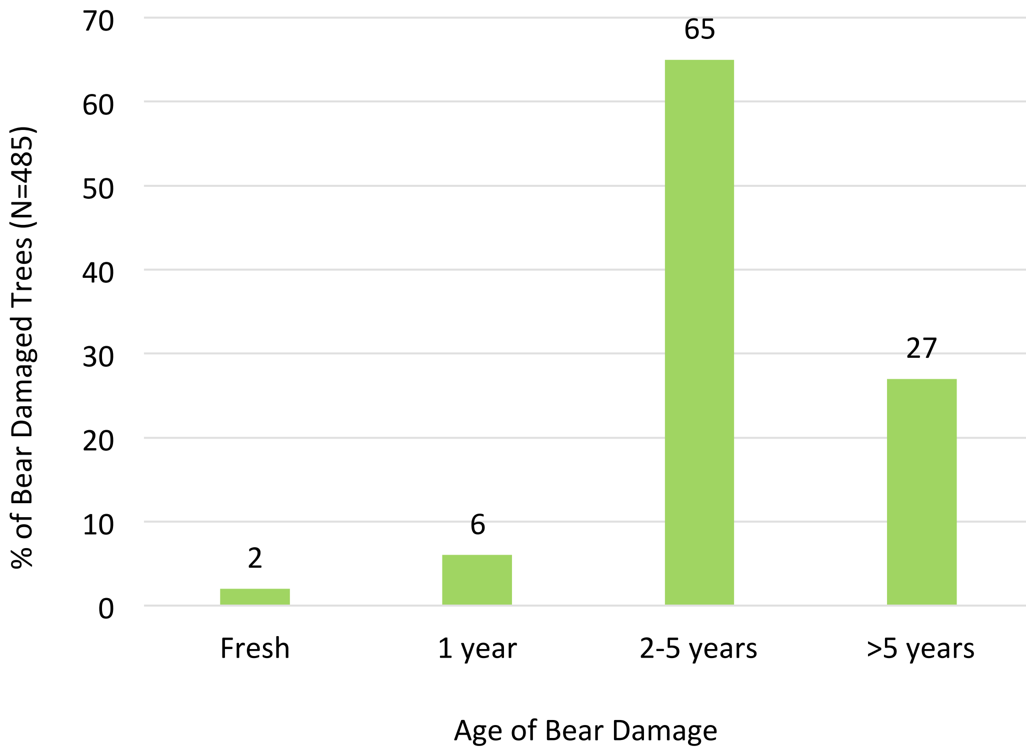

Figure 3.5. Age structure of bear damage across all plots surveyed in western Oregon, 2014-2015.

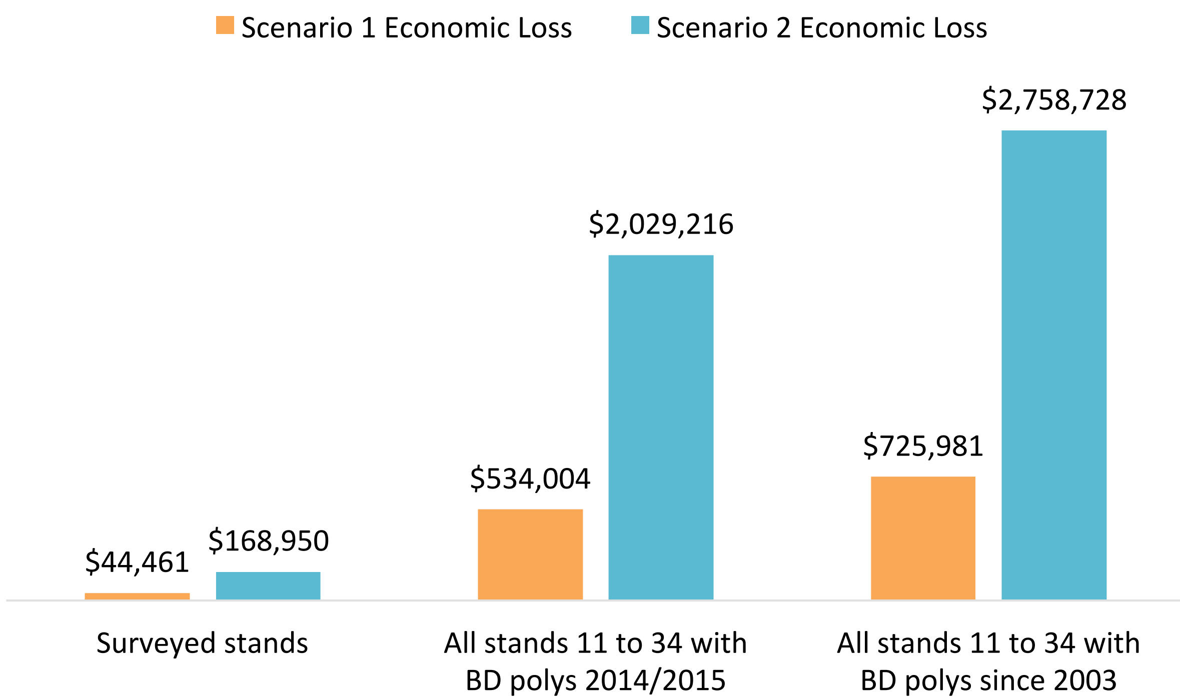

Figure 3.6. Multi-spatial scale economic losses across two bear damage scenarios in western Oregon, 2014-2015.

CHAPTER 4: CONCLUSION

Understanding the direct economic impacts that bear damage can cause at various spatial scales will inform future bear damage management decisions. Evaluating impacts of bear damage under various damage scenarios resulted in a wide range of possible economic losses. At the stand level, economic losses as a result of severe bear damage ranged from $6,000 to $75,000, while at varying degrees of the landscape level, economic losses ranged from $44,500 across 3,000 ha to $2.8 million across 49,000 ha. Our estimates of economic loss improve existing estimates by verifying the frequency and severity of damage on the ground, including the additional impacts of wounded trees and accounting for loss based on the severity of individual tree damage. Our estimates reflect a range in economic loss based on spatial scale and how landowners perceive the impacts of bear damage on their lands, and thus may be useful to a diversity of stakeholders. Although our study was limited to western Oregon and a small portion of western Washington, our approach should be applicable to any similar forested landscape where bear damage occurs. Additionally, the conceptual framework for simulating bear damage impacts included variables that can be applied to many other locations and forest types where bear damage occurs.

Our case study illuminated the losses small landowners can experience as a result of severe bear damage at the stand level. However, we found that at the landscape level, overall bear damage exists at low severities. We also found that annual aerial survey estimates of bear damage across the landscape are likely an overestimate. The past two decades of bear damage management appear to have become efficient enough to maintain bear damage at these low levels. Our results suggest that using red crowns as the leading identifier of bear damage may be outdated as an accurate and useful technique. Until aerial surveys are ground-verified more frequently, estimating from aerial surveys will likely overestimate actual bear damage frequency.

Management Implications

Black bears are valued highly in Oregon and Washington as game animals and the general public values them as an important part of Oregon and Washington's wildlife (ODFW 2012). Thus, understanding and managing conflicts with bears, as well as the impacts their damage can have is an important endeavor. Current bear damage severity at the landscape level seems reflective of a damage management system that is working well. However, for those areas that continue to be "hotspots" for bear damage and experience continued damage at more severe levels, additional management considerations are suggested. Trapping efforts in these stands should be continued with increased emphasis on selective removal of damaging bears. It may be beneficial for private landowners to team up with local hunters by providing them with access and location information on bear damage hotspots on their lands. For areas that seem to experience higher levels of damage post-thinning or post-fertilization, it may be advisable, as others have suggested, to delay thinning or fertilization until stands are past the most susceptible age for peeling (Barnes and Engeman 1995, Schmidt and Gourley 1992). This will require landowners to assess whether the volume losses potentially incurred from delaying thinning will offset the volume losses that may incur if severe bear damage follows thinning.

Future Research

The knowledge that, on average, 2.5 bear-wounded trees exist for every bear-killed tree on the landscape underscores one of the best ways that the accuracy of loss estimates can be improved. Future bear damage research should be devoted to determining bear-wounded tree survival and growth rates as a function of damage severity for a full timber rotation (45-60 years). Currently, the only database that exists pertaining to this covers eight years following tree damage (Harrington et al. 2015). Knowing true mortality rates for varying severities of bear-wounded trees over a larger temporal scale would vastly increase the accuracy of volume loss estimates, and therefore, economic loss estimates, from bear damage. Until this information exists, estimates will continue to rely on various assumptions.

With the frequency that root disease contributes to tree mortality across the landscape, as well as the trend of increasing amounts of root disease identified from aerial surveys, future research might also focus on the synergistic effects of both bear damage and root disease co-existing in industrial forests. We found that with a mean of 4 root-diseased trees/ha across roughly 3,000 hectares there was no economic loss. Additionally, when both bear damage and root disease were included in analysis together, the presence of mortality from root disease somehow dampened the losses from bear damage. This is likely a result of the way these two damage agents were treated in the models. Bear-damaged trees represented the larger diameter class of trees and root-disease trees represented the full range of diameter classes. Thus, root-diseased trees in our models may have been more representative of a pre-commercial thin, while the loss of larger trees to bear damage likely had a long-term effect on stand growth. Nevertheless, it is an incidental finding that could potentially be studied further.

It is important to continue to monitor the status of bear damage severity across western Oregon and Washington at both the stand and landscape levels. The most straightforward way to achieve this is to ground-verify the annual aerial surveys more frequently. The levels of bear damage we observed over the past two years will not likely be the same levels of bear damage that will exist in the next ten years. Understanding how bear damage severity changes over time as a result of management decisions will allow for adaptive management. Additionally, if landowners choose to rely on aerial estimates to inform them of the status of bear damage on their lands, the adjustments in this study should help improve the accuracy of inferred levels of losses from bear damage.

LITERATURE CITED

Barnes, V.G. and R.M. Engeman. 1995. Black bear damage to lodgepole pine in central Oregon. Northwestern Naturalist 76:127-129.

Harrington, C., P. Gould, and D. Marshall. 2015. Effect of artificial damage on survival, growth, and wound occlusion of Douglas-fir. USFS Pacific Northwest Research Station, Unpublished report.

Oregon Department of Fish and Wildlife (ODFW). 2012. Oregon black bear management plan. Oregon Department of Fish and Wildlife, Portland, Oregon. 61 pages.

Schmidt, W., and M. Gourley. 1992. Black bear. Pages 309-311 *in* H. Black (editor), Silvicultural approaches to animal damage management in Pacific Northwest forests. USDA Forest Service General Technical Report PNW-GTR-287. Portland, Oregon.

BIBLIOGRAPHY

Askham, L.R. 1992. Voles. Pages 187-204 *in* C. Black (editor), Silvicultural approaches to animal damage management in Pacific Northwest forests. USDA Forest Service General Technical Report PNW-GTR-287. Portland, Oregon.

Barnes, V.G. and R.M. Engeman. 1995. Black bear damage to lodgepole pine in central Oregon. Northwestern Naturalist 76:127-129.

Black, H. C., E. J. Dimock II, J. Evans and J.A. Rochelle. 1979. Animal damage to coniferous plantations in Oregon and Washington. Part I: a survey, 1963-1975. Research Bulletin 25. Corvallis, OR: Oregon State University, School of Forestry. 44 pages.

Brodie, D., H.C. Black, E.J Dimock II, J. Evans, C. Kao and J.A. Rochelle. 1979. Animal damage to coniferous plantations in Oregon and Washington. Part II: an economic evaluation. Research Bulletin 26. Corvallis, OR: Oregon State University, School of Forestry. 26 pages.

Campbell, S., D. Azuma, and D. Weyermann. 2004. Forests of western Oregon: an overview. US Department of Agriculture Forest Service, Portland, Oregon. 20 pages.

Childs, T.W. and N.P. Worthington. 1955. Bear damage to young Douglas-fir. USDA. Pacific Northwest For. & Range Exp. Stn. Res. Note No. 113, Portland, OR. 4 pp.

Collins, G.H., R.B. Wielgus, and G.M. Koehler. 2002. Effects of sex and age of American black bear on conifer damage and control. Ursus 13:231-236.

Cooper, S. M., and T. F. Ginnett. 2000. Potential effects of supplemental feeding of deer on nest predation. Wildlife Society Bulletin 28:660-666.

Curtis, R.O. 1967. Height-diameter and height-diameter-age equations for second-growth Douglas-fir. Forest Science. 13:365-375.

Cushman, S.A. and Kevin McGarigal. 2003. Landscape-level patterns of avian diversity in the Oregon Coast Range. Ecological Monographs 73:259-281.

Dixon, G.E. 2002. Essential FVS: A users guide to the forest vegetation simulator. USDA Forest Service, Internal Rep., Forest Management Service Center, Fort Collins, CO. 246 p.

Doenier, P. B., G. D. DelGiudice, and M. R. Riggs. 1997. Effects of winter supplemental feeding on browse consumption by white-tailed deer. Wildlife Society Bulletin 25:235-243.

Doman, E. R., and D. I. Rasmussen. 1944. Supplemental winter feeding of mule deer in northern Utah. The Journal of Wildlife Management 8: 317–38.

Dunkley, L., and M. R. L. Cattet. 2003. A comprehensive review of the ecological and human social effects of artificial feeding and baiting of wildlife. Canadian Cooperative Wildlife Health Centre. University of Saskatchewan, Saskatoon, Canada. 70 pages.

Dykstra, D. 2010. Batch processing in FRCS. User's guide for FRCS fact sheet. USDA Forest Service, Pacific Northwest Research Station. Portland, OR. 10 p.

Engeman, R.M. 2002. Economic considerations of damage assessment. In: Clark, L., Hone, J., Shivik, J.A., Watkins, R.A., Vercauteren, K.C., Yoder, J.K., eds. Human conflicts with wildlife: economic considerations. Proceedings, 3rd National wildlife research center special symposium; 2000 August 1-3; Fort Collins, CO. [Fort Collins, CO]: U.S. Department of Agriculture, Wildlife Services, National Wildlife Research Center: 163-168.

Fersterer, P., D.L. Nolte, G.J. Ziegltrum, and H. Gossow. 2001. Effect of feeding stations on the home ranges of American black bears in western Washington. Ursus 12:51-54.

Fight, R.D., B.R. Hartsough, and P. Noordijk. 2006. Users guide for FRCS: fuel reduction cost simulator software. USDA Forest Service General Technical Report PNW-GTR-668. Portland, OR. 30 p.

Flowers, R.H. 1987. Supplemental feeding of black bear in tree-damaged areas of western Washington. Pages 147-148 *in* Baumgartner, D.M., R.L. Mahoney, J. Evans, J. Caslick, and D.W. Breuer (Eds.). Animal damage management in Pacific Northwest forestry. Cooperative Extension, Washington State University Press, Pullman, WA.

Flowers, R., M. Norlander, D., and A. Kanaskie. 2014. Memorandum: 2014 aerial survey of tree mortality in northwest Oregon. Oregon Department of Forestry, Salem, OR. 7 pages.

Flowers, R., M. McWilliams, and A. Kanaskie. 2012. Memorandum: 2012 aerial survey of tree mortality in northwest Oregon. Oregon Department of Forestry, Salem, OR. 7 pages.

Freese, F. 1960. Testing accuracy. Forest Science 6:139-145.

Freund, R.J., W.J. Wilson, and P. Sa. 2006. Regression Analysis: Statistical Modeling of a Response Variable. Academic Press, MA. 480 pages.

Garber, S.M., H. Temesgen, V.J. Monleon, and D.W. Hann. 2009. Effects of height imputation strategies on stand volume estimation. Canadian Journal of Forest Resources. 39: 681-690.

Giusti, G. 1990. Black bear feeding on second growth redwoods: a critical assessment. Proceedings of the Vertebrate Pest Conference. 14:214-217.

Glover, F.A. 1955. Black bear damage to redwood reproduction. Journal of Wildlife Management 19:437-443.

Harrington, C., P. Gould, and D. Marshall. 2015. Effect of artificial damage on survival, growth, and wound occlusion of Douglas-fir. USFS Pacific Northwest Research Station, Unpublished report.

Hartwell, H.D., and L.E. Johnson. 1987. Silvicultural effects of basal girdling by black bear in a young Douglas-fir plantation. Washington State Department of Natural Resources Technical Report. 31 pages.

Hennon, P.E., E.M. Hansen, and C.G. Shaw III. 1990. Causes of basal scars on Chamaecyparis nootkatensis in Southeast Alaska. Northwest Science 64:45-54.

Hosack, D.A. and K.A. Fulgham. 1996. Black bear damage to regenerating conifers in northwestern California. Journal of Wildlife Research. 1:32-37.

Immell, D., D.H. Jackson, and M.C. Boulay. 2013. Denning ecology of American black bears in the Cascade Mountains of Oregon. Ursus 24:1-12.

Kanaskie, A., M. McWilliams, D. Overhulser, and R. Christian. 2001. Black bear damage to forest trees in northwest Oregon, aerial and ground surveys 2000. Oregon Department of Forestry, Salem, OR. 29 pages.

Kanaskie, A., G. Irwin, J. Chetock, and D. Overhulser. 1990. Black bear damage to forest trees in northwest Oregon 1988-1989. Pest Management Report 90-1. Oregon Department of Forestry, Salem, OR. 37 pages.

Kimball, B.A., D.L.Nolte, R.M. Engeman, J.J. Johnston, and F.R. Stermitz. 1998a. Chemically mediated foraging preference of black bear (Ursus americanus). Journal of Mammalogy 79:448-456.

Kimball, B.A., E.C. Turnblom, D.L. Nolte, D.L. Griffin, and R.M. Engeman. 1998b. Effects of thinning and nitrogen fertilization on sugars and terpenes in Douglas-fir vascular tissues: implications for black bear foraging. Forest Science 44:599-602.

Kimball, B.A., D.L. Nolte, D.L. Griffin, S.M. Dutton, and S. Ferguson. 1998c. Impacts of live canopy pruning on the chemical constituents of Douglas-fir vascular tissues: implications for black bear foraging. Forest Ecology and Management 109:51-56.

Landenberger, F. 1960. Bear damage to young-growth trees. California Redw. Ass. Res. Proj. No. 1. 36123, Int. Rep. H. San Francisco, CA. 4 pp.

Landriault, L.J., G. S. Brown, J. Hamr, and F.F. Mallory. 2009. Age, sex and relocation distance as predictors of return for relocated nuisance black bears *Ursus americanus* in Ontario, Canada. Wildlife Biology. 15:155-164.

Lowell, E.C., D. Dykstra, and G. McFadden. 2010. Effects of bear damage on Douglas-fir lumber recovery. Western Journal of Applied Forestry. 25:73-80.

Lutz, H.J. 1951. Damage to trees by black bears in Alaska. Journal of Forestry 49:522-52.

Maguire, D.A., D.B. Mainwaring, and A. Kanaskie. 2011. Ten year growth and mortality in young Douglas-fir stands experiencing a range in Swiss needle cast severity. Canadian Journal of Forest Research. 41:2064-2076.

Mason, A.C. and D.L. Adams. 1989. Black bear damage to thinned stands in northwest Montana. Western Journal of Applied Forestry 4:10-13.

McDonald, P., and S.R. Radosevich. 1992. General principles of forest vegetation management. Pages 67-86 *in* A. Black (editor), Silvicultural approaches to animal damage management in Pacific Northwest forests. USDA Forest Service General Technical Report PNW-GTR-287. Portland, Oregon.

Miller, R.E., H.W. Anderson, D.L. Reukema, and T.A. Max. 2007. Growth of bear-damaged trees in a mixed plantation of Douglas-fir and red alder. USDA. Pacific Northwest Research Station Research Paper PNW-RP-571. 40 pages.

Molnar, A.C., and R.G. McMinn. 1960. The origin of basal scars in the B.C. interior white pine type. Forestry Chronicles 36:50-60.

Nelson, C.E., J.B. McCarter, J. Wilson, P.J. Baker, J.S. Hall, and C.D. Oliver. 1999. Landscape Management System User's Manual. University of Washington, College of Forest Resources, Internal Rep., Silviculture Laboratory, Seattle, WA. 100 p.

Nelson, E.E. 1989. Bears prefer urea fertilized trees. Western Journal of Applied Forestry 4:13-15.

Noble, W.O., and E.C. Meslow. 1998. Spring foraging and forest damage by black bears in the central Coast Ranges of Oregon. Ursus. 10:293-298.

Nolte, D. L. 2003. Bears prefer trees in the spring. Western Forester 8-9.

Nolte, D.L., Dykzeul, M. 2002. Wildlife impacts on forest resources. In: Clark, L., Hone, J., Shivik, J.A., Watkins, R.A., Vercauteren, K.C., Yoder, J.K., eds. Human conflicts with wildlife: economic considerations. Proceedings, 3rd National wildlife research center special symposium; 2000 August 1-3; Fort Collins, CO. [Fort Collins, CO]: U.S.

Department of Agriculture, Wildlife Services, National Wildlife Research Center: 163-168.

Nolte, D.L., B.A. Kimball, and G.J. Ziegltrum. 1998. The impact of timber management on the phytochemicals associated with black bear damage. Proceedings of the Vertebrate Pest Conference 18:111-117.

Oregon Department of Fish and Wildlife (ODFW). 2012. Oregon black bear management plan. Oregon Department of Fish and Wildlife, Portland, Oregon. 61 pages.

Oregon Department of Fish and Wildlife. 2006. Oregon conservation strategy. Oregon Department of Fish and Wildlife, Portland, Oregon. 12 pages.

Oregon Forest Resources Institute. 2013. OFRI county sheets. Oregon Forest Resources Institute, Portland, OR. 36 p.

Pierson, D.J. 1966. Washington's black bear problem. Western Asscociation of Game and Fish Commissioners 46: 96-100.

Poelker, R. J., and H. D. Hartwell. 1973. Black bear of Washington. Washington State Game Dept. Biology Bulletin 14:180pp.

R Development Core Team. 2010. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Radwan, M.A. 1969. Chemical composition of vascular tissue of four tree species on relation to feeding by black bear. Forest Science 15:11-16.

Reidinger, R.F. and J.E. Miller. 2013. Wildlife damage management: prevention, problem solving, and conflict resolution. Baltimore, Maryland. Johns Hopkins University Press.

SAS Institute Inc. 2011. Base SAS® 9.2 Procedures Guide. Cary, NC: SAS Institute Inc.

Schmidt, K. T., and H. Hoi. 2002. Supplemental feeding reduces natural selection in juvenile red deer. Ecography 25: 265–72.

Schmidt, W.C. 1989. Management of young Larix occidentalis forests in the northern Rocky Mountains of the United States. Int. Union For. Res. Organ. Working Party S 1.05-03:246- 253.

Schmidt, W., and M. Gourley. 1992. Black bear. Pages 309-311 *in* H. Black (editor), Silvicultural approaches to animal damage management in Pacific Northwest forests. USDA Forest Service General Technical Report PNW-GTR-287. Portland, Oregon.

Schmitt, S. M., S. D. Fitzgerald, T. M. Cooley, C. S. Bruning-Fann, L. Sullivan, D. Berry, T. Carlson, R. B. Minnis, J. B. Payeur, and J. Sikarskie. 1997. Bovine tuberculosis in free-ranging white-tailed deer from Michigan. Journal of Wildlife Diseases 33:749-758.

Spies, T.A., J.F. Franklin, and M. Klopsch. 1990. Canopy gaps in Douglas-fir forests of the Cascade Mountains. Canadian Journal of Forest Research. 20:649-658.

Stewart, W.B., G.W. Witmer, G.M. Koehler, and M. Norton. 2002. Incisor analysis technique to predict the gender of black bears damaging trees. International Biodeterioration and Biodegradation. 49:209-212.

Sullivan, T.P. 1993. Feeding damage by bears in managed forests of western hemlock-western redcedar in midcoastal British Columbia. Canadian Journal of Forest Research 23:49-54.

Takahashi, K. and K. Takahashi. 2013. Spatial distribution and size of small canopy gaps created by Japanese black bears: estimating gap size using dropped branch measurements. BMC Ecology. 13:1-12.

Taylor, J., Morzillo, A., and A. Anderson. 2014. Estimating the total economic impact of black bear peeling in western Oregon using GIS and REMI. Vertebrate Pest Conference 26:419-422.

U.S. Department of Agriculture (USDA) Forest Service. “What is FVS?”. US Forest Service Forest Management Service Center. Web. 24 June 2014.

Wang, C. and D.W. Hann. 1988. Height-diamater equations for sixteen tree species in the central western Willamette Valley of Oregon. Oregon State University College of Forestry Forest Research Lab. Research paper 51. 14 pages.

Watanabe, H. 1977. Damage to conifers by the Japanese black bear. International Conference Bear Research and Management. International Union for Conservation of Nature and Natural Resources. Morges, Switzerland. 3:67-70.

Williams, E. S., M. W. Miller, T. J. Kreeger, R. H. Kahn, and E. T. Thorne. 2002. Chronic wasting disease in deer and elk: a review with recommendations for management. Journal of Wildlife Management 66: 551-567.

Witmer, G., D. Nolte, and W. Stewart. 2000. Integrated pest management of black bear reforestation damage. USDA National Wildlife Research Center-Staff Publications. Paper 824:228-235.

Zeedyk, W.D. 1957. Why do bears girdle balsam fir in Maine? Journal of Forestry 55:731-732.

Ziegltrum, G.J. 2006. Cost-effectiveness of the black bear supplemental feeding program in western Washington. Wildlife Society Bulletin 34:375-379.

Ziegltrum, G.J. 2004. Efficacy of black bear supplemental feeding to reduce conifer damage in western Washington. Journal of Wildlife Management 68:470-474.