

AN ABSTRACT OF THE THESIS OF

Scott T. Walter for the degree of Master of Science in Forest Science presented on November 24, 2003. Title: Snag Longevity, Bird Use of Cavities, and Conifer Response Across Three Silvicultural Treatments in the Oregon Coast Range

Abstract approved:

Signature redacted for privacy.

Chris C. Maguire

In the interest of meeting multiple forest management goals that include maintenance of wildlife, particularly cavity-nesting birds, uneven-aged silvicultural treatments are used increasingly in the Pacific Northwest. However, questions remain regarding the responses of cavity-nesting birds and residual green trees to different harvest intensities and patterns. To study these issues, between 1989 and 1991 the Oregon State University College of Forestry Integrated Research Project (CFIRP) applied 3 silvicultural treatments to 30 mature (85-125 year old) Douglas-fir stands in the Oregon Coast Range. Silvicultural treatments consisted of group-selection cuts (18 stands with 33% of the timber volume extracted from 0.2-0.6 ha patches), two-story regeneration harvests (6 stands with 75% scattered removal of the timber volume resulting in 20-30 distributed residual trees/ha), and clearcuts (6 stands that retained 1.2 mature green trees/ha). In addition, 939 conifers (≥ 53 cm diameter at breast height [DBH]) were topped to create snags in clustered and scattered arrangements. In the current study, CFIRP

stands were utilized to 1) test for differences in cavity-nesting bird use of snags across silvicultural treatments and snag arrangements 10 years after harvest, 2) compare 10 year with 5 year nesting levels, 3) evaluate associations between snag characteristics and cavity nest site location, 4) quantify snag fall, 5) assess silvicultural treatment effects on residual tree growth and condition, and 6) quantify tree mortality.

Snags and topped conifers that remain alive were observed for nesting and foraging use during the 2001 breeding season. Eight species of birds nested in created snags and a mean of 5.1 total cavities/ snag were found one decade after creation. However, no active nesting was observed in topped trees that remained alive. Higher cavity-nesting bird levels, species richness, and species diversity occurred in open-canopy stands (two-story and clearcut treatments) compared to closed-canopy stands (group-selection treatment). Bird species composition was most similar between two-story and clearcut stands, and least similar between clearcut and group-selections stands. No difference was found in nesting or foraging levels between clustered and scattered snags. Active nests in created snags were most commonly located in the top 25% of bole, cavities on average faced northeast, and created snags with and without dead branches received equal nesting use. Compared with 6 years prior, the mean number of cavities per created snag increased 3.3- to 6-fold, and 4 additional avian species were observed nesting. One topped conifer fell in the decade since creation.

Residual green trees ($n = 848$) were measured for growth and condition from November, 2001 to February, 2002. Across silvicultural treatments, residual

green tree basal area, DBH, and height growth, and crown width and crown fullness did not differ among silvicultural treatments 10-12 years following harvest. Overall, 45% of trees experienced greater basal area growth in the decade following harvest than in the decade prior to harvest. Among silvicultural treatments, mean live crown ratio (live crown length/total tree height) of residual trees was significantly greater (0.74) in clearcuts and the percentage of trees with epicormic branching (35%) was significantly higher in two-story stands. Over the last decade residual tree mortality resulted in 134 standing dead trees (snags) and 185 blowdowns. Two-story stands experienced the highest recruitment of snags (0.76 per ha) and blowdowns (1.12 per ha).

Results from this study suggest that topped, large conifers provide snags that offer valuable nesting and foraging habitat for cavity-nesting birds during the first decade after treatment, if the tree dies. Snags in both clustered and scattered arrangements appear to receive equal use by cavity-nesting birds. Also, snags created by topping may have the potential to stand for several decades in the Oregon Coast Range. Furthermore, although silvicultural treatments in this study did not appear to affect residual tree basal area growth during the first 10 years after treatment, partial harvests can promote increased diversity in stand structural complexity, which includes longer tree crowns, epicormic branching, and new snag recruitment, that also can benefit cavity-nesting bird populations through increased nesting and foraging opportunities.

©Copyright by Scott T. Walter
November 24, 2003
All Rights Reserved

SNAG LONGEVITY, BIRD USE OF CAVITIES, AND CONIFER RESPONSE
ACROSS THREE SILVICULTURAL TREATMENTS IN THE
OREGON COAST RANGE

by
Scott T. Walter

A THESIS

submitted to

Oregon State University

In partial fulfillment of
the requirements for the
degree of

Master of Science

Presented November 24, 2003
Commencement June 2004

ACKNOWLEDGEMENTS

First and foremost, I thank Chris Maguire for providing abundant and extremely helpful assistance throughout my degree. Chris' advise proved far more than I could have hoped for, and due to her guidance I have gained an incredible amount of knowledge and experience. I also thank Doug Maguire, Richard Schmitz, and John Tappeiner for advice and help throughout the project, and Eric Maloney for serving as a graduate representative on my committee. Manuela Huso and Lisa Ganio provided help with the study design and statistical components of the project. Manuela in particular provided a great deal of time and help during the entire project. Debbie Johnson kindly provided inside knowledge and maps of the study sites.

The following people deserve many thanks for providing helpful critiques during the writing of this thesis: L. Maggie Byrkit, L. Liza Jane, G. Dave Ritts, T. Gancho Slavov, and particularly Steve Roberts. Dave Waldien, Troy Smith, and Margo Stoddard also provided critiques, but more importantly friendship and encouragement during this project. David Voson Zahler and Abril Turple provided not only editorial reviews, but also cherished friendship and a roof over my itinerant head. Also, Jake Verschuyt and Ryan Emig provided very welcome help and company in the field during a very wet and cold winter field season. Tom Manning also spent time in the field providing advise on bird survey techniques. Field visits by C. M. Duncan Wilson and Justin Soares were greatly appreciated.

My family also has been quite helpful and supportive during my varied academic adventures.

The OSU College of Forestry Fish and Wildlife program and a J. Richard Dilworth Scholarship for Forestry provided funding for this project. Finally, the Department of Forest Science provided tuition for the Organization for Tropical Studies Tropical Biology field course in Costa Rica – which was a truly unique and greatly valued experience during my degree.

TABLE OF CONTENTS

	<u>Page</u>
CHAPTER 1. INTRODUCTION	1
CHAPTER 2. SNAG LONGEVITY AND BIRD USE OF CAVITIES ACROSS THREE SILVICULTURAL TREATMENTS IN THE OREGON COAST RANGE	7
ABSTRACT.....	7
INTRODUCTION.....	8
STUDY AREA and EXPERIMENTAL DESIGN.....	11
METHODS.....	13
Active Cavities and Foraging.....	13
Cumulative Cavities and Foraging Excavations.....	14
Snag and Live Topped-conifer Condition and Snag Recruitment.....	15
Statistical Analyses.....	15
Cavity-nesting Bird Community.....	15
Created Snags.....	16
Natural Snags and Live Topped-conifers.....	17
Temporal Comparison of Cavity Abundance.....	17
RESULTS.....	18
Cavity-nesting Birds.....	18
Community Characteristics.....	18
Active Cavities.....	18
Cumulative Cavities.....	20
Active Foraging and Foraging Excavations.....	21
Snag and Live Topped-conifer Condition and Snag Recruitment	22

TABLE OF CONTENTS (CONTINUED)

	<u>Page</u>
DISCUSSION.....	22
Silvicultural Treatments.....	22
Snag Arrangements.....	26
Temporal Change in Snag Use.....	27
Snag and Live Topped-conifer Characteristics and Nest Site Location.....	30
Snag Longevity and Recruitment.....	33
MANAGEMENT RECOMMENDATIONS.....	35
ACKNOWLEDGEMENTS.....	37
LITERATURE CITED.....	37
CHAPTER 3. CONIFER RESPONSE TO THREE SILVICULTURAL TREATMENTS IN THE OREGON COAST RANGE.....	67
ABSTRACT.....	67
INTRODUCTION.....	68
STUDY AREA and EXPERIMENTAL DESIGN.....	71
METHODS.....	72
Green Tree Measurements.....	72
Plot Surveys.....	72
Grid Surveys.....	73
Density and Mortality	74
Statistical Analyses.....	74
Plot Trees.....	74
Grid Trees.....	74
Plot and Grid Survey Comparison.....	75

TABLE OF CONTENTS (CONTINUED)

	<u>Page</u>
RESULTS.....	75
Tree Growth.....	75
Plot Trees.....	75
Grid Trees.....	76
Plot and Grid Survey Comparison.....	76
Tree Condition.....	77
Density and Mortality.....	78
DISCUSSION.....	78
Tree Growth.....	78
Tree Condition.....	81
Tree Mortality.....	83
MANAGEMENT IMPLICATIONS.....	86
ACKNOWLEDGEMENTS.....	88
LITERATURE CITED.....	88
CHAPTER 4. CONCLUSIONS.....	108
BIBLIOGRAPHY.....	111

LIST OF TABLES

<u>Table</u>		<u>Page</u>
2.1	Observed cavity-nesting bird activities associated with nesting and foraging on created snags (n = 836), natural snags (n = 221), and live topped-conifers (n = 102) in the McDonald-Dunn Research Forest, Oregon.....	44
2.2	Randomized block, 2-factor Analysis of Variance model structure used to assess effects of silviculture treatment and snag arrangement on cavity-nesting bird use of 836 created snags 10-12 yr after their creation (trees were topped between 1989 and 1991), and to test for increases in accumulated cavities from 1995 to 2001 in the same snags.....	45
2.3	Cavity-nesting birds observed during the 2001 breeding season nesting and/or foraging on created (n = 836) and natural (n = 221) snags, and live topped-conifers (n = 102) in the McDonald-Dunn Research Forest, Oregon.....	46
2.4	Shannon-Weiner species diversity indices (H') bracketed by theoretical minimum (H' min.) and maximum (H' max.) values and associated evenness indices (H'/H' max.) for cavity-nesting birds nesting in created snags in 3 silvicultural treatments in the McDonald-Dunn Research Forest, Oregon.....	47
2.5	Counts of created, natural-old, and natural-new snags with active cavity-nesting bird cavities in a) 3 silvicultural treatments and b) 2 snag arrangement treatments in 30 stands in the McDonald-Dunn Research Forest, Oregon....	48
2.6	Counts of created snags with and without dead branches (> 10 cm diameter and > 0.3 m long) and with and without active bird cavities in 30 experimental stands in the McDonald-Dunn Research Forest, Oregon.....	49
2.7	Mean heights and numbers of cavities in created snags (n = 836) used for nesting in the McDonald-Dunn Research Forest, Oregon.....	50

LIST OF TABLES (CONTINUED)

<u>Table</u>		<u>Page</u>
2.8	The number of natural-old snags, natural-new snags, and live topped-conifers with and without bird cavities in 30 experimental stands in the McDonald-Dunn Research Forest, Oregon.....	51
2.9	Total number, number per hectare, and percent residual green mortality as blowdowns and snags across 3 silvicultural treatments (group-selection cuts, n = 18 stands; two-story regeneration harvests, n = 6 stands; and clearcuts with reserve green trees, n = 6 stands) one decade after harvest in the McDonald-Dunn Research Forest, Oregon.....	52
3.1	Randomized block, 1 factor Analysis of Variance model structure used to test for silviculture treatment effects on growth, size, and condition of residual green trees measured a) in small (0.08-0.4 ha) standard radius circular plots and b) large (4 ha) square grids.....	94
3.2	ANOVA results for silviculture effects on residual green tree attributes 10-12 years after stand harvest in the McDonald-Dunn Research Forest, Oregon. Treatments were group-selection cuts (n = 18 stands), two-story regeneration harvests (n = 6 stands), and clearcuts with reserve green trees (n = 6 stands).....	95
3.3	The number of the largest 70% of survey trees with and without epicormic branching on the tree bole below the live crown across 3 silvicultural treatments (group-selection = 18 stands, two-story = 6 stands, clearcut = 6 stands) one decade after harvest.....	96
3.4	Total number, number per hectare, and percent residual green mortality as blowdowns and snags across 3 silvicultural treatments (group-selection cuts, n = 18 stands; two-story regeneration harvests, n = 6 stands; and clearcuts with reserve green trees, n = 6 stands) one decade after harvest in the McDonald-Dunn Research Forest, Oregon.....	97

LIST OF FIGURES

<u>Figure</u>	<u>Page</u>	
2.1	Locations of a) the Oregon State University McDonald-Dunn Research Forest in the Coast Range of Oregon, and b) College of Forestry Integrated Research Program (CFIRP) managed stands (n = 30) across 3 blocks within the Research Forest.....	53
2.2	Cumulative number of cavity-nesting bird species observed nesting in created and natural snags in a) group-selection (n = 18), b) two-story (n = 6), and c) clearcut (n = 6) stands in the McDonald-Dunn Research Forest, Oregon.....	55
2.3	Mean numbers of cavities used by birds for nesting in each 10-12 yr old created snag (n = 836) across a) 3 silvicultural treatments (gs: group-selection, ts: two-story, cc: clearcut) and b) 2 snag arrangements (c: clustered, s: scattered) in 30 stands in the McDonald-Dunn Research Forest, Oregon.....	57
2.4	Mean number of active nests observed in 2001 for all, native, and primary cavity-nesting birds per 10-12 yr old created snag across a) 3 silvicultural treatments and b) 2 snag arrangements in the McDonald-Dunn Research Forest, Oregon.....	59
2.5	Cumulative number of active nests of European starlings and native cavity-nesting birds in 2001 in 10-12 yr old created snags per hectare across 2 open-canopy silvicultural treatments (two-story, clearcut) in 3 blocks (Dunn, Peavy, Lewisburg Saddle) of the McDonald-Dunn Research Forest, Oregon.....	61
2.6	Aspect of the cavity face for 171 active bird nests in 10-12 yr old created snags in the McDonald-Dunn Research Forest, Oregon.....	62

LIST OF FIGURES (CONTINUED)

<u>Figure</u>		<u>Page</u>
2.7	Median numbers of cumulative cavities per created snag in 1995 and 2001 in a) 3 silvicultural treatments and b) 2 snag arrangement treatments in the McDonald-Dunn Research Forest, Oregon.....	64
2.8	Estimated numbers of bird foraging excavations in created snags (n = 836) in a) 3 silvicultural treatments and b) 2 snag arrangements in the McDonald-Dunn Research Forest, Oregon.....	66
3.1	Locations of the a) Oregon State University McDonald-Dunn Research Forest in Oregon and b) College of Forestry Integrated Research Program (CFIRP) managed stands (n = 30) across 3 blocks within the Research Forest.	98
3.2	Location schematic of plot and grid surveys to assess residual green tree growth across group-selection cuts (n = 18 stands) and two-story regeneration harvests (n = 6 stands).....	100
3.3	Mean 1992 and 2002 plot survey results for tree a) DBH b) height, and c) live crown ratio across silviculture harvest treatments (n = 5 group-selection stands, 6 two-story stands) implemented between 1989 and 1991.....	101
3.4	Ratios of post-/pre-harvest basal area growth for conifers (> 10 cm DBH) measured between November 2001 and February 2002 across 3 silvicultural treatments (18 group-selection, 6 two-story, and 6 clearcut stands)	103
3.5	Mean DBH, live crown ratio, basal area growth, height, crown width, percent crown fullness, and epicormic branching ratio of all survey trees (> 10 cm DBH, n = 452 trees) and the largest 70% of survey trees (> 48 cm DBH, n = 192 trees) across 3 silvicultural treatments (n = 18 group-selection, 6 two-story, and 6 clearcut stands) one decade following harvest.....	105

LIST OF FIGURES (CONTINUED)

<u>Figure</u>		<u>Page</u>
3.6	Number of reserve green trees per hectare in each study stand in 2001 that died (blowdowns and snags) across 3 silvicultural treatments (n = 18 group-selection, 6 two-story, and 6 clearcut stands) that were implemented between 1989 and 1991 in the McDonald-Dunn Research Forest, Oregon.....	107

SNAG LONGEVITY, BIRD USE OF CAVITIES, AND CONIFER RESPONSE ACROSS THREE SILVICULTURAL TREATMENTS IN THE OREGON COAST RANGE

CHAPTER 1

INTRODUCTION

The Douglas-fir (*Pseudotsuga menziesii*) region of the Pacific Northwest has some of the most productive forestland in North America and consequently has been subject to timber harvest for over 150 years (Curtis and Carey 1996). Initially, large and valuable trees were selectively logged. In recent decades, entire forest stands have been increasingly clearcut and converted to plantations stocked with fast-growing conifers (Franklin 1989, Salwasser 1990, Swanson and Franklin 1992, Emmingham 1998). Dense, even-aged young plantations now occupy vast expanses of forestland, particularly in the Oregon Coast Range (Spies and Franklin 1991, Aubry et al. 1999). Concerns regarding the ecological health of these structurally simplified stands (Curtis and Carey 1996) have prompted the development and implementation of forest management practices emphasizing non-timber components of ecosystems. These “New Forestry” techniques (Franklin 1989) reflect a new land ethic and endeavor to maintain ecological integrity across the landscape, including the preservation and promotion of habitat for forest wildlife (Grumbine 1994, Perry 1998).

Maintenance of snags for cavity-nesting birds is an important component of forest wildlife habitat management. Cavity nesters utilize snags for foraging and nesting (Neitro et al. 1985, Lundquist and Mariani 1991, Bull et al. 1997,

Weikel and Hayes 1999, Johnson and O'Neil 2000, Lehmkuhl et al. 2003); large snags (> 50 cm diameter at breast height and 15 m tall) typically receive the greatest use (Mannan et al. 1980). In past decades, snags commonly were removed during logging out of safety concerns, with little concern for wildlife needs (Cline et al. 1980, Zarnowitz and Manuwal 1985). This resulted in a reduction of snags compared to past, natural levels. To increase snag numbers, land managers can create snags by killing live trees (Dickson et al. 1983, Bull and Partridge 1986, Hallet et al. 2001). However, long-term trends of cavity-nesting bird use of created snags are unknown (Chambers et al. 1997), and created snag fall rates are yet to be quantified (Brandeis et al. 2002).

Forest structure in addition to snag abundances impacts cavity-nesting bird communities. Thinnings that retain large live trees are used to diversify forest complexity; this in turn increases habitat potential for wildlife (Franklin 1989, Salwasser 1990, Hunter and Bond 2001). Although thinning benefits many bird species (Hayes et al. 1997), differences in harvest intensities and patterns can create variable conditions that have mixed effects on bird species composition and abundance (Hagar et al. 1996, Chambers and McComb 1997, Weikel and Hayes 1999, Tittler et al. 2001).

Aside from wildlife concerns, few studies have quantified timber production rates of retained trees in thinned stands (Swanson and Franklin 1992). Silvicultural treatments alter stand conditions that can affect residual tree growth, condition, and mortality following harvest (Franklin et al. 1987, Franklin and Forman 1987, Swanson and Franklin 1992, Franklin et al. 1997, Latham and

Tappeiner 2002). Timber managers may be reluctant to accept forestry practices alternative to conventional even-aged management until retained tree responses after harvest are better understood (Barbour et al. 1997, Emmingham 1998).

In 1989, the College of Forestry Integrated Research Program (CFIRP) was initiated to provide land managers information regarding vegetation, wildlife, and societal responses to different silvicultural treatments in the Oregon Coast Range (Maguire and Chambers *in press*). For the research, 30 stands in the Oregon State University McDonald-Dunn Research Forest were harvested as group-selection cuts, two-story thinnings, and clearcuts with retained trees (Kellog et al. 1996). In addition, conifers were topped to create snags in clustered and scattered arrangements. Immediate post-harvest results were reported in the ensuing years (summarized in Maguire and Chambers *in press*).

In the current study, CFIRP stands were utilized to 1) test for differences in cavity-nesting bird use of snags across silvicultural treatments and snag arrangements 10 years after harvest, 2) compare 10 year with 5 year nesting intensity, 3) quantify snag fall rates, 4) assess silviculture treatment effects on residual tree growth and condition, and 5) quantify tree mortality. The results of cavity-nesting bird and snag research are reported in Chapter 2 of this thesis and green tree responses to silviculture treatment are reported in Chapter 3. Chapter 4 integrates all results of the current study and provides snag and forest management recommendations based on the findings.

LITERATURE CITED

Aubry, K. B., M. P. Amaranthus, C. B. Halpern, J. D. White, B. L. Woodard, C. E. Peterson, C. A. Lagoudakis, and A. J. Horton. 1999. Evaluating the effects of varying levels and patterns of green-tree retention: experimental design of the DEMO study. *Northwest Science* 73:12-26.

Barbour, R. J., S. Johnston, J. P. Hayes, and G. F. Tucker. 1997. Simulated stand characteristics and wood product yields from Douglas-fir plantations managed for ecosystem objectives. *Forest Ecology and Management* 91:205-219.

Brandeis, T. J., M. Newton, G. M. Filip, and E. C. Cole. 2002. Cavity-nester habitat development in artificially made Douglas-fir snags. *Journal of Wildlife Management* 66(3):625-633.

Bull, E. L., C. G. Parks, and T. R. Torgersen. 1997. Trees and logs important to wildlife in the interior Columbia river basin. U.S. Department of Agriculture Forest Service General Technical Report PNW-GTR-391.

Bull, E. L. and A. D. Partridge. 1986. Methods of killing trees for use by cavity nesters. *Wildlife Society Bulletin* 14(2):142-146.

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

Chambers, C. L. and W. C. McComb. 1997. Effects of silvicultural treatments on wintering bird communities in the Oregon Coast Range. *Northwest Science* 71(4):298-304.

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

Curtis, R. O. and A. B. Carey. 1996. Managing for economic and ecological values in Douglas-fir forests. *Journal of Forestry* 94(9):4-7 and 35-37.

Dickson, J. G., R. N. Conner, and J. H. Williamson. 1983. Snag retention increases bird use of a clear-cut. *Journal of Wildlife Management* 47(3):799-804.

Emmingham, B. 1998. Uneven-aged management in the Pacific Northwest. *Journal of Forestry* 96(7):37-39.

Franklin, J. F. 1989. Toward a new forestry. *American Forests* 95(11):37-44.

- Franklin, J. F., D. R. Berg, D. A. Thornburg, and J. C. Tappeiner. 1997. Alternative silvicultural approaches to timber harvesting: variable retention systems. Pages 111-139 in K. A. Kohm and J. F. Franklin, editors. *Creating a forestry for the 21st century: the science of ecosystem management*. Island Press, Washington D.C., USA.
- Franklin, J. F., and R. T. T. Forman. 1987. Creating landscape patterns by forest cutting: Ecological consequences and principles. *Landscape Ecology* 1(1):5-8.
- Franklin, J. F., H. H. Shugart, and M. E. Harmon. 1987. Tree death as an ecological process. *BioScience* 37(8):550-556.
- Grumbine, R. E. 1994. What is ecosystem management? *Conservation Biology* 8(1):27-38.
- Hagar, J. C., W. C. McComb, and W. H. Emmingham. 1996. Bird communities in commercially thinned and unthinned Douglas-fir stands in western Oregon. *Wildlife Society Bulletin* 24(2):353-366.
- Hallet, J. G., T. Lopez, M. A. O'Connell, and M. A. Borysewicz. 2001. Decay dynamics and avian use of artificially created snags. *Northwest Science* 75(4):378-386.
- Hayes, J. P., S. S. Chan, W. H. Emmingham, J. C. Tappeiner, L. D. Kellogg, and J. D. Bailey. 1997. Wildlife response to thinning in young forests in the Pacific Northwest. *Journal of Forestry* 95(8):28-33.
- Hunter, J. E. and M. L. Bond. 2001. Residual trees: wildlife associations and recommendations. *Wildlife Society Bulletin* 29(3):995-999.
- Johnson, D. H., and T. A. O'Neil. 2000. *Wildlife-habitat relationships in Oregon and Washington*. Oregon State University Press, Corvallis, Oregon, USA.
- Kellogg, L. D., P. Bettinger, and R. M. Edwards. 1996. A comparison of logging planning, felling, and skyline yarding costs between clearcutting and five group-selection harvesting methods. *Western Journal of Applied Forestry* 11(3):90-96.
- Latham, P. and J. Tappeiner. 2002. Response of old-growth conifers to reduction in stand density in western Oregon forests. *Tree Physiology* 22:137-146.
- Lehmkuhl, J. F., R. L. Everett, R. Schellhaas, P. Ohlson, D. Keenum, H. Riesterer, and D. Spurbeck. 2003. Cavities in snags along a wildlife chronosequence in eastern Washington. *Journal of Wildlife Management* 67(1):219-228.

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

Maguire, C. C. and C. L. Chambers, editors. *In press*. College of Forestry Integrated Research Project: Ecological and socioeconomic responses to alternative silvicultural treatments. Oregon State University, College of Forestry, Forestry Research Lab Publication #3582.

Mannan, R. W., E. C. Meslow, and H. M. Wight. 1980. Use of snags by birds in Douglas-fir forests, western Oregon. *Journal of Wildlife Management* 44(4):787-797.

Neitro, W. A., V. W. Binkley, S. P. Cline, R. W. Mannan, B. G. Marcot, D. Taylor, and F. F. Wagner. 1985. Snags (wildlife trees). Pages 129-167 in *Management of wildlife and fish habitats in forests of western Oregon and Washington. Part 1 – chapter narratives*. U.S. Department of Agriculture Forest Service Pacific Northwest Region.

Perry, D. A. 1998. The scientific basis of forestry. *Annual Review of Ecology and Systematics* 29:435-66.

Salwasser, H. 1990. Gaining perspective: forestry for the future. *Journal of Forestry* 88:32-38.

Spies, T. A. and J. F. Franklin. 1991. The structure of natural young, mature, and old-growth Douglas-fir Forests in Oregon and Washington. Pages 91-109 in *Wildlife and vegetation of unmanaged Douglas-fir forests*. U.S. Department of Agriculture Forest Service General Technical Report PNW-GTR-285.

Swanson, F. J. and J. F. Franklin. 1992. New forestry principles from ecosystem analysis of Pacific Northwest forests. *Ecological Applications* 2(3):262-274.

Tittler, R., S. J. Hannon, and M. R. Norton. 2001. Residual tree retention ameliorates short-term effects of clear-cutting on some boreal songbirds. *Ecological Applications* 11(6):1656-1666.

Weikel, J. M. and J. P. Hayes. 1999. The foraging ecology of cavity-nesting birds in young forests of the northern Coast Range of Oregon. *The Condor* 101:58-66.

Zarnowitz, J. E. and D. A. Manuwal. 1985. The effects of forest management on cavity-nesting birds in Northwestern Washington. *Journal of Wildlife Management* 49(1):255-263.

SNAG LONGEVITY AND BIRD USE OF CAVITIES ACROSS THREE SILVICULTURAL TREATMENTS IN THE OREGON COAST RANGE

CHAPTER 2

ABSTRACT

Created snags can provide nesting and foraging opportunities for cavity-nesting birds in managed forests. This study assessed cavity-nesting bird use of natural snags and 10-12 year old snags created by topping mature conifers (≥ 53 cm diameter at breast height) at 17 m across 3 silvicultural treatments (group-selection cuts, two-story regeneration harvests, and clearcuts with retained trees) and 2 snag arrangements (clustered and scattered) in 30 Douglas-fir stands in the Oregon Coast Range. Snags and topped conifers that remain alive were observed for active nesting and foraging during the 2001 breeding season, and their condition was assessed. Eight cavity-nesting species nested in created snags. Open-canopy stands (two-story and clearcut treatments) had higher levels of nesting, species richness, and species diversity compared to closed-canopy group-selection stands. Species composition was most similar between open-canopy stands and least similar between clearcut and group-selection stands. No difference was found in nesting levels between clustered and scattered snags. The average height of active nests in created snags was in the top 25% of bole, cavity entrances normally faced northeast, and the presence of dead branches did not affect snag use for nesting. Topped conifers that remain alive were rarely used for

nesting or foraging. Since the last survey 6 years prior, the number of cavities per created snag increased 3.3- to 6-fold and 4 additional avian species were observed nesting; most were secondary nesters. Overall cavities/snag were 5.1, 4.3, 2.5 for created snags, natural snags > 12 years old, and natural snags < 12 years old, respectively. Most created snags had low decay and only 1 created snag fell in the decade since topping. Natural new snag recruitment resulting from residual green tree mortality exceeded snag losses; recruitment was highest in two-story stands (0.76 snag/ha) and lowest in clearcuts (0.2 snags/ha). These results suggest that snags created by topping large conifers provide nesting and foraging structures for cavity-nesting birds under a range of silvicultural conditions, and that use is influenced more by residual tree density than snag arrangement. In addition, the habitat value of snags increases through the first decade after creation. Use of created snags by birds demonstrates their value as a beneficial habitat management option.

Key words: cavity-nesting birds, created snags, Douglas-fir, Oregon Coast Range, *Pseudotsuga menziesii*, silviculture, snag arrangement, snag longevity

INTRODUCTION

In the 1970s, trends in forest management practices on public lands in the Pacific Northwest began to shift from clearcuts and high timber production goals to multiple-objective management regimes based on partial harvests that focus on sustainable ecosystems (Swanson and Franklin 1992). One objective of forest ecosystem management, initially called “New Forestry” (Franklin 1989), is to maintain viable wildlife populations, including those of cavity-nesting birds

(Grumbine 1994, Perry 1998). Primary cavity-nesting birds excavate nest cavities each breeding season, then abandon them after nesting. In subsequent years these cavities are available to non-excavating secondary cavity nesters. The ability of non-excavating birds to find a nest cavity may be largely or wholly dependent upon the presence of excavating species (Bull et al. 1997, Hansell 2000).

Although cavity-nesting birds use a variety of decayed trees and snags for nesting, foraging, and roosting (Neitro et al. 1985, Lundquist and Mariani 1991, Bull et al. 1997, Weikel and Hayes 1999), snag use depends on many factors. For instance, large snags (> 50 cm diameter at breast height [DBH] and 15 m tall) are used disproportionately more than small snags when they are available (Mannan et al. 1980, Lundquist and Mariani 1991, Schreiber and deCalesta 1992, Lehmkuhl et al. 2003). Furthermore, large cavity-nesting birds such as the pileated woodpecker require large snags to accommodate cavity creation (Bull et al. 1990). Both scattered and clustered snags created by natural tree mortality agents (e.g., fire, insects, root disease; Franklin et al. 1987) offer nesting sites for some cavity-nesting bird species (Raphael and White 1984, Zarnowitz and Manuwal 1985, Li and Martin 1991). Although clustered snags may attract some cavity-nesting species because of abundant foraging opportunities in a concentrated area (Raphael and White 1984, Li and Martin 1991), clustered snags occupied by territorial woodpecker species may limit nesting of other competing individuals of the same or different species within the cluster (Bull et al. 1997).

Over time, forestry practices have precipitated reductions in the historic range of snag size, density, and distribution pattern to the general detriment of

many snag dependent species (Cline et al. 1980). During timber harvest snags frequently are removed to reduce fire risks and safety hazards (Cline et al. 1980, Mannan et al. 1980, Zarnowitz and Manuwal 1985). Following harvest, regeneration efforts focus on fast-growing, healthy trees that in turn result in low rates of natural snag recruitment (Mannan et al. 1980, Peet and Christensen 1987, Bull et al. 1997, Showalter and Whitmore 2002). In addition, short harvest rotations (40-50 yr; Curtis and Carey 1996) limit the availability of large trees and the source of future large snags (Cline et al. 1980, Mannan et al. 1980).

Following widespread recognition of the importance of snags for many wildlife species, forest managers began to intentionally kill trees to increase snag numbers depleted in managed forests over the past decades (Cline et al. 1980, Dickson et al. 1983, Bull and Partridge 1986). Snag creation is still practiced today, and methods to kill trees include chainsaw or dynamite topping, girdling, herbicide injection, and pheromone application to attract bark beetles (Bull and Partridge 1986, Ross and Niwa 1997). No method is consistently effective at killing trees, and each method provides snags of differential durability.

For birds to nest in or forage upon snags, the wood must be sufficiently decayed (Neitro et al. 1985, Bull et al. 1997). Snag decay and the length of time a snag persists is influenced not only by cause of death, but also by tree species, age, amount of heartwood, diameter, height, and local environmental conditions, including stand density (Franklin et al. 1987, Everett et al. 1999). Because snags naturally decay and fall with time, snag longevity is the primary factor for determining the number of green trees to retain during harvest to maintain a

desired snag supply over time (Bull et al. 1997). Although snag fall rates are quantified for some geographic regions (Dickson et al. 1983, Bull and Partridge 1986, Morrison and Raphael 1993, Everett et al. 1999), to date few studies have evaluated the persistence of natural or created snags or their suitability to cavity-nesting species under different silvicultural treatments in the moist forests of western Oregon (Everett et al. 1999).

The following study was undertaken to better understand interactions between snags, cavity-nesting birds, and multiple-objective silviculture practices. The specific objectives of this study were to 1) test for differences in snag use by cavity-nesting birds across 3 silvicultural treatments and 2 snag arrangements in the Oregon Coast Range one decade after treatment implementation, 2) compare avian use of created snags at 5 versus 10 years after creation, 3) evaluate associations between snag characteristics and cavity nest site location, and 4) quantify snag longevity and recruitment.

STUDY AREA and EXPERIMENTAL DESIGN

In 1989, the Oregon State University College of Forestry Integrated Research Project (CFIRP) was initiated in the McDonald-Dunn Research Forest in the Coast Range foothills northwest of Corvallis, Oregon. This project was designed to assess the effects of a range of silviculture harvest intensities and patterns on vegetation, wildlife, and societal responses. It consists of 30 managed stands across 3 blocks: Dunn, Peavy, and Lewisburg Saddle (Figure 2.1). Stand sizes range from 5.5-17.8 ha and elevations range from 120-400 m. Douglas-fir (*Pseudotsuga menziesii*) between 85-125 years old dominate stands, but other tree

species include grand fir (*Abies grandis*), big leaf maple (*Acer macrophyllum*), Oregon white oak (*Quercus garryana*), Pacific madrone (*Arbutus menziesii*), red alder (*Alnus rubra*), Pacific dogwood (*Cornus nuttallii*), Oregon ash (*Fraxinus latifolia*), and bitter cherry (*Prunus emarginata*). Common understory plants include vine maple (*Acer circinatum*), red huckleberry (*Vaccinium parvifolium*), salal (*Gaultheria shallon*), Oregon-grape (*Berberis nervosa*), and sword fern (*Polystichum munitum*). The McDonald-Dunn Research Forest typically has warm summers with an average of 5 cm of rain, and cool winters with approximately 95 cm of precipitation between October and June (Franklin and Dyrness 1988:111). Additional study area and harvest information is published elsewhere (Kellogg et al. 1996, Chambers et al. 1999b, Maguire and Chambers *in press*).

Each of the 30 CFIRP stands received 1 of 3 silvicultural treatments and 1 of 2 snag treatments in a randomized complete block design; 1 block was treated each year in 1989, 1990, and 1991 (Chambers et al. 1997). Silvicultural treatments were group-selection cuts (18 stands), two-story regeneration harvests (6 stands), and clearcuts with retained green trees (6 stands). Treatments were designed to simulate different levels and patterns of natural forest disturbances (Chambers et al. 1999b). Group-selection stands had 33% of the timber volume removed in 0.2-0.6 hectare patches. Two-story stands had 75% of the timber volume removed uniformly across the area resulting in the retention of 20-30 scattered mature trees per ha. All but 1.2 trees per hectare were harvested in clearcut stands. Douglas-fir and a minor component of grand fir were planted after harvest.

Snag treatments consisted of clustered (15 stands) or scattered (15 stands) arrangements at a target density of 3.8 snags per hectare; each silvicultural treatment received both clustered and scattered snags. Individual clusters contained 8-12 snags. Natural snags were included when available ($n = 87$), but most snags were created by topping large (≥ 53 cm DBH) Douglas-fir ($n = 925$) and grand fir ($n = 14$) trees with a chainsaw at approximately 17 m above ground. In group-selection stands snags were restricted to the residual forest. Most topped trees died ($n = 836$); these dead trees are identified as “created snags” and they were 10-12 yr old at the time of this study. Some topped trees that retained live foliage below the point of topping did not die ($n = 102$); these trees are identified as “live topped-conifers.” Natural snags encountered during treatment implementation are identified as “natural-old snags.” In clustered snag treatments, created snags were grouped around natural-old snags. Large trees (≥ 53 cm DBH and ≥ 9.7 m tall) that died between treatment implementation and 2001 ($n = 134$) are identified as “natural-new snags.” Natural-new snags are not present in the clustered snag arrangement. All snags and live topped-conifers are individually identified with aluminum tags and their GPS locations are filed in the McDonald-Dunn Forest research office.

METHODS

Active Cavities and Foraging

During the 2001 breeding season, I randomly observed all snags and live topped-conifers for the number and species of cavity-nesting birds engaged in 9 different nesting or foraging activities (Table 2.1). After arriving at each

observation point, I waited 1 min before recording 5 min of bird activity. Height and aspect of active cavities were determined with a clinometer and compass, respectively. Each snag and live topped-conifer was observed 3 times at approximate 1 mo intervals between 12 April and 12 July for a total of 96.6 observation hours. Observations were made between 0630 and 1700 hr because cavity-nesting birds are active and readily visible throughout the day while breeding and rearing young. Surveys were not conducted when rain hindered the ability to detect birds.

Cumulative Cavities and Foraging Excavations

Between 19 July and 7 November 2001, I counted the number of all cavities and estimated the abundance of all foraging excavations in each snag and live topped-conifer. These counts included cavities and foraging excavations from past years plus those observed during the spring survey. Cavities were identified as circular openings that appeared to have a minimum depth adequate for a nest of the house wren (*Troglodytes aedon*), the smallest cavity-user in the study area, or rectangular openings created by the pileated woodpecker (*Dryocopus pileatus*) (Chambers et al. 1997), the largest cavity-nesting bird. Foraging excavations were irregularly shaped, superficial openings too small for a house wren nest or ≥ 7.5 cm diameter (Chambers et al. 1997). Cavities and foraging excavations were counted from 3 viewpoints around each snag or live topped-conifer when possible (94% of observations) using binoculars. When vegetation blocked 1 or 2 views, an adjusted cavity number was calculated with the formula (3/number of viewpoints)

x (number of cavities in that snag or live topped-conifer) to estimate a complete count. Foraging excavations were numerous and difficult to individually count; therefore, estimates were grouped into 7 abundance categories: 0, 1-10, 11-25, 26-50, 51-75, 76-100, and > 100 excavations.

Snag and Live Topped-conifer Condition and Snag Recruitment

Between July and November 2001, I visually estimated whether each snag and live topped-conifer had no, low, moderate, or advanced decay based on the amount of retained bark and firmness of the exterior wood. Intact bark and hard wood suggested no decay; little bark and extensive wood decomposition suggested advanced decay (Cline et al. 1980). I also estimated the number of dead branches (> 10 cm diameter, > 0.3 m long) on each snag and live topped-conifer, and assigned them to 7 abundance categories: 0, 1-10, 11-25, 26-50, 51-75, 76-100, and > 100 branches. Furthermore, I recorded if the snag had fallen or broken since CFIRP was implemented. Finally, residual green tree (≥ 53 cm DBH) mortality was quantified as new snags, or blowdown resulting from tree fall of live and/or dead trees, across all treatments.

Statistical Analyses

Cavity-nesting Bird Community. I calculated separate Shannon-Weiner Diversity Indices, their associated theoretical minimum and maximum values, and species evenness (Krebs 1999:444) for birds actively using nest cavities across the 3 silvicultural treatments. I also compared the similarity of bird communities across silvicultural treatments using Morisita's Index (Krebs 1999:390). This measure gives the probability that 2 randomly selected individuals from a

community will be the same species. Larger Morisita's numbers in the range 0-1 indicate greater similarity in species composition between two communities.

Created Snags. Randomized block, 2-factor Analysis of Variance (ANOVA) (SAS Institute System, 1999, PROC MIXED) was used to assess effects of the 3 silvicultural treatments and 2 snag arrangements on number of active cavities, cumulative cavities, and foraging excavations in created snags (Table 2.2). To standardize bird use across stands of different sizes and numbers of snags, I used mean bird use per snag per stand as the response variable. Mean foraging excavations per stand were calculated from the mean value of the abundance category range for each snag, and 125 excavations was used for the > 100 excavations category. Significant differences in bird use between silvicultural treatments and snag arrangements were tested at $\alpha = 0.05$, and Tukey's multiple comparison tests were used when appropriate. Cumulative cavities and foraging excavations response variables were log-transformed to adhere to statistical requirements of data normality and equality of variance. These estimates are presented as log back-transformed median values.

Separate additional ANOVAs were used to test for silviculture and snag arrangement effects on number of active cavities per created snag for native primary and secondary cavity nesters and for primary cavity-nesters only. Native species included all cavity nesters encountered except European starlings (*Sturnus vulgaris*). Because active cavities of secondary cavity-nesters were found in less than half of the stands ($n = 13$), this group was not analyzed with ANOVA. Similarly, ANOVAs were not performed on nest use by individual species because

no species was observed using cavities in created snags in more than 22 of the 30 stands.

A 2 x 2 contingency table was used to test for differences in the number of created snags with and without branches that had active cavities, regardless of silviculture treatment or snag arrangement (Ramsey and Schafer 1997:556). The Rayleigh test (Zar 1999:616) was used to test for directionality in active cavity placement in created snags.

Natural Snags and Live Topped-conifers. Due to low samples sizes, contingency tables instead of ANOVAs were used to test for differences in the number of natural-old snags with and without active cavities across silvicultural treatments (2 x 3 table) and between snag arrangements (2 x 2 table), and for differences in natural-new snags with and without cavities across silvicultural treatments (2 x 3 table). Active cavities were not observed in live topped-conifers. A 2 x 3 contingency table also was used to test for differences in the counts of natural-old snags, natural-new snags, and live topped-conifers with and without any cavities.

Temporal Comparison of Cavity Abundance. A randomized block, 2-factor ANOVA was used to test for silviculture treatment and snag arrangement effects on the mean increase in cavities per snag from 1995 to 2001, expressed as the ratio 2001/1995 cavities. Data for 1995 are from Chambers et al. (1997) and are used with permission.

RESULTS

Cavity-nesting Birds

Community Characteristics. I observed 11 cavity-nesting bird species using snags and live topped-conifers for nesting or foraging (Table 2.3). One additional primary (black-capped chickadee [*Parus atricapillus*]) and 2 secondary (American kestrel [*Falco sparverius*], tree swallow [*Tachycineta bicolor*]) cavity-nesters were observed perching on snags. Species accumulation curves suggest that most cavity-nesting birds nesting in the area were encountered (Figure 2.2). The species richness of birds with active cavities in created snags was lowest in group-selection stands and highest in clearcuts; species diversity and evenness was highest in two-story stands and lowest in group-selection stands (Table 2.4, Figure 2.3). The community composition of species with active cavities was most similar between two-story and clearcut stands (Morisita's Index = 0.89), followed by two-story and group-selection stands (Morisita's Index = 0.78). Group-selection and clearcut stands were least similar (Morisita's Index = 0.42).

Active Cavities. Cavity-nesting birds were observed nesting in 19.9% of created snags, in 12.6% of natural-old snags, and in 6.0% of natural-new snags (Table 2.5a). Active cavities were not observed in live topped-conifers. Multiple active cavities were observed in only 1.8% of all snags (Table 2.5a). On average 1 active cavity was located for every 4.9 created snags (mean = 0.2 active cavity per created snag).

Silviculture treatment had a significant effect on the number of active cavities observed in created snags ($F_{2, 10} = 5.05$, $p = 0.03$; Figure 2.4a). Active

cavities were 2.9 times more abundant in clearcuts than in group-selection stands ($t_{10} = 3.13$, $p = 0.01$). However, the number of active cavities was similar between group-selection and two-story stands ($t_{10} = 1.86$, $p = 0.09$) and two-story and clearcut stands ($t_{10} = 1.22$, $p = 0.25$). An increasing trend in active cavity numbers is apparent going from group-selection to two-story to clearcut stands (Figure 2.4a). A difference in the number of active nests was not observed between clustered and scattered snags ($F_{1, 10} = 0.08$, $p = 0.79$; Figure 2.4b). There was no interaction between silviculture treatment and snag arrangement ($F_{2, 10} = 1.47$, $p = 0.28$).

Of the 171 active nests located in created snags, 28 (16.4%) belonged to the exotic European starling; 26 of these nests (93%) were in two-story and clearcut stands in the Dunn block (Figure 2.5). With the removal of starlings from the analysis, native cavity-nesting birds did not respond to either silvicultural treatments ($F_{2, 10} = 2.45$, $p = 0.14$) or snag arrangements ($F_{1, 10} = 0.01$, $p = 0.92$) effects (Figure 2.4), but an increasing trend in active cavity numbers is evident going from group-selection to two-story to clearcut stands. No interaction between silviculture and snag treatments was evident ($F_{2, 10} = 0.85$, $p = 0.46$). When primary cavity-excavators were analyzed in isolation, neither silviculture treatment ($F_{2, 10} = 0.85$, $p = 0.46$) nor snag arrangement ($F_{1, 10} = 0.14$, $p = 0.72$) impacted the number of active cavities in created snags, nor was a trend across silvicultural treatments evident (Figure 2.4); again there was no interaction effect ($F_{2, 10} = 0.44$, $p = 0.66$).

There was no difference in the number of natural-old snags with active nests across silvicultural treatments ($\chi^2_{df=2} = 3.18, p = 0.21$) or between snag arrangements ($\chi^2_{df=1} = 0.08, p = 0.9$) (Table 2.5). The number of natural-new snags with active nests also was not different across silvicultural treatments ($\chi^2_{df=2} = 1.89, p = 0.5$) (Table 2.5a).

Overall, 60% of created snags retained dead branches. There was little evidence to suggest that cavity-nesting birds disproportionately used created snags with or without dead branches for nesting ($\chi^2_{df=1} = 1.37, p = 0.24$; Table 2.6). Among created snags with active cavities, 56% had dead branches. The mean height of active cavities in the 17 m tall created snags was 13.3 m (Table 2.7). The lowest mean active cavity height was 9.8 m; this single nest belonged to a hairy woodpecker. Active cavities faced predominately northeast (mean angle = 49°) ($Z_{171} = 7.62, p = 0.0001$; Figure 2.6).

Cumulative Cavities. Cavities were found in 88% of created snags and there were 5.1 mean cavities per snag 10-12 years after creation. The mean number of cavities differed across silvicultural treatments ($F_{2,10} = 5.08, p = 0.03$; Figure 2.7a). Snags in two-story stands had 1.7 times more cavities than snags in group-selection stands ($t_{10} = 2.9, p = 0.04$). No difference was evident between group-selection and clearcut stands ($t_{10} = 2.13, p = 0.13$) or between two-story and clearcut stands ($t_{10} = 0.66, p = 0.79$). Snag arrangement did not affect cumulative cavity number in 2001 ($F_{1,10} = 0, p = 0.95$; Figure 2.7b). There was no interaction between silviculture treatment and snag arrangement ($F_{2,10} = 0.22, p = 0.81$).

Total increases in cavities per snag from 1995 to 2001 differed among silvicultural treatments ($F_{2, 10} = 8.09$, $p = 0.008$; Figure 2.7a). The increase in cavities in group-selection stands (6.0 times more cavities in 2001 than in 1995) was significantly greater than the increase in either two-story stands (3.3-fold increase, $t_{10} = 3.35$, $p = 0.02$) or clearcuts (3.5-fold increase, $t_{10} = 3.02$, $p = 0.03$). There was no difference in the increase in cavities per snag between two-story and clearcut stands ($t_{10} = 0.27$, $p = 0.96$). Snag arrangement did not affect cumulative cavity increases between 1995 and 2001 ($F_{2, 10} = 0.02$, $p = 0.89$; Figure 2.7b). There was no interaction between silviculture treatment and snag arrangement ($F_{2, 10} = 0.14$, $p = 0.87$).

The number of natural-old snags, natural-new snags, and live topped-conifers with and without excavated cavities differed significantly ($\chi^2_{df=2} = 85.7$, $p < 0.001$; Table 2.8). Although more than half of natural-old (69.8%) and natural-new snags (56.7%) had cavities, only 7.8% of live-topped conifers contained them. Additionally, natural-old and natural-new snags averaged 4.3 and 2.5 cavities per snag, respectively, while live topped-conifers averaged 0.2 cavities.

Active Foraging and Foraging Excavations. Foraging was observed only 43 times during 96.6 observation hours of created, natural-old and natural-new snags, and live topped-conifers. Birds foraged on the bole as opposed to branches in 83% of these observations (Table 2.1), although 64% of snags and topped live-conifers retained branches. Neither silviculture treatment ($F_{2, 10} = 2.83$, $p = 0.11$) nor snag

arrangement ($F_{1,10} = 1.15$, $p = 0.11$) affected the number of foraging excavations per created snag (Figure 2.8) and there was no interaction between variables ($F_{2,10} = 0.03$, $p = 0.97$). Natural-old snags had twice as many foraging excavations as natural-new snags (76 versus 35 foraging excavations per snag, respectively). Live topped-conifers were seldom used for foraging (2 excavations per tree).

Snag and Live Topped-conifer Condition and Snag Recruitment

Most snags (98 %) had low decay and 94% of live topped-conifers had no decay. Only 1 (0.1%) of the 939 topped conifers (created snags and live-topped conifers) fell and another broke since treatment implementation in 1989; both were in clearcuts. Six of 95 (6.3%) natural-old snags either broke or fell; 5 of the 47 (10.6%) in group-selection stands broke and 1 of the 21 (4.8%) in clearcuts fell. In the 12 years since initiation of the study, 134 residual green trees died and remained standing as snags. Natural-new snags in two-story stands were 1.9 and 3.8 times more numerous per hectare than in group-selection and clearcut stands, respectively (Table 2.9). Also since treatment implementation 185 residual green trees blew down. Two-story stands also experienced the highest rate of tree fall per hectare, which was 2.3 and 6.6 more numerous than in group-selection stands and clearcuts, respectively (Table 2.9).

DISCUSSION

Silvicultural Treatments

Aside from presence of snags for nesting, forest structure may influence bird abundance and species composition (Li and Martin 1991, Lundquist and Mariani 1991). Partial harvests in closed-canopy forests typically increase vertical

and horizontal stand structural diversity. Open canopies allow increased light to the understory that stimulates vegetative growth (Hayes et al. 1997, Bailey and Tappeiner 1998, Buermeyer and Harrington 2002), increased light to the lower crown and bole promotes longer crowns (through retention of the lower crown) and epicormic branching (Van Pelt and North 1996, Collier and Turnblom 2001, Franklin et al. 2002, Ishii and Wilson 2001, Chapter 3 of this thesis), and the removal of some trees creates open areas.

Both in this study, and in a study of the same created snags 6 years prior (Chambers et al. 1997), two-story and clearcut stands with open canopies supported higher cavity-nesting bird nesting levels, higher species richness, and greater species diversity compared to group-selection stands with closed canopies between cut patches. Similarly, higher abundances of cavity-nesters and songbirds have been found in 40-55 year old thinned Douglas-fir stands (360 trees/ha) with less dense canopies versus unthinned stands (495 trees/ha) with closed canopies in western Oregon (Hagar et al. 1996). As a consequence of increased diversity in forest structure, increased foraging opportunities are available to some cavity-nesting birds. Although snags are typically used by woodpeckers (e.g., hairy woodpecker, northern flicker, pileated woodpecker) for foraging (Bull et al. 1997), shrubs and live tree boles and crowns that support insect food sources (Sharpe 1996, Winchester and Ring 1996, Halaj et al. 2000) are commonly foraged upon by some cavity-nesting birds that glean insects from vegetative surfaces (e.g., brown creeper, chestnut-backed chickadee, house wren, red-breasted nuthatch, European starling; Carey et al. 1991, Weikel and Hayes 1999). Although foraging

on substrates other than snags was not measured in this study, the low number of observed active foraging events on snags may suggest that the majority of foraging occurred elsewhere. Shrub cover and insect abundance also was not measured in this study, but other research shows that stands with low tree densities allow light to reach the understory and stimulate vegetative growth (Bailey and Tappeiner 1998, Buermeyer and Harrington 2002) and create warm microhabitat conditions that favor insect populations (Sharpe 1996). In response to increased stand openness and shrub cover, bird abundance has been found to increase (Hagar et al. 1996). Therefore, when snag densities are similar, open-canopy stands may support higher numbers and more species of cavity-nesting birds compared to stands with closed-canopies (Hagar et al. 1996, Sharpe 1996, Chambers et al. 1997).

In addition to bird abundance and species richness, the degree of canopy closure can also influence cavity-nesting bird species compositions (Hansen et al. 1995). In this study, group-selection and clearcut stands, with the greatest and lowest tree densities, respectively, had the least similar cavity-nesting bird species compositions. Two-story and clearcut stands that have open-canopies had the most similar species compositions. Also, cavity-nesting and songbird species composition was most similar between two-story and clearcut stands during the first 4 years after silviculture treatment implementation (Chambers and McComb 1997, Chambers et al. 1999a). Bird guilds based on habitat use can be broadly divided into species groups associated with either open- or closed-canopy forests (Hansen et al. 1995, Kaufman 1996). For instance, violet-green swallows that

forage on the wing require forest conditions with large open areas between tree crowns to permit aerial foraging (Kaufman 1996). Therefore, stands with low tree densities and open-canopies likely provide similar forest structure that favors bird species associated with open conditions compared to stands with dense forest canopies (Hansen et al. 1995, Kaufman 1996).

Although open-canopy stands provided habitat structure that supported the majority of cavity-nesting birds in this study, closed-canopy forest are valuable to species that require intact forest conditions for nesting, such as the pileated woodpecker. This species typically nests in large snags (> 50 cm DBH and 9 m tall; Bull et al. 1997) found in old-growth forest (> 195 years old; Spies and Franklin 1991) with > 60% canopy cover (Bull et al. 1990, Bull and Holthausen 1993, Aubry and Raley 2002). In this study, despite the presence of snags of suitable nesting sizes and observations of pileated woodpeckers foraging in group-selection stands, no evidence of nesting was found in any of the treatments in the 85-125 year old CFIRP stands. The absence of nesting pileated woodpeckers in this study is likely because study stands presumably have not yet fully developed old-growth structural attributes that attract nesting individuals common in forests > 195 years old (i.e., large hollow trees, abundant large down wood and live trees; Bull et al. 1990). However, as CFIRP group-selection stands approach 200 years of age, their closed-canopies may attract and support nesting pileated woodpeckers (Bull et al. 1990, Bull and Holthausen 1993). Silvicultural treatments that create both closed- and open-canopies are important to promote forest structure that supports cavity-nesting birds with a range of habitat associations.

Snag Arrangements

Snags in unmanaged Pacific Northwest conifer forests occur in both clustered and scattered arrangements (Cline et al. 1980) because of a host of tree mortality agents (e.g., fire, insects, root disease) that kill individuals and groups of trees (Franklin et al. 1987, Ohmann et al. 1994, Bull et al. 1997). However, land managers have questioned which snag spatial configuration most effectively provides cavity-nesting bird nesting and foraging opportunities (Chambers et al. 1997) while meeting worker safety regulations (Neitro et al. 1985).

In this study, clustered and scattered snags received equal nesting and foraging use. Likewise, these same snags held equal numbers of nest cavities in both arrangements 6 years prior this study (Chambers et al. 1997). Most cavity-nesting bird studies in the Pacific Northwest only report snag use of isolated snags (Schreiber and deCalesta 1992, Hallet et al. 2001, Brandeis et al. 2002, Lehmkühl et al. 2003). However, a few studies have indicated that cavity-nesting birds opportunistically nest in clustered snags when available, but these studies do not compare use between clustered and scattered arrangements (Raphael and White 1984, Zarnowitz and Manuwal 1985, Li and Martin 1991). Raphael and White (1984) and Li and Martin (1991) suggest that clustered snags may attract cavity-nesting birds because of abundant foraging opportunities on snags in close proximity to one another. This advantage mostly would benefit woodpeckers that predominately forage on snags, relative to other cavity-nesting species that predominately forage on live vegetation (e.g., brown creeper, chestnut-backed

chickadee, European starling, red-breasted nuthatch; Kaufman 1996, Weikel and Hayes 1999).

Although Bull et al. (1997) suggest that territorial woodpeckers in clustered snags may restrict nesting of other birds, they do not provide details of snag proximity and abundance, cavity-nesting bird abundance, and forest type. Because many created snags were unused for active nesting during this study (only one active nest was located in every 4.9 created snags), this indicates that CFIRP snag densities possibly met local cavity-nesting bird requirements and competition for nest sites did not limit nesting in clustered snags. However, the lack of data on cavity nester abundance, and distances between nesting individuals within clustered snags do not allow for assessment of territoriality effects on nesting.

From a wildlife habitat perspective, creation of both clustered and scattered snags appears useful for the provision of cavity-nesting bird habitat in the first decade after creation (Chambers et al. 1997). From a safety perspective, previous studies have suggested that grouped snags can be more easily avoided during timber harvest compared to scattered snags, and consequently provide safer logging conditions (Neitro et al. 1985, Bull et al. 1997). Therefore, clustered snags may best meet both habitat management and worker safety goals.

Temporal Change in Snag Use

Decay must be sufficiently advanced in order to provide wood soft enough for excavation by primary cavity-nesting birds (Bull et al. 1997). Decay development in snags and subsequent cavity-nesting bird use is dependent upon several factors, particularly the source of tree mortality (Franklin et al. 1987).

Some causes of mortality, such as those that expose the inner wood (i.e., crown loss), promote greater snag decay than others (Bull et al. 1997). Because there are multiple techniques used to kill trees for snags (Bull and Partridge 1986), researchers and land managers have questioned which method provides the most usable habitat for cavity-nesting birds (Brandeis et al. 2002, Hallet et al. 2001).

The CFIRP snags created by topping were utilized for nesting within 4-6 years after creation (Chambers et al. 1997). In this study, there was a several-fold increase in cavities from 4-6 years to 10-12 years after snag creation. In other studies that compare various conifer snag creation techniques in the Pacific Northwest, snags created by topping consistently result in higher cavity-nesting bird foraging and nesting use within the first 9 years after snag creation (Bull and Partridge 1986, Hallet et al. 2001, Brandeis et al. 2002). The majority of active nest cavities in the CFIRP created snags were placed in the upper portion of the bole, as found in other cavity-nesting bird studies (Mannan et al. 1980, Li and Martin 1991). Snag creation by topping appears to provide favorable nesting sites because crown removal exposes the inner wood to decay organisms (Neitro et al. 1985, Bull et al. 1997, Hallet et al. 2001) that soften the wood in the upper snag bole, thereby facilitating cavity excavation (Bull and Partridge 1986, Bull et al. 1997, Hallet et al. 2001, Brandeis et al. 2002).

In addition to increased nesting in created CFIRP snags over time, the number of cavity-nesting bird species observed in study stands increased from 7 species at one year following silvicultural treatment implementation to 14 species during this study (Chambers et al. 1999a). Furthermore, the number of species

that nested in created snags also increased over time since creation. All species observed in 1995 (Chambers et al. 1997) were observed again in 2001, and 4 new species, of which 3 were secondary cavity nesters (e.g., European starling, house wren, violet-green swallow), were observed nesting during this study. Secondary cavity nesters rely upon existing cavity nest sites that are often excavated by primary cavity-nesting birds (Bull et al. 1997). When the snags were 4-6 years old, abandoned nest cavities were likely scarce because > 5 years typically must pass before snags possess sufficient decay for extensive cavity excavation by primary excavators (Mannan et al. 1980, Bull et al. 1997). Therefore, secondary cavity-nesters were likely unable to secure nest cavities at that time. Since then, nest sites have become more available, presumably due to increased decay (Cline et al. 1980) and cavity excavation, and can now support secondary cavity-nesting birds.

The recent detection of the European starling in two-story and clearcut stands is of particular interest, as this exotic species has the potential to negatively affect native cavity-nesting birds (Peterson and Gauthier 1985, Weitzel 1988, Ingold 1996) through aggressive nest site competition (Feare 1984:40, Cabe 1993, Kaufman 1996). The majority of starling nests were located in stands in the Dunn block that neighbor 780 hectares of agricultural lands including hayfields. Fields grazed by cattle on this farm provide ideal foraging habitat for insectivorous starlings (Feare 1984:56). Nesting starlings can reduce numbers of nest cavities available to secondary nesters, and also usurp cavities from primary and secondary nesters (Feare 1984:40, Weitzel 1988). Starlings forced up to 39% of

woodpeckers out of nest cavities in snags located near agricultural pastures in Ohio (Ingold 1994). Even if cavity-nesting birds that lose nest sites to starlings secure or create new cavities, delayed nesting may result in reduced reproductive output for several reasons, such as deleterious cavity temperatures for eggs or young and reduced seasonal food sources for nestlings (Ingold 1996). Although CFIRP stands with starlings still supported other cavity-nesting species, the continued establishment of starlings may preclude some native species from nesting in the future.

Snag and Live Topped-conifer Characteristics and Nest Site Location

Some researchers suggest that branches on snags are beneficial because they can provide shelter over nest cavities (McEllin 1979). Others indicate that branch surfaces provide some birds with foraging opportunities (Lundquist and Mariani 1991, Weikel and Hayes 1999). However, in the decade following snag creation in this study, the presence or absence of dead branches on created snags did not significantly affect cavity nesting, although a trend was evident for more cavities when branches were present. In a study of natural snags in western Oregon, the absence of branches did not appear to hinder nesting as nest cavities were commonly found in snags with few or no dead branches (Mannan et al. 1980). In the CFIRP stands, less than 20% of foraging events were observed on branches of snags and live topped-conifers. Branches offer relatively little foraging surface area in comparison to snag boles. Also, insect food sources found within decayed wood are more common in the snag bole than in branches with dense wood (Cline et al. 1980, Ross and Niwa 1997).

In contrast to snags with dead branches, topped-conifers with live branches contained no active nests and were rarely used for foraging during this study. No sapwood decay was evident in the vast majority of these live topped-conifers. Birds rarely create cavities in live trees because of the hard structural properties of the wood (Mannan et al. 1980, Lundquist and Mariani 1991, Spies and Franklin 1991). Birds in this study were likely unable to create nests in live topped-conifers due to a lack of sapwood decay that is required for cavity excavation (Mannan et al. 1980, Bull et al. 1997). Furthermore, foraging on topped conifers that remain alive also may have been limited because most insect food sources are found in decayed compared with hard wood (Neitro et al. 1985).

Although branches did not significantly impact cavity placement in snags, cavity orientation was highly directional. Most cavities faced northeast, away from prevailing spring winds from the south and west (Oregon Climate Service 2003). Earlier research suggests that cavity-nesting birds often position nests to minimize their exposure to wind and rain (Collias and Collias 1984, Hansell 2000). In regions with cool climates such as in the Pacific Northwest, cavities that face away from prevailing winds provide more stable and warmer nest conditions for eggs and chicks that can result in increased nest success (McEllin 1979, Hansell 2000).

Most active nests in this study were in the top 25% of the 17 m tall created snags. Because nest cavities that are closer to the ground experience higher predation rates than those located at greater heights (Li and Martin 1991), it is advantageous for cavity nesters to locate nests at the tallest height where snag

diameter requirements are still sufficient (Bull et al. 1997). Cavity nesting birds in the Oregon Coast Range typically use natural snags > 15 m in total height for nesting and place nests in the upper third of the snag bole (Mannan et al. 1980). The 17 m height of snags created in this study closely matches the average nest height (18 m) used by cavity-nesting birds in the area, as documented by Mannan et al. (1980).

As previously suggested, differences in the interrelated factors of snag age and decay (Cline et al. 1980) can result in differential snag use by cavity-nesting birds (Mannan et al. 1980). The differences in nesting use between created and natural snags in this study may be related to differences in snag age and decay. Created snags and natural-old snags had similar mean numbers of excavated cavities per snag. However, there were over 2 times more cavities in created snags than in natural-new snags. Because of the older ages of created snags in comparison to natural-new snags, snags created by topping likely have higher levels of decay that allows for greater cavity excavation (Mannan et al. 1980). In comparison to other snags in the Oregon Coast Range, 10 years after creation the CFIRP created snags held 2.3 times the number of cavities found in natural snags (2.2 cavities/snag) in unmanaged forest stands (Mannan et al. 1980). However, smaller snag sizes (as small as 9 cm DBH) and younger stand ages (as young as 10 years old) in the Mannan et al. (1980) study may explain the lower mean snag use, as larger snag sizes and older forest ages (found in this study) typically result in greater cavity-nesting bird use (Mannan et al. 1980, Lundquist and Mariani 1991, Schreiber and deCalesta 1992, Lehmkuhl et al. 2003).

Snag Longevity and Recruitment

Aside from questions regarding which snag creation technique best provides habitat for cavity-nesting birds, researchers and land managers have also questioned which technique creates snags with the greatest longevity (Bull and Partridge 1986). To date, nearly all created and natural CFIRP snags remain standing. Similar results were observed in eastern Washington, where the vast majority (98.6%) of conifer snags (> 28 cm DBH) remained standing 9 years after creation by topping (Hallet et al. 2001). In drier forests of eastern Oregon, snags created by topping also experience greater snag survival compared to other methods 5 years after treatments (100% versus 75% for herbicide injection, and 42% for girdling at the tree base). Because the removal of crowns offers less wind resistance to the snag, topping appears to reduce susceptibility of blowdown of created snags (Bull and Partridge 1986).

Besides the method of snag creation, the species of tree can influence decay rates due to different wood properties, decay resistance, and thus snag durability (Bull et al. 1997). Among tree species, Douglas-fir snags, particularly those > 50 cm DBH, decay relatively slowly and can maintain the structural integrity to resist snag fall for > 100 years in the Oregon Coast Range (Cline et al. 1980, Neitro et al. 1985, Bull et al. 1997). In addition to snags created in this study, the majority of natural snags also remain standing. Based on the high initial snag survival rates, large snag diameters, and absent crowns in created snags, the majority of the CFIRP snags likely have the potential to stand for several additional decades (Cline et al. 1980, Bull and Partridge 1986, Bull et al. 1997).

To ensure a supply of large snags (> 50 cm DBH) over time as current snags fall, large residual trees can be retained at harvest to provide future snag sources (Neitro et al. 1985). However, windthrow of trees retained at harvest (Franklin and Forman 1987, Buermeyer and Harrington 2002) can reduce future snag sources. Based on the highest rate of tree blowdown in this study (0.1 tree/ha/yr in two-story stands; Table 2.9), 15 trees retained per hectare would provide sufficient snag sources to maintain 4 snags per hectare (the mean density found in old-growth forests in the Oregon Coast Range; Spies et al. 1988) for 100 years after harvest. At that time, current tree regeneration would approach sizes sufficient for new large snag recruitment (Mannan et al. 1980). Because retained tree blowdown is generally highest during the first few years after harvest (Franklin et al. 1997), the above blowdown rate, calculated from blowdown in the first decade after harvest, likely underestimates long-term annual rates. However, to account for possible tree losses due to future intense storm events that can cause severe blowdown (Veblen et al. 2001), more than 15 trees per hectare may be required for future snag sources.

Reserve green tree mortality across silvicultural treatments resulted in new snags in most study stands and outweighed snag loss. Although a host of mortality agents (e.g., insects, disease, environmental stress) likely contributed to tree death (Franklin et al. 1987), logging damage may have been one possible cause, particularly in two-story and clearcut stands. During logging, falling trees and/or harvest equipment can break branches and gouge boles of retained trees (Cline et al. 1991, Han et al. 2000, Youngblood 2000, Hartsough 2003). These tree wounds

offer an entry point for decay organisms (Han et al. 2000, Matzka and Kellogg 2003) that may eventually kill the tree (Franklin et al. 1987, Emmingham 1998). Residual green trees in two-story and clearcut stands in this study experienced considerably higher mortality rates than trees in group-selection stands. Other studies in the Pacific Northwest have found high proportions of residual tree damage (between 27 and 39%) following harvest of timber uniformly across the stand (Howard 1996, Youngblood 2000). Additionally, higher residual tree damage typically occurs during scattered harvest versus concentrated harvest (Moore et al. 2002). Thus when harvests extract timber throughout the stand, a greater proportion of the area is disturbed and a higher percentage of trees are susceptible to logging damage relative to group-selection cuts that retain intact forest patches (Howard 1996, Youngblood 2000, Moore et al. 2002).

MANAGEMENT RECOMMENDATIONS

To improve habitat for cavity-nesting birds in managed forest stands, this study indicates that snags created by topping large Douglas-fir trees can provide valuable nesting and foraging sites. Removal of remaining live branches following topping would be beneficial to ensure tree death and subsequent wood decay necessary for cavity excavation. Branch removal apparently would not hinder snag use for nesting as suggested by similar nesting use in snags with and without branches in this study.

High created snag longevity in this study suggests that topping large conifers may provide long-standing snag habitat. However, to replace current snags that fall or break over time, the retention of at least 15 large trees/ha at

harvest can provide future snag sources to meet snag densities found in old-growth forest in the Oregon Coast Range (4.2 snags > 50 cm DBH per ha; Spies et al. 1988) until current tree regeneration reaches large diameters.

In dense, mature conifer stands, silvicultural treatments that retain 30 or fewer green trees per hectare appear to promote increased diversity in stand structure that supports relatively higher numbers and species of cavity-nesting birds, and greater species diversity compared to treatments that maintain dense forest with closed canopies. However, the exotic European starling, which has been previously reported to negatively affect native cavity nesters (Weitzel 1988, Ingold 1994, Ingold 1996), also favors open-canopy forest habitat. For conservation of native cavity-nesting bird species, partial harvests that maintain closed-canopies may deter starlings that seldom nest in dense forests (Cabe 1993, Chambers and McComb 1997). Closed-canopy forest, particularly at ages of 200+ years old, also may be valuable in the provision of habitat for species that nest in intact forest, such as the pileated woodpecker.

Although there were no differences between cavity-nesting bird use of clustered and scattered snags at the time of this study, grouped arrangements may present a more desirable option to land managers. Clustered snags not only meet snag habitat goals 10 years after creation, but because they can be more easily avoided during harvest compared to scattered snags, they present safer logging conditions relative to evenly distributed snags (Cline et al. 1980, Neitro et al. 1985, Bull et al. 1997, Franklin et al. 1997).

ACKNOWLEDGEMENTS

This project was funded by the Oregon State University College of Forestry Fish and Wildlife Program and a J. Richard Dilworth Scholarship for Forestry. I would like to thank Chris Maguire for extensive help on all aspects of the project; Lisa Ganio and Manuela Huso for statistical advise; Debbie Johnson for study site maps; Steve Roberts, Troy Smith, Margo Stoddard, April Turtle, Dave Waldien, and David Zahler for discussion and editorial reviews throughout the project; Tom Manning, Duncan Wilson, and Justin Soares for field assistance; and Bill Emmingham, Doug Maguire, Richard Schmitz, and John Tappeiner for technical advise.

LITERATURE CITED

- Aubry, K. B. and C. M. Raley. 2002. Selection of nest and roost trees by pileated woodpeckers in coastal forests of Washington. *Journal of Wildlife Management* 66(2):392-406.
- Bailey, J. D. and J. C. Tappeiner. 1998. Effects of thinning on structural development in 40- to 100-year-old Douglas-fir stands in western Oregon. *Forest Ecology and Management* 108(2):99-113.
- Brandeis, T. J., M. Newton, G. M. Filip, and E. C. Cole. 2002. Cavity-nester habitat development in artificially made Douglas-fir snags. *Journal of Wildlife Management* 66(3):625-633.
- Buermeyer, K. R. and C. A. Harrington. 2002. Fate of overstory trees and patterns of regeneration 12 years after clearcutting with reserve trees in southwest Washington. *Western Journal of Applied Forestry* 17(2):78-85.
- Bull, E. L. and R. S. Holthausen. 1993. Habitat use and management of pileated woodpeckers in Northeastern Oregon. *Journal of Wildlife Management* 57(2):335-345.

- Bull, E. L., R. S. Holthausen, and M. G. Henjum. 1990. Techniques for monitoring pileated woodpeckers. U.S. Department of Agriculture Forest Service General Technical Report PNW-GTR-269.
- Bull, E. L., C. G. Parks, and T. R. Torgersen. 1997. Trees and logs important to wildlife in the interior Columbia river basin. U.S. Department of Agriculture Forest Service General Technical Report PNW-GTR-391.
- Bull, E. L. and A. D. Partridge. 1986. Methods of killing trees for use by cavity nesters. *Wildlife Society Bulletin* 14(2):142-146.
- Cabe, P. R. 1993. European starling. Pages 1-24 in A. Poole and F. Gill, editors. *The birds of North America: life histories for the 21st century*. Smith-Edwards-Dunlap, Philadelphia, Pennsylvania, USA.
- Carey, A. B., M. M. Hardt, S. P. Horton, and B. L. Biswell. 1991. Spring bird communities in the Oregon Coast Range. Pages 123-141 in *Wildlife and vegetation of unmanaged Douglas-fir forests*. U.S. Department of Agriculture Forest Service General Technical Report PNW-GTR-285.
- Chambers, C. L., T. Carrigan, T. E. Sabin, J. Tappeiner, and W. C. McComb. 1997. Use of artificially created Douglas-fir snags by cavity-nesting birds. *Western Journal of Applied Forestry* 12:93-97.
- Chambers, C. L. and W. C. McComb. 1997. Effects of silvicultural treatments on wintering bird communities in the Oregon Coast Range. *Northwest Science* 71(4):298-304.
- Chambers, C. L., W. C. McComb, and J. C. Tappeiner. 1999a. Breeding bird responses to three silvicultural treatments in the Oregon Coast Range. *Ecological Applications* 9(1):171-185.
- Chambers, C. L., W. C. McComb, J. C. Tappeiner, L. D. Kellog, R. L. Johnson, and G. Spycher. 1999b. CFIRP: What we learned in the first ten years. *The Forestry Chronicle* 75(3):431-434.
- Cline, S. P., A. B. Berg, and H. M. Wight. 1980. Snag characteristics and dynamics in Douglas-fir forests, western Oregon. *Journal of Wildlife Management* 44(4):773-786.
- Cline, M. L., B. F. Hoffman, M. Cyr, and W. Bragg. 1991. Stand damage following whole-tree partial cutting in northern forests. *Northern Journal of Applied Forestry* 8(2):72-76.

- Collias N. E. and E. C. Collias. 1984. Nest building and bird behavior. Princeton University Press, New Jersey, USA.
- Collier, R. L. and E. C. Turnblom. 2001. Epicormic branching on pruned coastal Douglas-fir. *Western Journal of Applied Forestry* 16(2):80-86.
- Curtis, R. O. and A. B. Carey. 1996. Managing for economic and ecological values in Douglas-fir forests. *Journal of Forestry* 94(9):4-7 and 35-37.
- Dickson, J. G., R. N. Conner, and J. H. Williamson. 1983. Snag retention increases bird use of a clear-cut. *Journal of Wildlife Management* 47(3):799-804.
- Emmingham, B. 1998. Uneven-aged management in the Pacific Northwest. *Journal of Forestry* 96(7):37-39.
- Everett, R., J. Lehmkuhl, R. Schelhaas, P. Ohlson, D. Keenum, H. Riesterer, and D. Spurbeck. 1999. Snag dynamics in a chronosequence of 26 wildfires on the east slope of the Cascade Range in Washington state, USA. *International Journal of Wildland Fire* 9(4):223-234.
- Feare C. 1984. *The starling*. Oxford University Press, New York, New York, USA.
- Franklin, J. F. 1989. Toward a new forestry. *American Forests* 95(11):37-44.
- Franklin, J. F., D. R. Berg, D. A. Thornburg, and J. C. Tappeiner. 1997. Alternative silvicultural approaches to timber harvesting: variable retention systems. Pages 111-139 in K. A. Kohm and J. F. Franklin, editors. *Creating a forestry for the 21st century: the science of ecosystem management*. Island Press, Washington D.C., USA.
- Franklin, J. F. and C. T. Dyrness. 1988. *Natural vegetation of Oregon and Washington*. Oregon State University Press, Corvallis, Oregon, USA.
- Franklin, J. F., and R. T. T. Forman. 1987. Creating landscape patterns by forest cutting: Ecological consequences and principles. *Landscape Ecology* 1(1):5-8.
- Franklin, J. F., H. H. Shugart, and M. E. Harmon. 1987. Tree death as an ecological process. *BioScience* 37(8):550-556.
- Franklin, J. F., T. A. Spies, R. Van Pelt, A. B. Carey, D. A. Thornburgh, D. R. Berg, D. B. Lindenmayer, M. E. Harmon, W. S. Keeton, D. C. Shaw, K. Bible, and J. Chen. 2002. Disturbances and structural development of natural forest ecosystems with silvicultural implications, using Douglas-fir forests as an example. *Forest Ecology and Management* 155(3):399-423.

- Grumbine, R. E. 1994. What is ecosystem management? *Conservation Biology* 8(1):27-38.
- Hagar, J. C., W. C. McComb, and W. H. Emmingham. 1996. Bird communities in commercially thinned and unthinned Douglas-fir stands in western Oregon. *Wildlife Society Bulletin* 24(2):353-366.
- Halaj, J., D. W. Ross, and A. R. Moldenke. 2000. Importance of habitat structure to the arthropod food-web in Douglas-fir canopies. *Oikos* 90(1):139-152.
- Hallet, J. G., T. Lopez, M. A. O'Connell, and M. A. Borysewicz. 2001. Decay dynamics and avian use of artificially created snags. *Northwest Science* 75(4):378-386.
- Han, H-S, L. D. Kellog, G. M. Filip, and T. D. Brown. 2000. Scar closure and future timber value losses from thinning damage in western Oregon. *Forest Products Journal* 50(1):36-42.
- Hansell, M. 2000. Bird nests and construction behaviour. Cambridge University Press, New York, New York, USA.
- Hansen, A. J., W. C. McComb, R. Vega, M. G. Raphael, and M. Hunter. 1995. Bird habitat relationships in natural and managed forests in the west Cascades of Oregon. *Ecological Applications* 5(3):555-569.
- Hartsough, B. 2003. Economics of harvesting to maintain high structural diversity and resulting damage to residual trees. *Western Journal of Applied Forestry* 18(2):133-142.
- Hayes, J. P., S. S. Chan, W. H. Emmingham, J. C. Tappeiner, L. D. Kellogg, and J. D. Bailey. 1997. Wildlife response to thinning in young forests in the Pacific Northwest. *Journal of Forestry* 95(8):28-33.
- Howard, A. F. 1996. Damage to residual trees from cable yarding when partial cutting second-growth stands in coastal British Columbia. *Canadian Journal of Forest Research* 26(8):1392-1396.
- Ingold, D. J. 1994. Influence of nest-site competition between European starlings and woodpeckers. *Wilson Bulletin* 106(2):227-241.
- Ingold, D. J. 1996. Delayed nesting decreases reproductive success in northern flickers: implications for competition with European starlings. *Journal of Field Ornithology* 67(2):321-326.

- Ishii, H. and M. E. Wilson. 2001. Crown structure of old-growth Douglas-fir in the western Cascade Range, Washington. *Canadian Journal of Forest Research* 31(7):1250-1261.
- Johnson, D. H., and T. A. O'Neil. 2000. *Wildlife-habitat relationships in Oregon and Washington*. Oregon State University Press, Corvallis, Oregon, USA.
- Kaufman, K. 1996. *Lives of North American birds*. Houghton Mifflin Company, Boston, Massachusetts, USA.
- Kellogg, L. D., P. Bettinger, and R. M. Edwards. 1996. A comparison of logging planning, felling, and skyline yarding costs between clearcutting and five group-selection harvesting methods. *Western Journal of Applied Forestry* 11(3):90-96.
- Krebs, C. J. *Ecological methodology*. Second edition. 1999. Addison Welsey Longman. Menlo Park, California, USA.
- Lehmkuhl, J. F., R. L. Everett, R. Schellhaas, P. Ohlson, D. Keenum, H. Riesterer, and D. Spurbeck. 2003. Cavities in snags along a wildlife chronosequence in eastern Washington. *Journal of Wildlife Management* 67(1):219-228.
- Li, P. and T. E. Martin. 1991. Nest-site selection and nesting success of cavity-nesting birds in high elevation forest drainages. *The Auk* 108(2):405-418.
- Lundquist, R. W. and J. M. Mariani. 1991. Nesting habitat and abundance of snag-dependent birds in the southern Washington Cascade Range. Pages 221-239 *in* *Wildlife and vegetation of unmanaged Douglas-fir forests*. U.S. Department of Agriculture Forest Service General Technical Report PNW-GTR-285.
- Maguire, C. C. and C. L. Chambers, editors. *In press*. College of Forestry Integrated Research Project: Ecological and socioeconomic responses to alternative silvicultural treatments. Oregon State University, College of Forestry, Forestry Research Lab Publication #3582.
- Mannan, R. W., E. C. Meslow, and H. M. Wight. 1980. Use of snags by birds in Douglas-fir forests, western Oregon. *Journal of Wildlife Management* 44(4):787-797.
- Matzka, P. J. and L. D. Kellogg. 2003. Harvest system selection and design for damage reduction in noble fir stands: a case study on the Warm Springs Indian Reservation, Oregon. *Western Journal of Applied Forestry* 18(2):118-126.
- McEllin, S. M. 1979. Nest sites and population demographics of white-breasted and pigmy nuthatches in Colorado. *Condor* 81:348-352.

- Moore, J. R., D. A. Maguire, D. L. Phillips, and C. B. Halpern. 2002. Effects of varying levels and patterns of green-tree retention on amount of harvesting damage. *Western Journal of Applied Forestry* 17(4):202-206.
- Morrison, M. L. and M. G. Raphael. 1993. Modeling the dynamics of snags. *Ecological Society of America* 3(2):322-330.
- Neitro, W. A., V. W. Binkley, S. P. Cline, R. W. Mannan, B. G. Marcot, D. Taylor, and F. F. Wagner. 1985. Snags (wildlife trees). Pages 129-167 in E. R. Brown, editor. *Management of wildlife and fish habitats in forests of western Oregon and Washington. Part 1: chapter narratives*. Portland, Oregon, U.S. Department of Agriculture Forest Service Pacific Northwest Region.
- Ohmann, J. L., W. C. McComb, and A. A. Zumrawi. 1994. Snag abundance for primary cavity-nesting birds on nonfederal forest lands in Oregon and Washington. *Wildlife Society Bulletin* 22(4):607-620.
- Oregon Climate Service. 2003. <http://www.ocs.orst.edu/>
- Peet, R. K. and N. L. Christensen. 1987. Competition and tree death. *BioScience* 37(8):586-595.
- Perry, D. A. 1998. The scientific basis of forestry. *Annual Review of Ecology and Systematics* 29:435-66.
- Peterson, B. and G. Gauthier. 1985. Nest site use by cavity-nesting birds of the Cariboo Parkland, British Columbia. *Wilson Bulletin* 97(3):319-331.
- Ramsey F. L. and D. W. Schafer. 1997. *The statistical sleuth*. Duxbury Press, California, USA.
- Raphael, M. G. and M. White. 1984. Use of snags by cavity-nesting birds in the Sierra Nevada. *Wildlife Monograph* 86:1-66.
- Ross, D. W. and C. G. Niwa. 1997. Using aggregation and antiaggregation pheromones of the Douglas-fir beetle to produce snags for wildlife habitat. *Western Journal of Applied Forestry* 12(2):52-54.
- SAS Institute System. 1999. SAS Institute Incorporated. Cary, North Carolina, USA.
- Schreiber, B. and D. S. deCalesta. 1992. The relationship between cavity-nesting birds and snags on clearcuts in western Oregon. *Forest Ecology and Management* 50:299-316.

Sharpe, F. 1996. The biologically significant attributes of forest canopies to small birds. *Northwest Science* 70:86-93.

Showalter, C. R. and R. C. Whitmore. 2002. The effect of gypsy moth defoliation of cavity-nesting bird communities. *Forest Science* 48(2):273-281.

Spies, T. A. and J. F. Franklin. 1991. The structure of natural young, mature, and old-growth Douglas-fir Forests in Oregon and Washington. Pages 91-109 *in* *Wildlife and vegetation of unmanaged Douglas-fir forests*. U.S. Department of Agriculture Forest Service General Technical Report PNW-GTR-285.

Swanson, F. J. and J. F. Franklin. 1992. New forestry principles from ecosystem analysis of Pacific Northwest forests. *Ecological Applications* 2(3):262-274.

Van Pelt, R. and M. P. North. 1996. Analyzing canopy structure in Pacific Northwest old-growth forests with a stand-scale crown model. *Northwest Science* 70:15-30.

Veblen, T. T., D. Kulakowski, K. S. Eisenhart, and W. L. Baker. 2001. Subalpine forest damage from a severe windstorm in northern Colorado. *Canadian Journal of Forest Research* 31(12):2089-2097.

Weikel, J. M. and J. P. Hayes. 1999. The foraging ecology of cavity-nesting birds in young forests of the northern Coast Range of Oregon. *The Condor* 101:58-66.

Weitzel, N. H. 1988. Nest-site competition between the European starling and native breeding birds in northwestern Nevada. *The Condor* 90(2):515-517.

Winchester, N. N. and R. A. Ring. 1996. Northern temperate coastal sitka spruce forests with special emphasis on canopies: studying arthropods in an unexplored frontier. *Northwest Science* 70:94-103

Youngblood, A. 2000. Damage to residual trees and advance regeneration from skyline and forwarder yarding in mixed-conifer stands of northeastern Oregon. *Western Journal of Forestry* 15(2):101-107.

Zarnowitz, J. E. and D. A. Manuwal. 1985. The effects of forest management on cavity-nesting birds in Northwestern Washington. *Journal of Wildlife Management* 49(1):255-263.

Zar, J. H. 1999. *Biostatistical analysis*. Fourth edition. Prentice-Hall, New Jersey, USA.

Table 2.1. Observed cavity-nesting bird activities associated with nesting and foraging on created snags (n = 836), natural snags (n = 221), and live topped-conifers (n = 102) in the McDonald-Dunn Research Forest, Oregon. Nesting numbers include multiple activity observations per unique cavity by different individuals and over 3 survey periods (96.6 total observation hours). A total of 171 active cavities were located.

Activity	No. (%) of Observations
Nesting	
Young calling	12 (1)
Transporting nesting material	77 (5)
Sitting in a cavity	90 (6)
Excavating a cavity	108 (7)
Exiting a cavity	144 (10)
Feeding young	336 (23)
Entering a cavity	696 (48)
Total	1463 (100)
Foraging	
On a branch	8 (17)
On the bole	39 (83)
Total	47 (100)

Table 2.2. Randomized block, 2-factor Analysis of Variance model structure used to assess effects of silviculture treatment and snag arrangement on cavity-nesting bird use of 836 created snags 10-12 yr after their creation (trees were topped between 1989 and 1991), and to test for increases in accumulated cavities from 1995 to 2001 in the same snags. Silviculture treatments consisted of group-selection ($n = 18$), two-story ($n = 6$), and clearcut ($n = 6$) stands across 3 blocks. Snags were clustered or scattered in 15 stands apiece.

Source of Variation	Degrees of Freedom
Block	2
Silviculture treatment	2
Snag arrangement treatment	1
Silviculture x arrangement	2
Error (block x treatments)	10
Block x silviculture = 4	
Block x arrangement = 2	
Block x silviculture x arrangement = 4	
Replication (block)	12
Total	29

Table 2.3. Cavity-nesting birds observed during the 2001 breeding season nesting and/or foraging on created (n = 836) and natural (n = 221) snags, and live topped-conifers (n = 102) in the McDonald-Dunn Research Forest, Oregon. Trees were topped between 1989 and 1991 to create snags; some trees did not die due to retained green branches.

Species	Acronym	Scientific Name
Primary Cavity Excavators		
Chestnut-backed chickadee	CBCH	<i>Parus rufescens</i>
Downy woodpecker	DOWO	<i>Picoides pubescens</i>
Hairy woodpecker	HAWO	<i>Picoides villosus</i>
Northern flicker	NOFL	<i>Colaptes auratus</i>
Pileated woodpecker	PIWO	<i>Dryocopus pileatus</i>
Red-breasted nuthatch	RBNU	<i>Sitta canadensis</i>
Red-breasted sapsucker	RBSA	<i>Sphyrapicus ruber</i>
Secondary Cavity Users		
Brown creeper	BRCR	<i>Certhia americana</i>
European starling	EUST	<i>Sturnus vulgaris</i>
House wren	HOWR	<i>Troglodytes aedon</i>
Violet-green swallow	VGSW	<i>Tachycineta thalassina</i>

Table 2.4. Shannon-Weiner species diversity indices (H') bracketed by theoretical minimum (H' min.) and maximum (H' max.) values and associated evenness indices (H'/H' max.) for cavity-nesting birds nesting in created snags in 3 silviculture treatments in the McDonald-Dunn Research Forest, Oregon.

Silviculture Treatment	Total Observations	Species Richness	H' min.	H'	H' max.	Evenness
Group-selection	65	5	0.32	1.13	1.61	0.70
Two-story	58	7	0.52	1.80	1.94	0.93
Clearcut	73	8	0.50	1.61	2.08	0.78

Table 2.5. Counts of created, natural-old, and natural-new snags with active cavity-nesting bird cavities in a) 3 silviculture treatments and b) 2 snag arrangement treatments in 30 stands in the McDonald-Dunn Research Forest, Oregon. Created snags are 10-12 yr old, natural-new snags are < 12 yr old, and natural-old snags are > 12 yr old. GS = group-selection, TS = two-story, CC = clearcut.

a) Silviculture Treatments

Snags	Treatment	Maximum No. Cavities/Snag	No. (%) of Snags with		Total Snag No. (% with Cavities)
			One Cavity	Multiple Cavities	
Created	GS	2	53 (12.1)	1 (0.2)	440 (12.3)
	TS	3	45 (22.3)	6 (3.0)	202 (25.3)
	CC	4	53 (27.3)	8 (4.1)	194 (31.4)
	Overall	4	151 (18.1)	15 (1.8)	836 (19.9)
Natural-old	GS	1	3 (6.7)	0 (0.0)	45 (6.7)
	TS	3	4 (16.7)	1 (4.1)	24 (20.8)
	CC	2	1 (5.6)	2 (11.1)	18 (16.7)
	Overall	3	8 (9.2)	3 (3.4)	87 (12.6)
Natural-new	GS	1	3 (4.3)	0 (0.0)	70 (4.3)
	TS	2	4 (7.3)	1 (1.8)	55 (9.1)
	CC	0	0 (0.0)	0 (0.0)	9 (0.0)
	Overall	2	7 (5.2)	1 (0.8)	134 (6.0)
All	Overall	4	166 (15.7)	19 (1.8)	1057 (17.5)

b) Snag Treatments

Snags	Arrang.	Maximum No. Cavities/Snag	No. (%) of Snags with		Total Snag No. (% with Cavities)
			One Cavity	Multiple Cavities	
Created	Clustered	3	81 (18.4)	8 (1.8)	441 (20.2)
	Scattered	4	70 (17.7)	7 (1.8)	395 (19.5)
	Overall	4	151 (18.1)	15 (1.8)	836 (19.9)
Natural-old	Clustered	3	4 (9.1)	1 (2.3)	44 (11.4)
	Scattered	2	4 (9.3)	2 (4.7)	43 (14.0)
	Overall	3	8 (9.2)	3 (3.5)	87 (12.7)
Natural-new	Overall	2	7 (5.2)	1 (0.8)	134 (6.0)
All	Overall	4	166 (15.7)	19 (1.8)	1057 (17.5)

Table 2.6. Counts of created snags with and without dead branches (> 10 cm diameter and > 0.3 m long) and with and without active bird cavities in 30 experimental stands in the McDonald-Dunn Research Forest, Oregon. Snags were created by topping mature conifers 10-12 yr prior to the survey.

	With Branches	Without Branches	Total
With Cavities	84	66	150
Without Cavities	416	264	680
Total	500	330	830

Table 2.7. Mean heights and numbers of cavities in created snags (n = 836) used for nesting in the McDonald-Dunn Research Forest, Oregon. Snags were 10-12 yr old and were created by topping conifers ≥ 53 cm DBH at 17 m.

Species	Mean Cavity Height (m)	No. of Cavities
Chestnut-backed chickadee	14.2	56
European starling	14.0	28
Hairy woodpecker	9.8	1
House wren	12.6	31
Northern flicker	15.6	7
Red-breasted nuthatch	13.2	15
Red-breasted sapsucker	13.0	21
Violet-green swallow	14.1	10
Overall	13.3	169

Table 2.8. The number of natural-old snags, natural-new snags, and live topped-conifers with and without bird cavities in 30 experimental stands in the McDonald-Dunn Research Forest, Oregon. Natural-new snags are < 12 yr old and natural-old snags are > 12 yr old. Live topped-conifers are the result of trees topped to create snags 10-12 yr prior to this study, but they have not died.

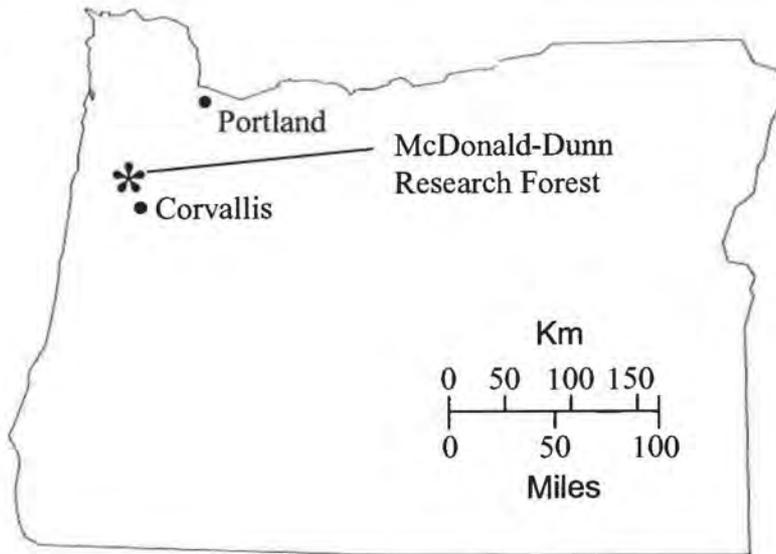
	With Cavities	Without Cavities	Total
Natural-old Snags	60	26	86
Natural-new Snags	76	58	134
Live Topped-conifers	8	94	102
Total	144	178	322

Table 2.9. Total number, number per hectare, and percent residual green mortality as blowdowns and snags across 3 silviculture treatments (group-selection cuts, n = 18 stands; two-story regeneration harvests, n = 6 stands; and clearcuts with reserve green trees, n = 6 stands) one decade after harvest in the McDonald-Dunn Research Forest, Oregon. Percent mortality is based on estimated numbers of residual green trees retained at harvest (Chambers et al. 1997).

Silviculture Treatment	Blowdowns			Snags			Total Mortality		
	No.	No./ha	%	No.	No./ha	%	No.	No./ha	Mean %
Group-selection	86	0.48	0.11	72	0.40	0.09	158	0.88	0.10
Two-story	90	1.12	4.46	53	0.76	0.30	143	1.88	2.38
Clearcut	9	0.17	14.03	9	0.20	16.60	18	0.37	15.32

Figure 2.1. Locations of a) the Oregon State University McDonald-Dunn Research Forest in the Coast Range of Oregon, and b) College of Forestry Integrated Research Program (CFIRP) managed stands ($n = 30$) across 3 blocks within the Research Forest. Dashed lines delineate the 3 CFIRP blocks: Dunn, Peavy, Lewisburg Saddle.

a)



b)

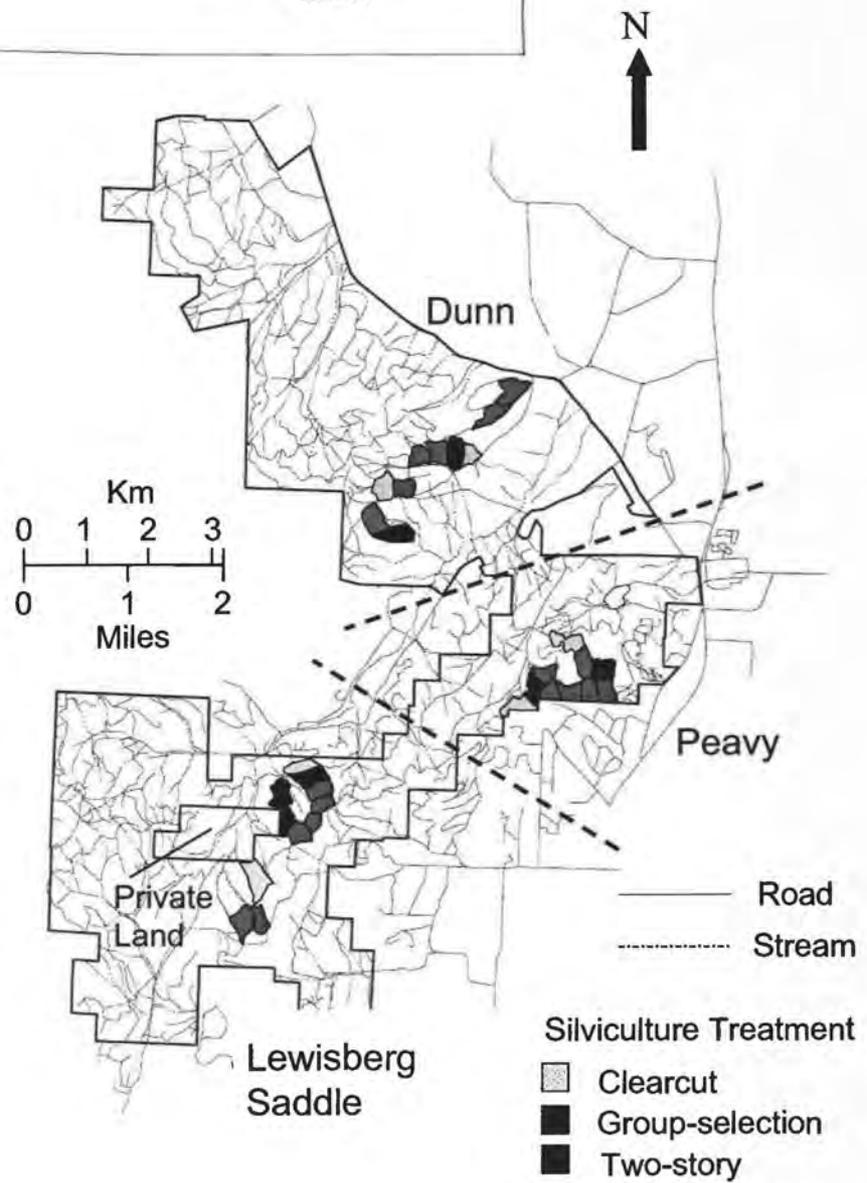
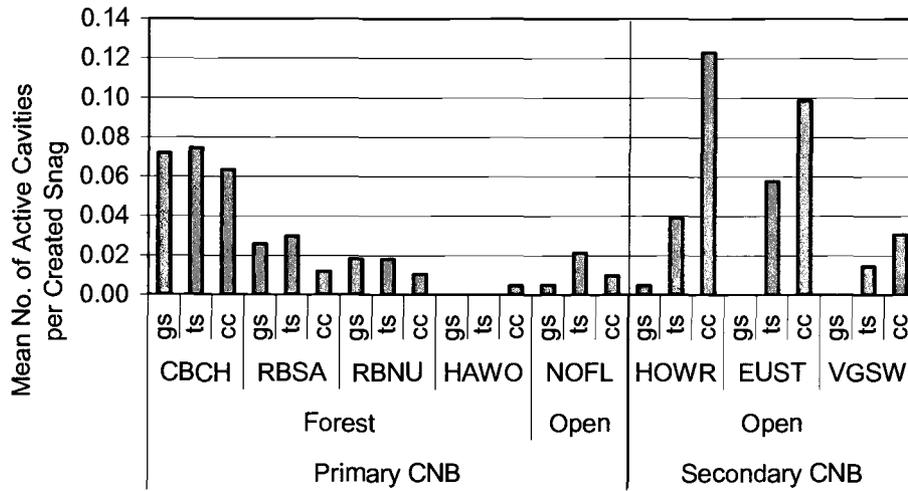


Figure 2.2. Cumulative number of cavity-nesting bird species observed nesting in created and natural snags in a) group-selection ($n = 18$), b) two-story ($n = 6$), and c) clearcut ($n = 6$) stands in the McDonald-Dunn Research Forest, Oregon. Each stand was surveyed 3 times in spring 2001 and points represent stand survey dates. Species acronyms (Table 2.3 lists species' names) coincide with the first date when each species was observed.

Figure 2.3. Mean numbers of cavities used by birds for nesting in each 10-12 yr old created snag (n = 836) across a) 3 silviculture treatments (gs: group-selection, ts: two-story, cc: clearcut) and b) 2 snag arrangements (c: clustered, s: scattered) in 30 stands in the McDonald-Dunn Research Forest, Oregon. Bird species acronyms are defined in Table 2.3. Forest and Open refer to the typical habitat conditions of the species (Kaufman 1996). CNB = cavity-nesting bird.

a) Silviculture treatments



b) Snag arrangements

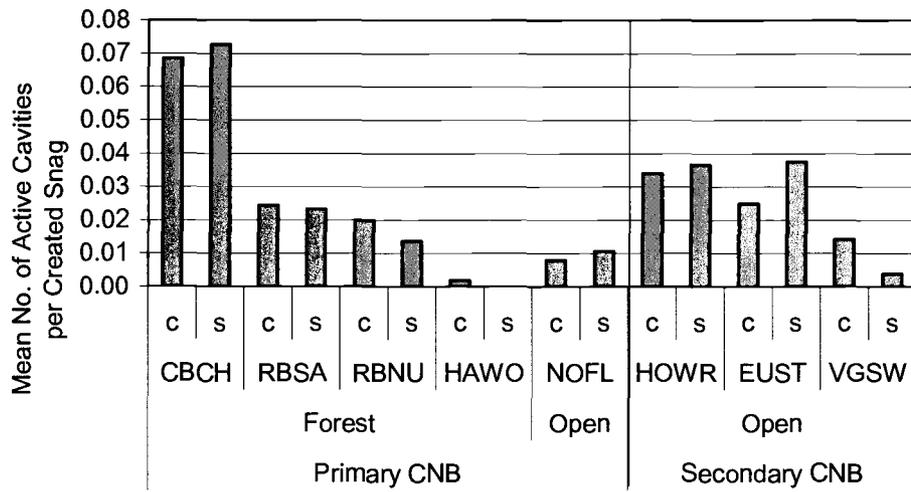
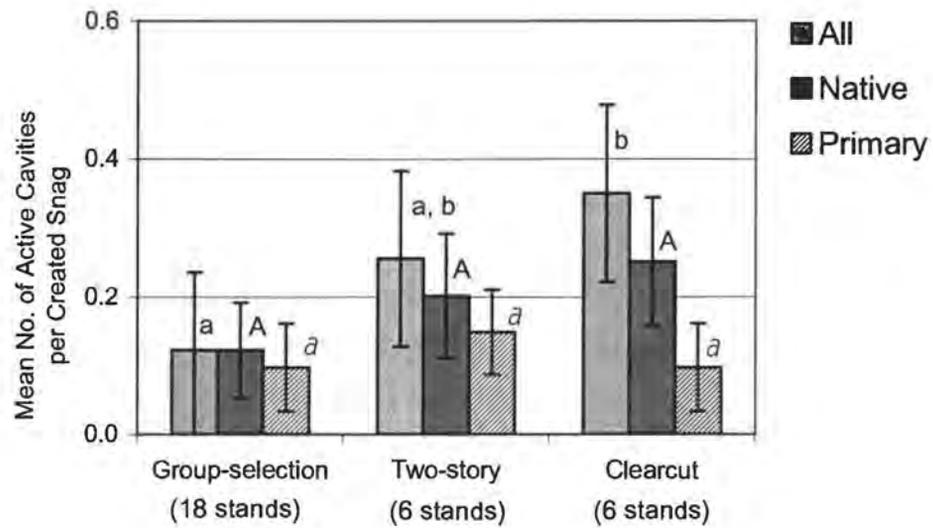


Figure 2.4. Mean number of active nests observed in 2001 for all, native, and primary cavity-nesting birds per 10-12 yr old created snag across a) 3 silviculture treatments and b) 2 snag arrangements in the McDonald-Dunn Research Forest, Oregon. Native birds were all cavity nesters minus European starlings (*Sturnus vulgaris*). Each error bar represents the 95% confidence interval around the mean. Significant differences at $\alpha = 0.05$ within bird groups, determined from Tukey's multiple comparison tests, are represented by different letters; different fonts are used for within bird group comparisons.

a) Silviculture treatments



b) Snag arrangements

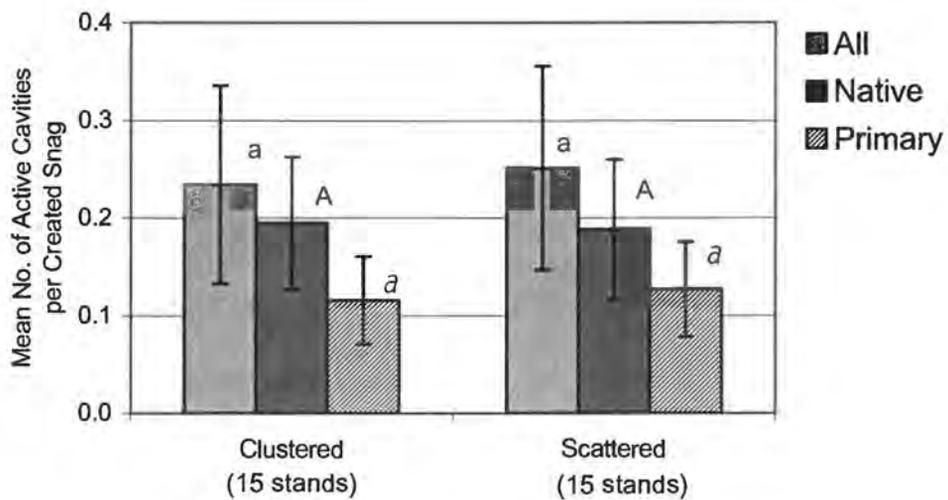


Figure 2.5. Cumulative number of active nests of European starlings and native cavity-nesting birds in 2001 in 10-12 yr old created snags per hectare across 2 open-canopy silviculture treatments (two-story, clearcut) in 3 blocks (Dunn, Peavy, Lewisburg Saddle) of the McDonald-Dunn Research Forest, Oregon.

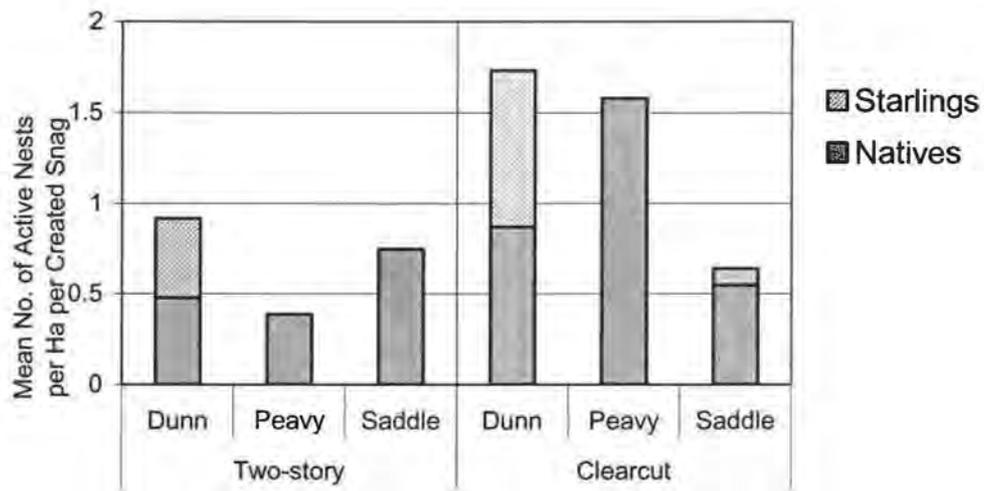


Figure 2.6. Aspect of the cavity face for 171 active bird nests in 10-12 yr old created snags in the McDonald-Dunn Research Forest, Oregon. Aspects are graphed in 15° intervals. There was significant directionality at 49° ($p = 0.0001$). Dashed arrows represent the 95% confidence interval around the mean aspect.

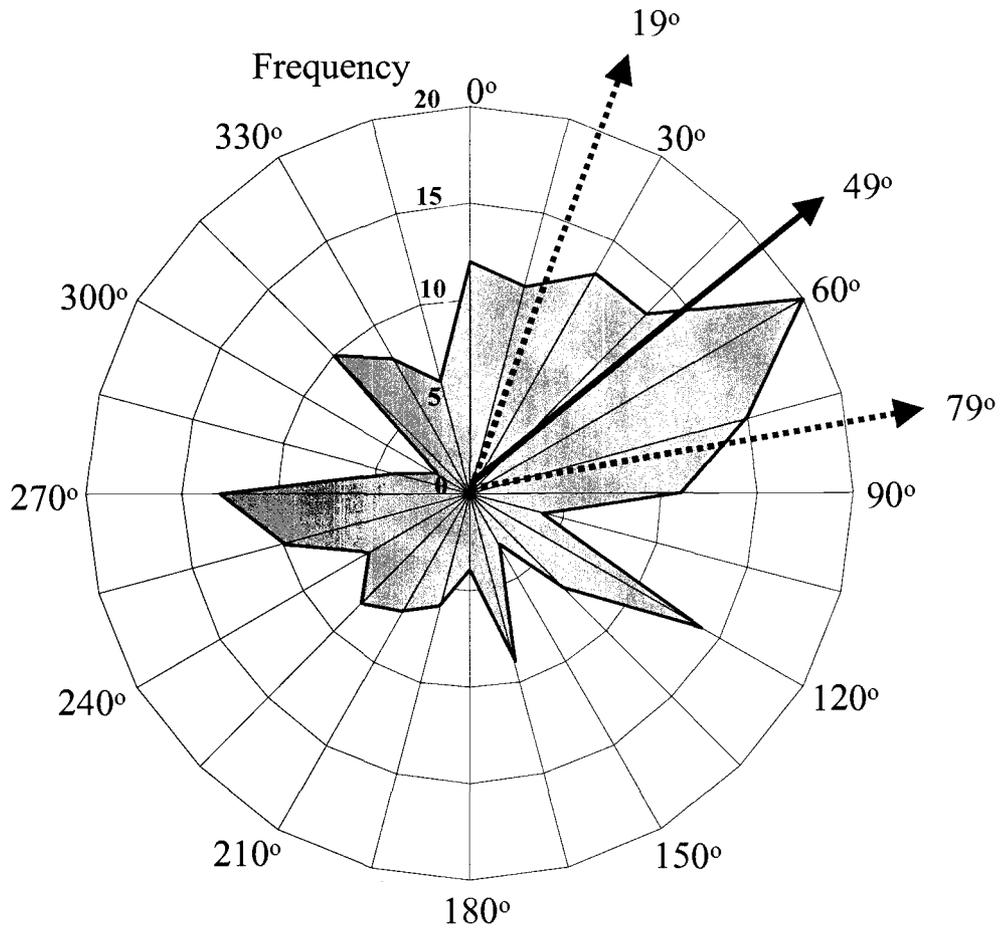
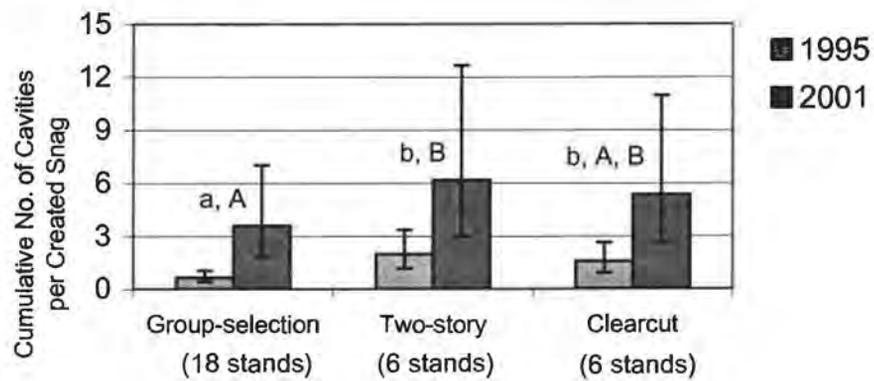


Figure 2.7. Median numbers of cumulative cavities per created snag in 1995 and 2001 in a) 3 silviculture treatments and b) 2 snag arrangement treatments in the McDonald-Dunn Research Forest, Oregon. Snags were created between 1989 and 1991; cumulative cavities in 1995 were recorded by Chambers et al. (1997). Error bars represent 95% confidence intervals around log back-transformed median values. Significant differences at $\alpha = 0.05$ as determined from Tukey's multiple comparison tests are represented by different letters; lower-case letters are for the mean increase in cavities per snag across treatments from 1995 to 2001 (expressed as the ratio: 2001/1995 cavity numbers) and upper-case letters are for 2001 median cavities/snag treatment comparisons.

a) Silviculture treatments



b) Snag arrangements

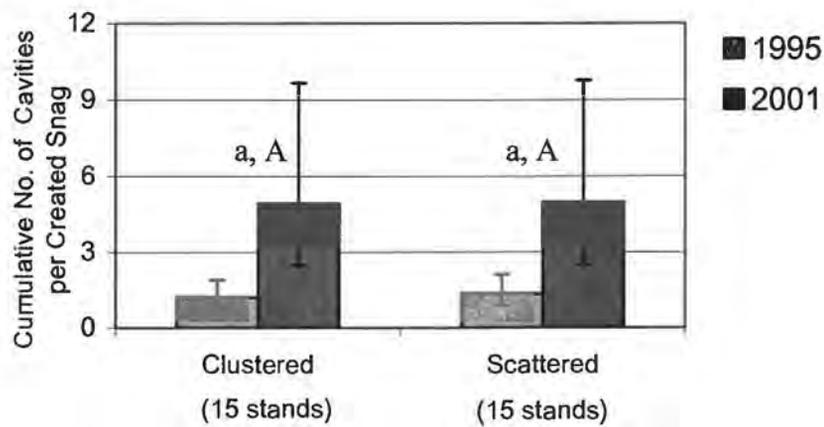
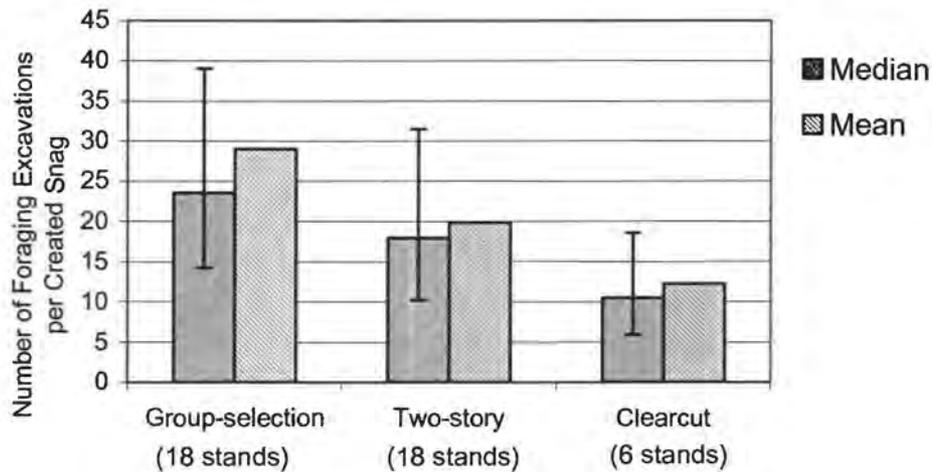
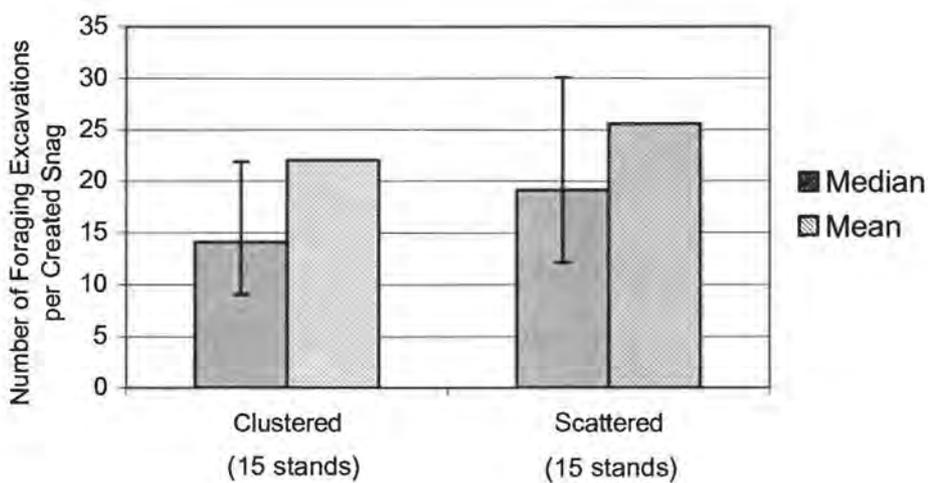


Figure 2.8. Estimated numbers of bird foraging excavations in created snags ($n = 836$) in a) 3 silviculture treatments and b) 2 snag arrangements in the McDonald-Dunn Research Forest, Oregon. Error bars represent 95% confidence intervals around log back-transformed median values. No significant differences were found at $\alpha = 0.05$ as determined from Tukey's multiple comparison tests.

a) Silviculture treatments



b) Snag arrangements



CHAPTER 3

CONIFER RESPONSE TO THREE SILVICULTURAL TREATMENTS IN THE OREGON COAST RANGE

ABSTRACT

Although uneven-aged silvicultural treatments are increasingly used to meet multiple stand objectives, questions remain regarding residual green tree responses to partial harvests. This study assessed growth, condition, and mortality of residual trees one decade after harvest across 3 silvicultural treatments in 30 85-125 year old Douglas-fir stands in the Oregon Coast Range. Treatments entailed group-selection cuts that extracted 33% of the timber volume in 0.2-0.6 ha patches, two-story regeneration harvests that removed 75% of the volume and left 20-30 distributed residual green trees/ha, and clearcuts that harvested all volume except 1.2 trees/ha. Both small circular plot (0.08-0.4 ha) and large 50x50 m grid (4 ha) surveys were used to measure trees. One decade after harvest, basal area, diameter, and height growth, and crown width and crown fullness did not differ among silvicultural treatments. Overall, 45% of trees had more basal area growth in the decade following harvest than in the decade prior to harvest. Among treatments, mean live crown ratio was significantly larger (0.74) in clearcuts and the proportion of trees with epicormic branching (35%) was significantly higher in two-story stands. Residual green tree mortality occurred across most (87%) stands. Based on numbers of trees retained at harvest, clearcuts experienced the highest percent mortality (30.6%) and group-selection stands experienced the

lowest (0.2%). Although growth of residual green trees did not vary across silvicultural treatments one decade after harvest, longer crown lengths and higher numbers of trees with epicormic branching in open-canopy stands (two-story and clearcut treatments) promoted increased stand structural complexity. Furthermore, higher levels of tree mortality under these treatment types can increase stand structural diversity consistent with many multiple forest management objectives.

Key words: basal area, Douglas-fir, tree growth, tree mortality, *Pseudotsuga menziesii*, silviculture, structure

INTRODUCTION

The Pacific Northwest, particularly the Coast Range in Oregon and Washington, holds some of the most productive forestland in North America (Curtis and Carey 1996). Vast and dense Douglas-fir (*Pseudotsuga menziesii*) forests in this region have provided timber for over 150 years to support a valuable commercial logging industry. During the late 1800s and early 1900s large trees were selectively cut under the perception of a seemingly endless supply of timber (Curtis and Carey 1996). In the mid- to late 1900s, intensive timber harvest and production practices, such as clearcutting and short-rotation plantation management, were increasingly used to meet growing demands for wood products (Franklin 1989, Salwasser 1990) and to increase profits by regeneration of a single, productive tree species (Swanson and Franklin 1992).

Douglas-fir was predominately selected for regeneration in plantations due to its rapid growth rates (Emmingham 1998), its tall and straight growth form (Curtis and Carey 1996), and its high wood quality. To accelerate stand

regeneration, increase timber production, and protect investment in forest resources, research generated techniques for vegetation and pest control, fertilization, tree improvement, and fire suppression (Perry 1998). As a result, densely stocked, young, single-species, and even-aged conifer plantations are now common throughout much of the Pacific Northwest (Spies and Franklin 1991, Barbour et al. 1997, Emmingham 1998).

In the 1980s, concerns developed about the impact that intensive forest management and extensive establishment of plantations may have on the range and variability of forest structure (Spies and Franklin 1991) and the ecological integrity of forest systems (Franklin 1989). In response to public pressure (Curtis and Carey 1996), harvest practices in the Pacific Northwest, particularly on federal lands, began to accommodate multiple management objectives that included maintenance of ecosystem processes and management of wildlife habitat (Birch and Johnson 1992, Swanson and Franklin 1992, Franklin et al. 1997, Miller and Emmingham 2001). To meet these objectives, partial harvest treatments such as shelterwood regeneration harvests that retain both large and healthy, and old and decadent trees were advocated to diversify structure in managed forests (Salwasser 1990, Curtis and Marshall 1993, Hunter and Bond 2001).

Although reductions in stand density, particularly in dense even-aged plantations, may benefit some forest wildlife species because of increased structural diversity (Hagar et al. 1996, Chambers and McComb 1997, Hayes et al. 1997, Tittler et al. 2001), residual trees retained at harvest may be more susceptible to mortality than in intact forest (Peet and Christensen 1987). Heavy

thinnings increase the exposure of isolated trees to winds that can cause blow down (Swanson and Franklin 1992, Franklin et al. 1997). Furthermore, removal of timber may increase the local water table level that can in turn kill retained trees that would remain standing as snags (Franklin et al. 1987). Although overall stand timber value is reduced when tree mortality occurs, resulting down wood and snags provide wildlife habitat long after tree death (Bull et al. 1997, Chambers et al. 1997, Franklin et al. 1997, Perry 1998, Hunter and Bond 2001). Therefore, the creation of an uneven-aged forest management plan with multiple stand objectives requires tradeoffs and balancing many factors such as wood production, economics, and habitat goals.

Despite the increased use of partial harvests, questions remain regarding the effects of silvicultural treatments on residual green trees and stand structure, particularly in mature (> 100 year old) forest stands (Emmingham 1998, Latham and Tappeiner 2002). Acceptance of alternatives to conventional even-aged forest management will require a better understanding of the creation and management of productive, uneven-aged forests (Swanson and Franklin 1992, Barbour et al. 1997, Emmingham 1998). To provide information on the effects of a range of stand density reductions, designed to mimic natural disturbances, have on residual green trees, this study utilized 30 Douglas-fir stands managed under 3 silvicultural treatments with different intensities and patterns of timber harvest. The objectives addressed in this paper were to assess treatment responses 10 years after harvest, including: 1) residual conifer growth, 2) changes in tree condition, and 3) tree mortality within the Oregon Coast Range.

STUDY AREA and EXPERIMENTAL DESIGN

The College of Forestry Integrated Research Project (CFIRP) was initiated in 1989 in the Oregon State University McDonald-Dunn Research Forest in the Coast Range foothills northwest of Corvallis, Oregon (Figure 3.1a). This project was designed to study the effects of a various silviculture harvest intensities and patterns on vegetation, wildlife, and societal responses. Mature Douglas-fir forest (85-125 years old) dominates the 30 managed study stands ranging from 5.5-17.8 hectares in size and from 120-400 m in elevation. At the time of treatment Douglas-fir basal area averaged 38 m²/ha. Additional tree species on the site include grand fir (*Abies grandis*), bigleaf maple (*Acer macrophyllum*), Oregon white oak (*Quercus garryana*), Pacific madrone (*Arbutus menziesii*), red alder (*Alnus rubra*), Pacific dogwood (*Cornus nuttallii*), Oregon ash (*Fraxinus latifolia*), and bitter cherry (*Prunus emarginata*). Common shrubs include vine maple (*Acer circinatum*), red huckleberry (*Vaccinium parvifolium*), salal (*Gaultheria shallon*), and Oregon-grape (*Berberis nervosa*). McDonald-Dunn Research Forest has warm summers and cool winters; most of the annual precipitation falls as rain between October and June (95 cm) and only 5 cm of rain falls in summer (Franklin and Dyrness 1988:111).

Between 1989 and 1991 trees were harvested in 30 CFIRP stands across 3 blocks (Dunn, Peavy, Lewisburg Saddle) in a randomized complete block design containing 3 treatments (Figure 3.1b). Silvicultural treatments consisted of group-selection cuts (18 stands), two-story regeneration harvests (6 stands), and clearcuts with retained green trees (6 stands). Group-selection stands had 33% of the timber

volume extracted from 0.2-0.6 hectare patches. Two-story stands had 75% of the timber volume removed resulting in 20-30 distributed residual trees per hectare. Clearcut stands had all trees harvested with the exception of 1.2 mature green trees per hectare. After harvest mean Douglas-fir (> 20 cm DBH) basal area was 29 m²/ha in group-selection stands, 12 m²/ha in two-story stands, and 1 m²/ha in clearcuts (Chambers et al 1997). Lewisburg Saddle was harvested in 1989, Peavy in 1990, and Dunn in 1991. Additional study area and harvest information is located in Kellogg et al. (1996), Chambers et al. (1999), and Maguire and Chambers (*in press*).

METHODS

Green Tree Measurements

Plot Surveys. In 1992, one year following the final CFIRP harvest, 0.08-0.4 hectare fixed-radius circular plots (n = 33) were established in study stands to gather baseline information on residual conifers (Douglas-fir, grand-fir); study plots were not located in all stands (10 group-selection and all clearcut stands lacked plots) and the number of plots per stand, when incorporated, varied between 1 and 5. Within each plot 2-21 trees (total number = 204 trees) were measured for height, diameter at breast height (DBH), and live crown ratio (LCR = live crown length/total tree height) (J. C. Tappeiner, Oregon State University, unpublished data). Trees were not individually tagged for future identification. In February 2002, all variables were re-measured for comparison with 1992 information on 2-8 randomly selected trees per plot in 31 (94%) of the plots; 2 plots were not located.

Grid Surveys. Between November 2001 and February 2002 permanent transects were established to gather tree data in all 30 CFIRP study stands and to uniformly establish sample trees across all stands for a point of comparison for future studies. I measured 20-25 conifers (> 10 cm DBH) in each group-selection ($n = 423$ trees) and two-story ($n = 147$ trees) stand by selecting the nearest, unique tree to intersections of a 50×50 m grid that covered each stand (entire grid area = 4 ha) (Figure 3.2). Grids were established 50 m away from stand boundaries. Because of low numbers of trees in clearcuts (8-18 trees per stand), all trees were measured ($n = 74$ trees). All trees selected for measurement were individually tagged for future identification. Trees were measured for DBH, height (determined with a clinometer and a laser distance finder [Bushnell Yardage Pro® 500]), mean crown width (the average of 2 crown widths measured perpendicular to each other; the first width was taken parallel with the stand slope and crown edges were estimated with the naked eye from the ground), LCR, epicormic branching ratio (length of tree bole below the live crown with epicormic branching/total tree height), and percent crown fullness (visually estimated and quantified as a visualized complete crown [100%] minus the percentage of crown missing due to broken branches [crown raggedness] as calculated using the formula described in Ferrel [1983]).

In addition to the measurements described above, 11-12 randomly selected sample trees per group-selection ($n = 202$ trees) and two-story ($n = 70$ trees) stand, and all trees in clearcuts ($n = 74$ trees), were cored in order to assess growth rates. Cores were extracted on the uphill side of trees. Growth rings were measured to the nearest 0.1 mm using electronic calipers for an equal number of years (10, 11,

and 12 years for trees in Dunn, Peavy, and Saddle stands, respectively) before and after harvest to calculate pre- and post-harvest mean basal area (BA) growth (Avery and Burkhart 1994:103). The post-/pre-harvest BA ratio was used to determine if growth was greater before or after harvest; ratios > 1 indicate greater growth following harvest and values < 1 represent greater growth before harvest.

Density and Mortality. Mean retained tree (> 10 cm DBH) density in group-selection and two-story stands was calculated from 5 randomly located 0.1 ha (20 x 50 m) tree count plots per stand. In group-selection stands plots were not located in cut patches. Retained trees (> 53 cm DBH) that died since harvest were identified as snags, or blowdowns resulting from tree fall of live and/or dead trees.

Statistical Analyses

Plot Trees. Randomized block, 1 factor Analysis of Variance (ANOVA; SAS Institute System, 1999: PROC MIXED) was used to test for effects of silviculture treatment (group-selection, two-story) on residual tree development one decade after harvest (Table 3.1a). One of 14 group-selection stands with plots established in 1992 was not included in the analysis because its plot was not located in 2002. Three separate analyses were performed on the mean ratio of 2002/1992 tree DBH, height, and live crown ratio response variables. Responses were averaged over plots within stands to produce a single value for each stand. Significant differences were tested at $\alpha = 0.05$, and when significance was detected Tukey adjustment was used for multiple comparisons.

Grid Trees. Randomized block, 1 factor ANOVA (SAS Institute System, 1999: PROC MIXED) was also performed to test for differences in tree size and

condition response variables across the 3 silvicultural treatments one decade following harvest (Table 3.1b). Separate ANOVAs were used for 1) DBH, 2) height, 3) mean crown width, 4) live crown ratio, 5) epicormic branching ratio, 6) percent crown fullness, and 7) BA growth ratio. To assess how the largest and presumably most fit trees (Franklin et al. 2002) are responding to the silvicultural treatments, the ANOVAs were repeated using only the largest 70% of survey trees (> 48 cm DBH). Stand averages were used to standardize for differences in numbers of trees sampled per stand. Data for ANOVAs met statistical requirements of normality and equality of variance, including percentages, and were not transformed for analysis.

A 2 x 3 contingency table was used to test for differences in the number of trees with and without epicormic branches for the largest 70% of survey trees across silvicultural treatments (Ramsey and Schafer 1997:556).

Plot and Grid Survey Comparison. Two-sided paired t-tests (SAS Institute System, 1999: PROC TTEST) were used to determine the comparability of plot and grid survey results to assess green tree diameter growth. Separate tests were used for group-selection and two-story stands to compare 2002 tree diameters obtained from plots versus grids. Similar tests were used for 1992 diameters. Grid survey tree diameters for 1992 were estimated from tree core measurements.

RESULTS

Tree Growth

Plot Trees. Trees in group-selection and two-story stands had similar diameter growth ($F_{1,2} = 0.11$, $p = 0.77$), height growth ($F_{1,2} = 1.61$, $p = 0.33$), and change in

live crown ratio ($F_{1,2} = 0.0$ $p = 0.98$) following the first decade after harvest.

(Figure 3.3)

Grid Trees. Basal area growth of all and of the largest 70% of survey trees was similar across silvicultural treatments one decade following harvest (Table 3.2). The mean post-/pre-harvest BA growth ratios were 1.08, 1.14, and 1.31 for group-selection, two-story, and clearcut treatments, respectively. For the largest 70% of trees, ratios were 0.95, 1.02, and 0.98 for the same treatments, respectively. Overall, 45% of trees expressed greater growth in the decade following harvest than the decade before (group-selection: 40%, two-story: 51%, clearcut: 53%; Figure 3.4).

Although 2001 tree diameters of the largest 70% of the survey trees were similar across silvicultural treatments one decade following harvest, there was marginal evidence to suggest that tree diameters of all trees differed across treatments (Table 3.2, Figure 3.5). For all trees, Tukey's multiple comparison tests indicate that mean DBH in two-story stands was 1.31 times greater than in group-selection stands ($t_4 = 3.52$, $p = 0.05$), although there were no differences in tree diameters between clearcuts and group-selection ($t_4 = 2.21$, $p = 0.18$) or clearcuts and two-story stands ($t_4 = 0.41$, $p = 0.91$).

Tree heights of all, and the largest 70% of trees were similar across treatments one decade post-harvest (Table 3.2, Figure 3.5).

Plot and Grid Survey Comparison. Tree diameters for 1992 estimated from 2002 tree cores were similar to diameters measured in 1992 plot surveys in both group-selection ($t_7 = 0.27$, $p = 0.80$) and two-story stands ($t_5 = 0.89$, $p = 0.41$).

Similarly, 2002 tree diameters measured in plot surveys were comparable to diameters measured in grid surveys in both group-selection ($t_6 = 0.20$, $p = 0.84$) and two-story stands ($t_5 = 0.79$, $p = 0.46$).

Tree Condition

Mean live crown ratios for all, and the largest 70% of grid survey trees differed across treatments one decade following harvest (Table 3.2, Figure 3.5). For all trees, the mean LCR for trees in clearcuts was 1.32 times greater than that of trees in two-story stands ($t_4 = 4.25$, $p = 0.03$) and 1.29 times greater than the mean LCR for trees in group-selection stands ($t_4 = 4.35$, $p = 0.03$). There was no difference in ratios between group-selection and two-story stands ($t_4 = 0.37$, $p = 0.93$). For the largest 70% of trees, the mean LCR in clearcuts was 1.33 times the LCR for trees in group-selection stands ($t_4 = 3.56$, $p = 0.05$). There were no differences in live crown ratios between two-story and group-selection ($t_4 = 3.56$, $p = 0.99$) or clearcut stands ($t_4 = 3.45$, $p = 0.06$).

For all, and the largest 70% of trees, tree crown width, percent crown fullness, and percent epicormic branching were similar across treatments one decade post-harvest (Table 3.2, Figure 3.5).

For the largest 70% of grid trees the number of residual green trees with epicormic branching differed across silvicultural treatments ($\chi^2_{df=2} = 14.77$, $p < 0.0001$). The highest percentage of trees with epicormic branching was in two-story stands (35%), while 17% and 18% of trees in clearcut and group-selection stands, respectively, had epicormic branching (Table 3.3).

Density and Mortality

Tree density was estimated at 156.7 trees/ha within the matrix of retained forest in group-selection stands, 16.3 trees/ha in two-story stands, and 1.38 trees/ha in clearcuts one decade after harvest. Residual green tree mortality resulted in blowdowns and snags across the majority (87%) of study stands (Figure 3.6). Among silvicultural treatments, clearcut stands experienced the greatest overall mean tree mortality (15.32%) and group-selection stands experienced the lowest (0.1%) based on estimated numbers of residual green trees retained at harvest (Chambers et al. 1997; Table 3.4).

DISCUSSION

Tree Growth

Tree growth rates are influenced by a combination of resources that include nutrients, water, and light. Partial harvests can also influence tree growth by reducing competition for these growth resources (Harrington and Ruckema 1983, Franklin et al. 1987, Marshall et al. 1992, Smith et al. 1997:47). Despite the expectation in this study of greater residual green tree growth in two-story and clearcut stands compared to group-selection stands, because of greater stand density and tree competition reductions, tree basal area growth ratio did not differ across treatments one decade after harvest.

Although mature conifers, like those in this study, are capable of growth response to stand density reductions (Newton and Cole 1987, Youngblood 1991), previous studies report a lag time of up to 10 or more years. For instance, in southwest Washington, Williamson (1982) found that 110 year old Douglas-fir

displayed 8-30% greater volume growth in thinned (25-50% stand basal area removed) versus unthinned stands 19 years after treatment and he attributes the extended observation period as an important factor in the detection of differences. In this study, 55% of trees had not responded with increased basal area growth 10 years following harvest. In a similar study of tree basal area growth in thinned (4-38 trees > 75 cm DBH retained per hectare) conifer stands (158-650 years old) in the Oregon Coast Range, only 36.8% of the trees had not responded with increased growth at 10 years after thinning (Latham and Tappeiner 2002). The larger percent response in Latham and Tappeiner's (2002) study may be explained by multiple species of survey trees, including ponderosa pine that had relatively high growth response, increasing overall tree response. Beyond 10 years in Latham and Tappeiner's (2002) study, the magnitude of tree growth progressively increased, and the greatest growth occurred between 15-20 years after thinning.

The inherently slow basal area growth rates of mature (> 100 years old), relative to young (< 50 years old) Douglas-fir trees (Poage and Tappeiner 2002) help explain why growth differences across silvicultural treatments may be difficult to detect one decade after harvest. Young trees typically grow vigorously, particularly following thinning, to avoid suppression mortality from competing neighbors (Harrington and Reukema 1983, Peet and Christensen 1987, Marshall et al. 1992, Smith et al. 1997:27). However, as trees approach mature ages and establish co-dominance or dominance in the canopy, growth rates naturally are reduced (Poage and Tappeiner 2002), as observed in this study. As survey tree diameters and presumably tree ages increased in the CFIRP stands, basal area

growth decreased (Figure 3.4). And, the highest individual tree basal growth rates were of small diameter (< 40 cm DBH) and presumably young trees (e.g., the 4 un-graphed trees listed in Figure 3.4). Furthermore, reduced growth of old versus young trees was demonstrated in the CFIRP stands by smaller mean basal area growth ratios (that indicate a smaller growth response) when only the largest 70% of trees were included compared to all the survey trees. Decreased growth with increasing age has also been observed by Williamson and Price (1971) who found that within the age span of 70-150 years old, older Douglas-fir trees experienced lower relative basal area growth rates than younger trees following thinning treatments (residual BA = 27.5-81.3 m²/ha) in western Oregon and Washington.

Despite the lack of differences to date, future growth ratios of the CFIRP residual green trees may differ across silvicultural treatments. Beyond a decade following stand density reductions, mature residual trees generally experience increased growth relative to tree growth in dense forest stands (Latham and Tappeiner 2002). For instance, in a shelterwood seed cut that retained 100 trees/ha in a 160 year old spruce stand in Alaska, residual tree basal area growth was 10.3% greater than growth of trees in an adjacent unharvested stand (494 trees/ha) 14 years after harvest (Youngblood 1991). Additionally, Latham and Tappeiner (2002) found greater basal area growth in mature and old-growth trees (> 75 cm DBH) in thinned stands (4-38 trees/ha) than in unthinned stands (24-60 trees/ha) 20 years following thinning. Tree growth is typically greatest in stands with the heaviest thinning prescriptions that remove trees uniformly throughout the stand. This trend was exemplified in a study in southwest Washington that compared

residual growth of 110 year old Douglas-fir among stands with heavy and light thinnings (50% and 25% reductions in basal area, respectively) and no thinning (Williamson 1982). Nineteen years after treatment, individual tree volume growth was 22% greater in heavily thinned stands than growth in lightly thinned stands; growth rates in both thinning treatments were greater than those in unthinned stands.

In this study, retained trees in group-selection stands are within the forest matrix, while trees in two-story and clearcut stands are isolated at low densities. Therefore, future tree growth is predicted to be the greatest in clearcut stands, because of lower tree competition, and lowest in group-selection stands. Although basal area growth across treatments was not significantly different one decade following harvest, there was a trend of increasing growth with increasing harvest intensity (Figure 3.5).

Tree Condition

With the exception of live crown ratio and the number of trees with epicormic branching, most 2001 tree attributes were similar among treatments one decade after harvest. However, because immediate post-harvest data for crowns and epicormic branching are not available for comparison, the observed differences cannot be attributed to silvicultural treatments. Nonetheless, in the interest of meeting multiple stand management goals that include increased stand structural diversity (Franklin et al. 1997, Hunter and Bond 2001), longer crown lengths and higher numbers of trees with epicormic branching can increase tree

and crown structure (Berg et al. 1996, Van Pelt and North 1996, Ishii and Wilson 2001, Miller and Emmingham 2001, Ishii and McDowell 2002).

When trees are harvested from closed-canopy stands, increased light levels can affect various tree characteristics, such as live crown length (Emmingham 1998, Buermeyer and Harrington 2002). Closed forest canopies limit light penetration to the lower crown and can cause lower branch death and crown recession (Franklin et al. 2002). Open canopies expose the entire crown to light and allow persistence of the lower crown. Maintenance of the live lower crown can lead to longer crown lengths as trees grow in height (Van Pelt and North 1996). In this study, higher live crown ratios in clearcuts relative to group-selection and two-story stands, may have implications for long-term tree vertical structure, as previously suggested by Miller and Emmingham (2001). These authors suggest that selection thinning (170-353 trees/ha retained) in 50-85 year old stands in western Oregon slowed impending canopy closure and crown recession, and consequently resulted in increased stand structural diversity 16-30 years after thinning. Retention of lower crowns following thinnings that increase light levels further down the canopy may ultimately result in more complex tree crown structure relative to dense pre-harvest stand conditions (Berg et al. 1996, Curtis and Carey 1996, Van Pelt and North 1996, Miller and Emmingham 2001, Ishii and McDowell 2002).

In addition to retention of long live crowns, epicormic branching also adds to tree structural complexity (Ishii and Wilson 2001, Ishii and McDowell 2002). Epicormic branches originate from dormant buds under the bark throughout the

bole and can sprout in response to partial loss of the live crown and/or increased tree exposure to sunlight and heat (Collier and Turnblom 2001, Franklin et al. 2002). Growth of epicormic branches below the live crown allows trees to re-establish crown lengths reduced by crown recession and partial breakage during windstorms (Spies and Franklin 1991, Emmingham 1998, Franklin et al. 2002). Among silvicultural treatments in this study, two-story stands had the greatest proportion of trees with epicormic branching. In another partial harvest study conducted in southwest Washington with 18 trees retained/ha (similar to densities in the CFIRP two-story stands), epicormic branching was observed, but not quantified, on tree boles of 145 year old Douglas-fir 12 years after thinnings (Buermeyer and Harrington 2002). In the CFIRP stands it is unclear why similar numbers of retained trees with epicormic branching were not found in two-story and clearcut stands given both these silvicultural treatments maintain open canopies that expose retained tree boles to light that can promote epicormic branching. Possible breakage of branches during harvest (Cline et al. 1991, Han et al. 2000, Youngblood 2000, Hartsough 2003) may be another factor that prompted epicormic branching (Collier and Turnblom 2001). However, similar degrees of crown fullness across treatments suggest that differences in crown damage was not a cause of a higher percentage of trees with epicormic branching in two-story stands.

Tree Mortality

Tree fall due to wind is a natural process of forest ecosystems (Franklin et al. 1987, Franklin and Forman 1987, Veblen et al. 2001). However, following

partial harvest of dense and mature forest stands, particularly when > 30% of the timber volume is uniformly removed throughout the stand, wind is able to pass through the stand and retained trees are more susceptible to blowdown relative to pre-harvest conditions (Franklin et al. 1997). Among silvicultural treatments in this study, two-story and clearcut stands experienced substantially greater blowdown (4 and 14% of retained trees, respectively) compared to group-selection stands (0.1%). In another Douglas-fir partial harvest study in southwest Washington, 7% of trees (145 years old) retained throughout the stand at 18 trees/ha had fallen 12 years after harvest (Buermeyer and Harrington 2002). In contrast to uniform thinnings across stands, partial harvests that maintain dense aggregates of trees, such as in group-selection stands of this study, function as windbreaks that can reduce wind speeds within the stand (Franklin et al. 1997). Thus, when silvicultural treatments retain isolated trees in open stands, scattered residual trees tend to be more susceptible to blowdown than trees in groups (Franklin et al. 1997).

In addition to tree density and arrangement within a stand, adjacent areas also can influence wind patterns within the managed stand (Franklin et al. 1997). When neighboring areas lack trees, such as in clearcuts, winds easily can pass through the area and enter forested stands causing windthrow (Franklin and Forman 1987). Among the CFIRP stands, 3 stands (2 group-selection and 1 two-story stand in the Dunn block) that experienced relatively high rates of blowdown border a 750 ha farm with open fields. Another two-story stand (located in the Saddle block) that experienced high windthrow is located adjacent to both a

clearcut and a road clearing. In other studies, large open areas ranging in size from road clearings to entire clearcut stands have been previously identified as a source of winds that cause blowdown in neighboring forest stands (Williamson and Price 1971). In one particular assessment of blowdown across thousands of hectares of forestland in Oregon and Washington, up to 81% of tree fall occurred in stands adjacent to open areas (Franklin and Forman 1987). As the amount of open area that borders forest stands increases, there is a greater opportunity for winds to enter the stand and cause blowdown (Franklin and Forman 1987).

Besides mortality by windthrow, other retained trees in this study died but remained standing as snags. Following harvests, retained trees may experience increased environmental stress, such as an increase in the water table level (Adams et al. 1991) that can promote tree death (Franklin et al. 1987, Franklin et al. 1997). Trees reduce soil moisture through transpiration, and interception and evaporation of rainfall in the crown (Rose 1996, Shaw and Bible 1996). In the Peavy block of this study, one particular two-story stand located on level, low-lying land experienced high tree mortality. Some local researchers speculate that following harvest in this stand the local water table rose and caused some trees to drown (G. M. Filip, Oregon State University, personal communication). Removal of timber in forest stands can increase soil moisture levels during the first 2 years following harvest (Adams et al. 1991) and render Douglas-fir, which is intolerant of poorly drained soils (Minore 1979), susceptible to death. Reduced evapotranspiration following large stand volume reductions (i.e., 75%) in low lying land may lead to increased soil moisture after harvest that contributes to retained tree death (Minore

1979; Rose 1996; Shaw and Bible 1996; G. M. Filip, Oregon State University, personal communication).

Logging damage also may have contributed to residual green tree mortality in this study. Partial harvests, particularly those that remove timber throughout the stand, can result in retained trees damaged by falling trees and/or harvest equipment (Cline et al. 1991, Han et al. 2000, Youngblood 2000, Hartsough 2003). Tree wounds sustained during harvest provide an access point for decay organisms (Han et al. 2000, Matzka and Kellogg 2003) that can promote tree death (Franklin et al. 1987, Emmingham 1998). In the CFIRP stands, two-story and clearcut stands experienced substantially greater tree mortality compared to group-selection stands. Percentages of retained trees damaged during uniform stand density reductions have been substantial (between 27 and 39%) in other studies in the Pacific Northwest (Howard 1996, Youngblood 2000). Furthermore, retained trees that have timber harvested around them generally experience greater tree damage than trees retained within intact patches of forest (Moore et al. 2002).

MANAGEMENT IMPLICATIONS

As observed in this study, regardless of a wide range of harvest intensities and patterns applied to mature Douglas-fir stands, residual trees may not show differential growth responses during the first decade after harvest in the Oregon Coast Range. However, a trend of increasing basal area growth with increasing timber harvest in the CFIRP stands suggests that greater harvest intensities (i.e., \geq 75% timber volume reduction) that occur throughout the stand may be utilized to

promote greater long-term growth of retained trees relative to partial harvests that maintain trees in dense forest patches.

Aside from tree growth, in the interest of promoting stand structural diversity silvicultural treatments used in this study can impact other tree attributes that can increase tree structural complexity. Among treatments, longer crowns ratios and higher numbers of residual trees with epicormic branching appeared to be associated with harvests that created open-canopy stands. Therefore, in dense conifer stands partial harvests that expose retained trees to increased light can be used to promote increased tree structural complexity through maintenance of lower crowns and stimulation of epicormic branching.

The occurrence of tree mortality following harvest also tends to be associated with harvest intensity and pattern. Trees retained in groups, such as group-selection treatments, provide windbreaks that can reduce tree fall compared to isolated trees that are more susceptible to windthrow. Additionally, as winds from areas adjacent to managed stands may be a source of winds, avoidance of intensive harvests (i.e., $\geq 75\%$ timber volume reduction) near clearcuts or road clearings may reduce blowdown. Environmental stress (i.e., an increase in the local water table level) and logging damage that also may contribute to residual tree death may be reduced through use of smaller partial harvests in patches (i.e., 33% removal of stand volume), relative to larger uniform harvests, because of grouped trees that offer greater tree protection from harvest activities and higher numbers of trees that maintain evapotranspiration processes. However, despite

losses of timber volume through green tree mortality, down logs and snags contribute to increased stand structure.

ACKNOWLEDGEMENTS

This project was funded by the Oregon State University College of Forestry Fish and Wildlife Program and a J. Richard Dilworth Scholarship for Forestry. I would like to thank Chris Maguire for extensive help on all aspects of the project; Lisa Ganio and Manuela Huso for statistical advise; Debbie Johnson for study site maps; Liza Jane, Dave Ritts, Steve Roberts, Troy Smith, Margo Stoddard, April Turple, Dave Waldien, and David Zahler for discussion and editorial reviews throughout the project; Ryan Emig and Jake Verschuyt for field assistance; and Bill Emmingham, Doug Maguire, Richard Schmitz, and John Tappeiner for technical advise.

LITERATURE CITED

- Adams, P. W., A. L. Fling, and R. L. Fredriksen. 1991. Long-term patterns in soil moisture and revegetation after a clearcut of a Douglas-fir forest in Oregon. *Forest Ecology and Management* 41(4):249-263.
- Avery, T. E. and H. E. Burkhart. 1994. *Forest measurements*. Fourth edition. McGraw Hill, Boston Massachusetts, USA.
- Barbour, R. J., S. Johnston, J. P. Hayes, and G. F. Tucker. 1997. Simulated stand characteristics and wood product yields from Douglas-fir plantations managed for ecosystem objectives. *Forest Ecology and Management* 91:205-219.
- Berg, D. R., T. K. Brown, and B. Blessing. 1996. Silvicultural systems design with emphasis on the forest canopy. *Northwest Science* 70:31-36.
- Birch, K. R. and K. N. Johnson. 1992. Stand-level wood-production costs of leaving live, mature trees at regeneration harvest in coastal Douglas-fir stands. *Western Journal of Applied Forestry* 7(3):65-68.

- Buermeyer, K. R. and C. A. Harrington. 2002. Fate of overstory trees and patterns of regeneration 12 years after clearcutting with reserve trees in southwest Washington. *Western Journal of Applied Forestry* 17(2):78-85.
- Bull, E. L., C. G. Parks, and T. R. Torgersen. 1997. Trees and logs important to wildlife in the interior Columbia river basin. U.S. Department of Agriculture Forest Service General Technical Report PNW-GTR-391.
- Chambers, C. L., T. Carrigan, T. E. Sabin, J. Tappeiner, and W. C. McComb. 1997. Use of artificially created Douglas-fir snags by cavity-nesting birds. *Western Journal of Applied Forestry* 12:93-97.
- Chambers, C. L. and W. C. McComb. 1997. Effects of silvicultural treatments on wintering bird communities in the Oregon Coast Range. *Northwest Science* 71(4):298-304.
- Chambers, C. L., W. C. McComb, J. C. Tappeiner, L. D. Kellog, R. L. Johnson, and G. Spycher. 1999. CFIRP: What we learned in the first ten years. *The Forestry Chronicle* 75(3):431-434.
- Cline, M. L., B. F. Hoffman, M. Cyr, and W. Bragg. 1991. Stand damage following whole-tree partial cutting in northern forests. *Northern Journal of Applied Forestry* 8(2):72-76.
- Collier, R. L. and E. C. Turnblom. 2001. Epicormic branching on pruned coastal Douglas-fir. *Western Journal of Applied Forestry* 16(2):80-86.
- Curtis, R. O. and A. B. Carey. 1996. Managing for economic and ecological values in Douglas-fir forests. *Journal of Forestry* 94(9):4-7 and 35-37.
- Curtis, R. O. and D. D. Marshall. 1993. Douglas-fir rotations – time for reappraisal? *Western Journal of Applied Forestry* 8(3):81-85.
- Emmingham, B. 1998. Uneven-aged management in the Pacific Northwest. *Journal of Forestry* 96(7):37-39.
- Ferrell, G. T. 1983. Growth classification systems for red fir and white fir in northern California. U.S. Department of Agriculture Forest Service General Technical Report PSW-72.
- Franklin, J. F. 1989. Toward a new forestry. *American Forests* 95(11):37-44.
- Franklin, J. F., D. R. Berg, D. A. Thornburg, and J. C. Tappeiner. 1997. Alternative silvicultural approaches to timber harvesting: variable retention systems. Pages

111-139 in K. A. Kohm and J. F. Franklin, editors. *Creating a forestry for the 21st century: the science of ecosystem management*. Island Press, Washington D.C., USA.

Franklin, J. F. and C. T. Dyrness. 1988. *Natural vegetation of Oregon and Washington*. Oregon State University Press, Corvallis, Oregon, USA.

Franklin, J. F., and R. T. T. Forman. 1987. Creating landscape patterns by forest cutting: Ecological consequences and principles. *Landscape Ecology* 1(1):5-8.

Franklin, J. F., H. H. Shugart, and M. E. Harmon. 1987. Tree death as an ecological process. *BioScience* 37(8):550-556.

Franklin, J. F., T. A. Spies, R. Van Pelt, A. B. Carey, D. A. Thornburgh, D. R. Berg, D. B. Lindenmayer, M. E. Harmon, W. S. Keeton, D. C. Shaw, K. Bible, and J. Chen. 2002. Disturbances and structural development of natural forest ecosystems with silvicultural implications, using Douglas-fir forests as an example. *Forest Ecology and Management* 155(3):399-423.

Hagar, J. C., W. C. McComb, and W. H. Emmingham. 1996. Bird communities in commercially thinned and unthinned Douglas-fir stands in western Oregon. *Wildlife Society Bulletin* 24(2):353-366.

Han, H-S, L. D. Kellogg, G. M. Filip, and T. D. Brown. 2000. Scar closure and future timber value losses from thinning damage in western Oregon. *Forest Products Journal* 50(1):36-42.

Harrington, C. A. and D. L. Reukema. 1983. Initial shock and long-term stand development following thinning in a Douglas-fir plantation. *Forest Science* 29(1):33-26.

Hartsough, B. 2003. Economics of harvesting to maintain high structural diversity and resulting damage to residual trees. *Western Journal of Applied Forestry* 18(2):133-142.

Hayes, J. P., S. S. Chan, W. H. Emmingham, J. C. Tappeiner, L. D. Kellogg, and J. D. Bailey. 1997. Wildlife response to thinning in young forests in the Pacific Northwest. *Journal of Forestry* 95(8):28-33.

Hunter, J. E. and M. L. Bond. 2001. Residual trees: wildlife associations and recommendations. *Wildlife Society Bulletin* 29(3):995-999.

Ishii, H. and N. McDowell. 2002. Age-related development of crown structure in coastal Douglas-fir trees. *Forest Ecology and Management* 169(3):257-270.

Ishii, H. and M. E. Wilson. 2001. Crown structure of old-growth Douglas-fir in the western Cascade Range, Washington. *Canadian Journal of Forest Research* 31(7):1250-1261.

Kellogg, L. D., P. Bettinger, and R. M. Edwards. 1996. A comparison of logging planning, felling, and skyline yarding costs between clearcutting and five group-selection harvesting methods. *Western Journal of Applied Forestry* 11(3):90-96.

Latham, P. and J. Tappeiner. 2002. Response of old-growth conifers to reduction in stand density in western Oregon forests. *Tree Physiology* 22:137-146.

Maguire, C. C. and C. L. Chambers, editors. *In press*. College of Forestry Integrated Research Project: Ecological and socioeconomic responses to alternative silvicultural treatments. Oregon State University, College of Forestry, Forestry Research Lab Publication #3582.

Marshall, D. D., J. F. Bell, and J. C. Tappeiner. 1992. Levels-of-growing-stock cooperative study in Douglas-fir: Report No. 10 – the Hoskins study, 1963-83. U.S. Department of Agriculture Forest Service Pacific Northwest Research Station Research Paper PNW-RP-448.

Miller, M. and B. Emmingham. 2001. Can selection thinning convert even-age Douglas-fir stands to uneven-age structures? *Western Journal of Applied Forestry* 16(1):35-43.

Minore, D. 1979. Comparative autecological characteristics of northwestern tree species – a literature review. U.S. Department of Agriculture Forest Service Pacific Northwest Forest and Range Experiment Station General Technical Report PNW-87.

Newton, M. and E. C. Cole. 1987. A sustained-yield scheme for old-growth Douglas-fir. *Western Journal of Applied Forestry* 2(1):22-25.

Peet, R. K. and N. L. Christensen. 1987. Competition and tree death. *BioScience* 37(8):586-595.

Perry, D. A. 1998. The scientific basis of forestry. *Annual Review of Ecology and Systematics* 29:435-66.

Poage, N. J. and J. C. Tappeiner II. 2002. Long-term patterns of diameter and basal area growth of old-growth Douglas-fir trees in western Oregon. *Canadian Journal of Forest Research* 32(7):1232-1243.

Ramsey F. L. and D. W. Schafer. 1997. *The statistical sleuth*. Duxbury Press, California, USA.

Rose, C. L. 1996. Forest canopy-atmosphere interactions. *Northwest Science* 70:7-14.

SAS Institute System. 1999. SAS Institute Incorporated. Cary, North Carolina, USA.

Salwasser, H. 1990. Gaining perspective: forestry for the future. *Journal of Forestry* 88:32-38.

Shaw, D. C. and K. Bible. 1996. An overview of forest canopy ecosystem functions with reference to urban and riparian systems. *Northwest Science* 70:1-6.

Smith, D. M., B. C. Larson, M. J. Kelty, P. M. S. Ashton. 1997. *The practice of silviculture: applied forest ecology*. John Wiley and Sons, New York, New York, USA.

Spies, T. A. and J. F. Franklin. 1991. The structure of natural young, mature, and old-growth Douglas-fir Forests in Oregon and Washington. Pages 91-109 *in* *Wildlife and vegetation of unmanaged Douglas-fir forests*. U.S. Department of Agriculture Forest Service General Technical Report PNW-GTR-285.

Swanson, F. J. and J. F. Franklin. 1992. New forestry principles from ecosystem analysis of Pacific Northwest forests. *Ecological Applications* 2(3):262-274.

Tittler, R., S. J. Hannon, and M. R. Norton. 2001. Residual tree retention ameliorates short-term effects of clear-cutting on some boreal songbirds. *Ecological Applications* 11(6):1656-1666.

Van Pelt, R. and M. P. North. 1996. Analyzing canopy structure in Pacific Northwest old-growth forests with a stand-scale crown model. *Northwest Science* 70:15-30.

Veblen, T. T., D. Kulakowski, K. S. Eisenhart, and W. L. Baker. 2001. Subalpine forest damage from a severe windstorm in northern Colorado. *Canadian Journal of Forest Research* 31(12):2089-2097.

Williamson, R. L. 1982. Response to commercial thinning in a 110-year-old Douglas-fir stand. U.S. Department of Agriculture Forest Service Pacific Northwest Forest and Range Experimental Station Research Paper PNW-296.

Williamson, R. L. and F. E. Price. 1971. Initial thinning effects in 70- to 150-year-old Douglas-fir – western Oregon and Washington. U.S. Department of Agriculture Forest Service Pacific Northwest Forest and Range Experimental Station Research Paper PNW-117.

Youngblood, A. P. 1991. Radial growth after a shelterwood seed cut in a mature stand of white spruce in interior Alaska. *Canadian Journal of Forest Research* 21(3):410-413.

Youngblood, A. 2000. Damage to residual trees and advance regeneration from skyline and forwarder yarding in mixed-conifer stands of northeastern Oregon. *Western Journal of Forestry* 15(2):101-107.

Table 3.1. Randomized block, 1 factor Analysis of Variance model structure used to test for silviculture treatment effects on growth, size, and condition of residual green trees measured a) in small (0.08-0.4 ha) standard radius circular plots and b) large (4 ha) square grids. Treatments consisted of group-selection cuts (GS; n = 18 stands), two-story regeneration harvests (TS; n = 6 stands), and clearcuts with reserve green trees (CC; n = 6 stands). Trees were measured in 13 stands in plot surveys and in all 30 stands in grid surveys.

a) Plot Surveys

Source of Variation	Degrees of Freedom
Block	2
Silviculture treatment (GS and TS)	1
Error (block x treatment)	2
Replication (block x treatment)	7
Total	12

b) Grid Surveys

Source of Variation	Degrees of Freedom
Block	2
Silviculture treatment (GS, TS, and CC)	2
Error (block x treatment)	4
Replication (block x treatment)	21
Total	29

Table 3.2. ANOVA results for silviculture effects on residual green tree attributes 10-12 years after stand harvest in the McDonald-Dunn Research Forest, Oregon. Treatments were group-selection cuts (n = 18 stands), two-story regeneration harvests (n = 6 stands), and clearcuts with reserve green trees (n = 6 stands). Basal area growth is expressed as the ratio: post-/pre-harvest basal area growth. Epicormic branching ratio = length of the tree bole below the live crown with epicormic branching/total tree height, and live crown ratio = live crown length/total tree height.

Response Variable	All Trees (> 10 cm DBH)		70% Largest Trees (> 48 cm DBH)	
	F _{2,4}	p	F _{2,4}	p
Basal area growth	0.49	0.65	0.54	0.62
Crown width (m)	4.06	0.11	1.02	0.44
DBH (cm)	7.39	0.05	5.07	0.08
Epicormic branching ratio	6.12	0.06	4.25	0.10
Height (m)	4.34	0.10	0.90	0.47
Live crown ratio	10.95	0.02	7.43	0.05
Percent crown fullness	0.86	0.49	1.08	0.42

Table 3.3. The number of the largest 70% of survey trees with and without epicormic branching on the tree bole below the live crown across 3 silviculture treatments (group-selection = 18 stands, two-story = 6 stands, clearcut = 6 stands) one decade after harvest.

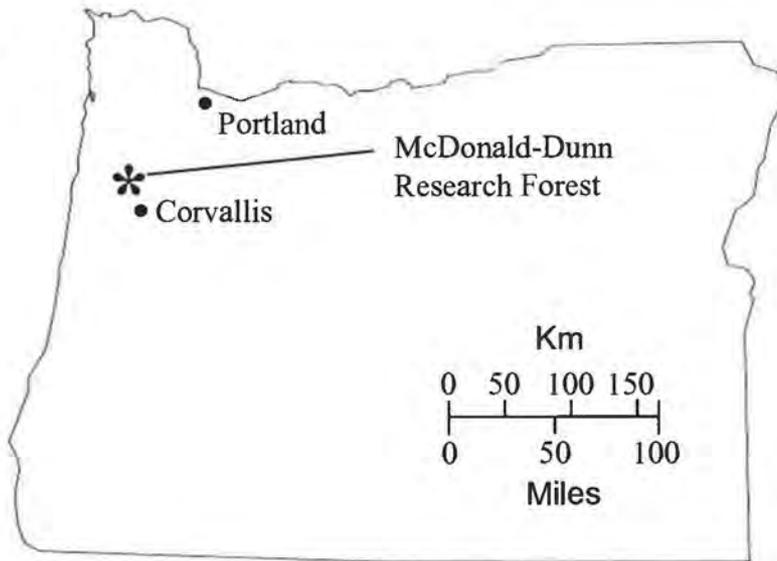
	Epicormic Branching		Total No. Trees
	No. Trees With	No. Trees Without	
Group-selection	50	228	278
Two-story	44	83	127
Clearcut	8	39	47
Total	102	350	452

Table 3.4. Total number, number per hectare, and percent residual green mortality as blowdowns and snags across 3 silviculture treatments (group-selection cuts, n = 18 stands; two-story regeneration harvests, n = 6 stands; and clearcuts with reserve green trees, n = 6 stands) one decade after harvest in the McDonald-Dunn Research Forest, Oregon. Percent mortality is based on estimated numbers of residual green trees retained at harvest (Chambers et al. 1997).

Silviculture Treatment	Blowdowns			Snags			Total Mortality		
	No.	No./ha	%	No.	No./ha	%	No.	No./ha	Mean %
Group-selection	86	0.48	0.11	72	0.40	0.09	158	0.88	0.10
Two-story	90	1.12	4.46	53	0.76	0.30	143	1.88	2.38
Clearcut	9	0.17	14.03	9	0.20	16.60	18	0.37	15.32

Figure 3.1. Locations of the a) Oregon State University McDonald-Dunn Research Forest in Oregon and b) College of Forestry Integrated Research Program (CFIRP) managed stands ($n = 30$) across 3 blocks within the Research Forest. Dashed lines delineate the 3 CFIRP blocks: Dunn, Peavy, Lewisburg Saddle.

a)



b)

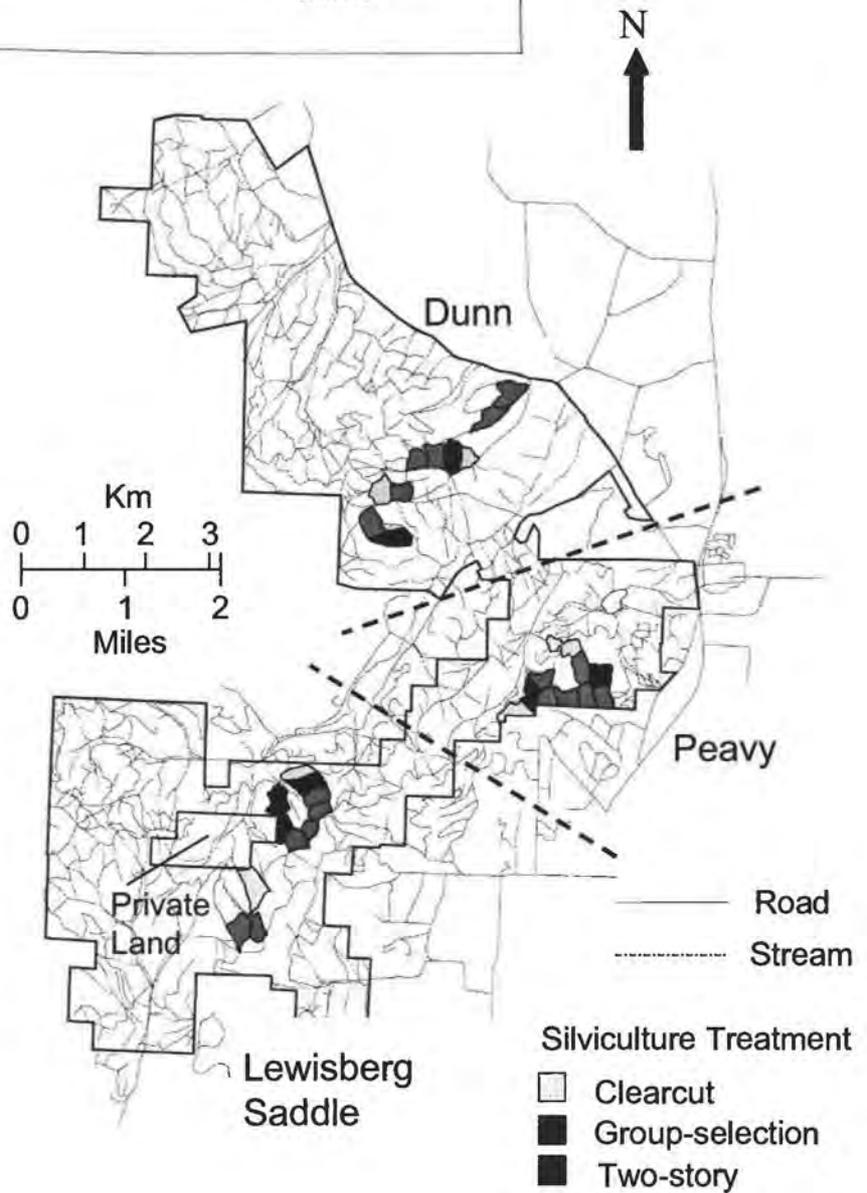


Figure 3.2. Location schematic of plot and grid surveys to assess residual green tree growth across group-selection cuts ($n = 18$ stands) and two-story regeneration harvests ($n = 6$ stands). All trees (>10 cm DBH) within 0.08-0.4 ha fixed-radius plots (open circles; not to scale) were measured in 1992 and 2002 and the nearest tree (>10 cm DBH) to each grid point was measured between November 2001 and February 2002 (entire grid area = 4 ha).

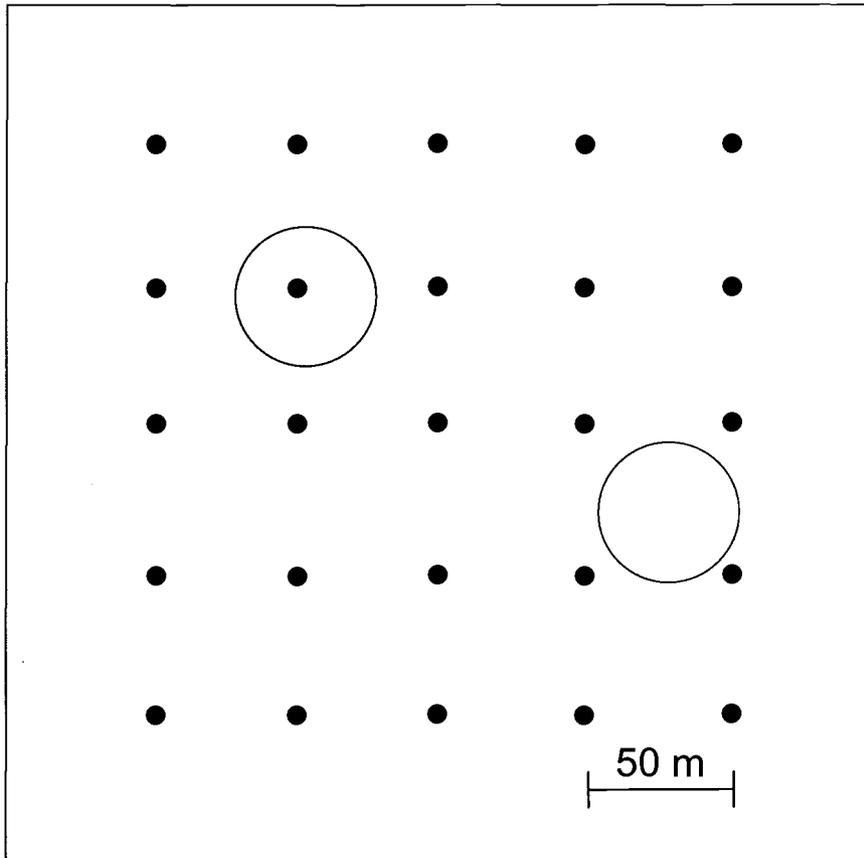


Figure 3.3. Mean 1992 and 2002 plot survey results for tree a) DBH b) height, and c) live crown ratio across silviculture harvest treatments (n = 5 group-selection stands, 6 two-story stands) implemented between 1989 and 1991. Silviculture treatments did not significantly affect ($p \geq 0.33$) increases in any of the 3 response variables (tested as 2002/1992 mean ratios) in the decade since harvest. Percent increases from 1992 to 2002 are presented and error bars represent 1 standard deviation around means.

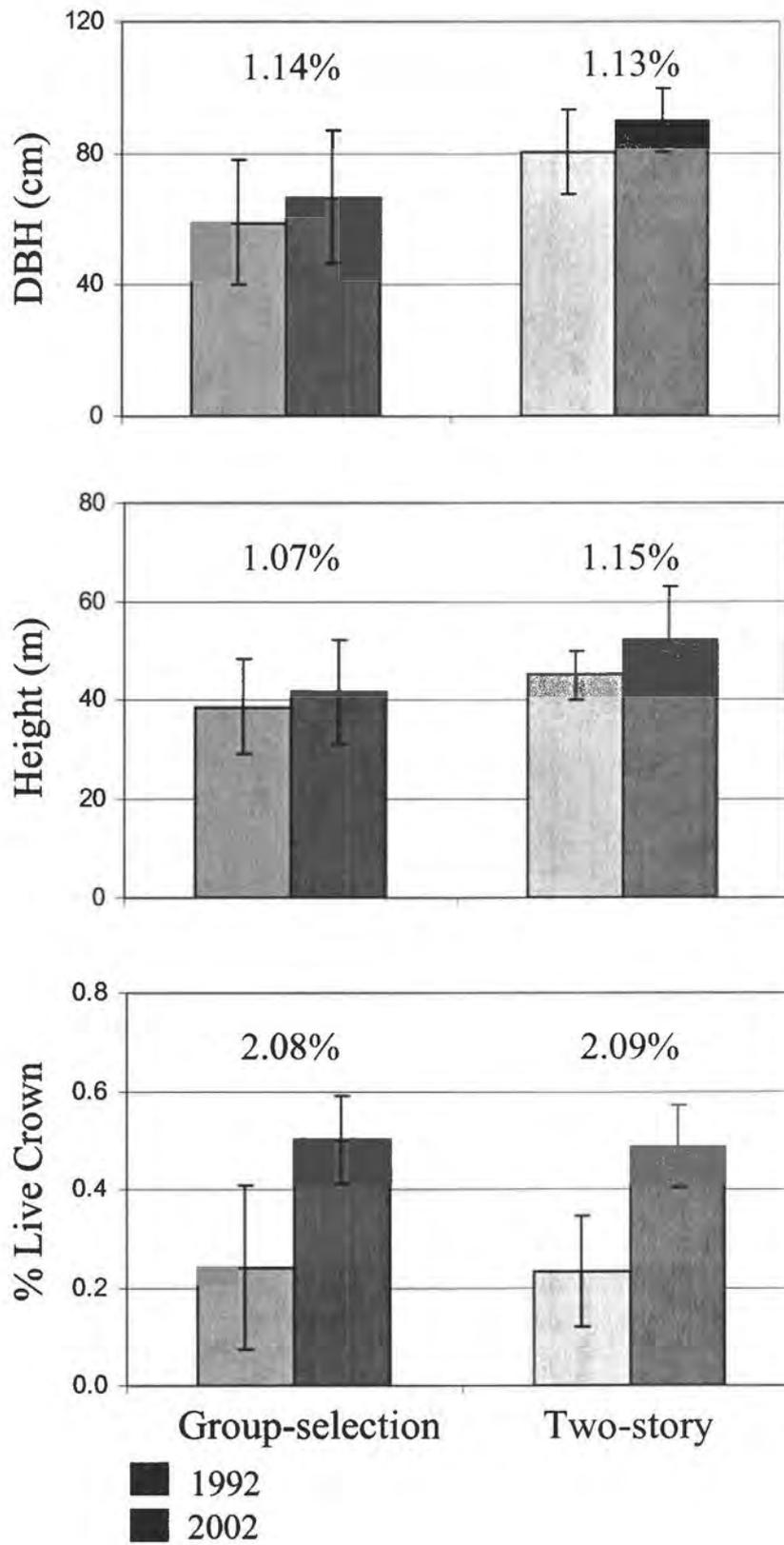
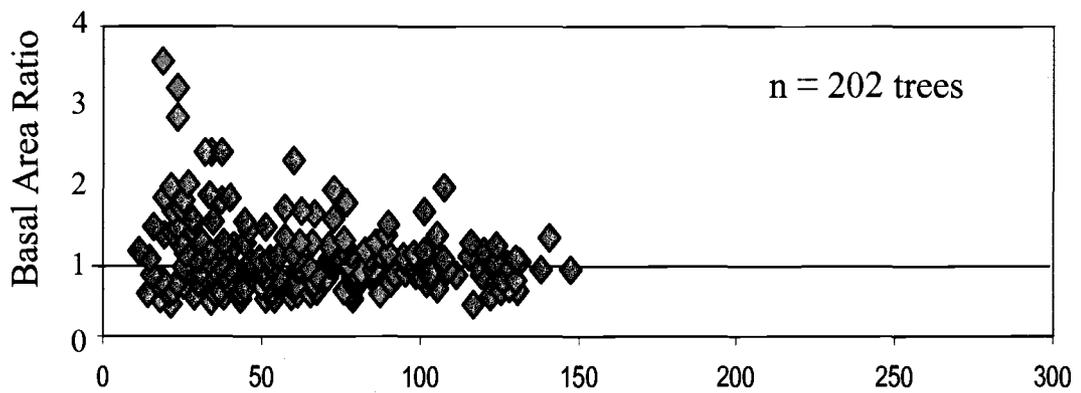
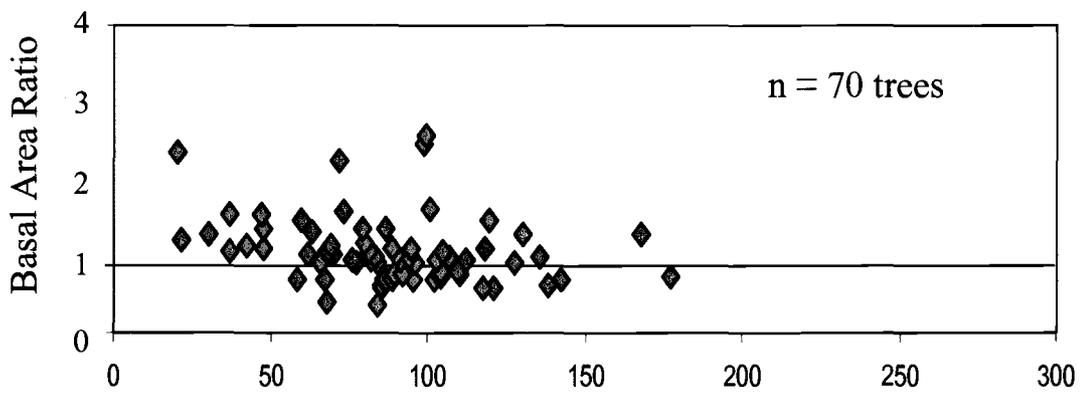


Figure 3.4. Ratios of post-/pre-harvest basal area growth for conifers (> 10 cm DBH) measured between November 2001 and February 2002 across 3 silviculture treatments (18 group-selection, 6 two-story, and 6 clearcut stands). Ratios > 1 indicate greater growth following harvest and values < 1 represent greater growth before harvest. Four trees are not graphically presented; their growth ratios are: group-selection = 12.64 (29.5 cm DBH), two-story = 5.71 (38.9 cm DBH), and clearcut = 4.5 (35.2 cm DBH) and 8.54 (39.1 cm DBH).

a) Group-selection



b) Two-story



c) Clearcut

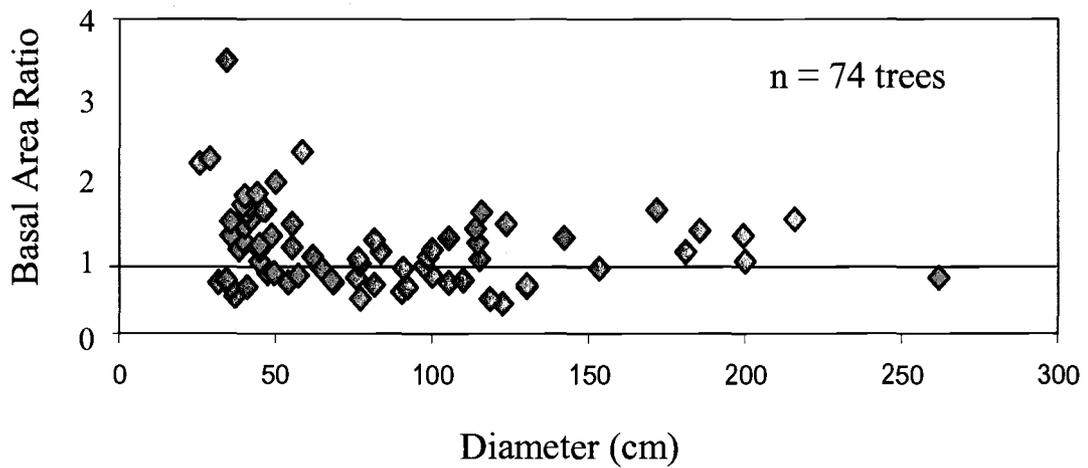
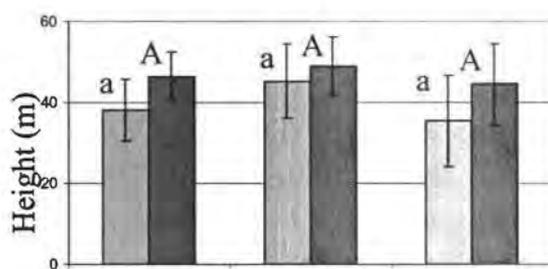
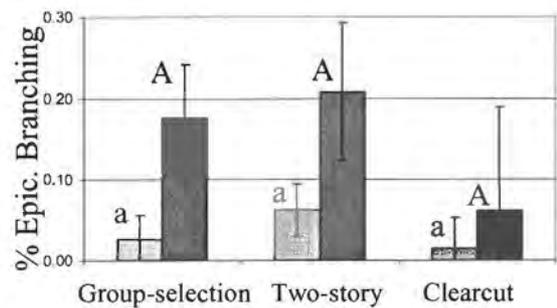
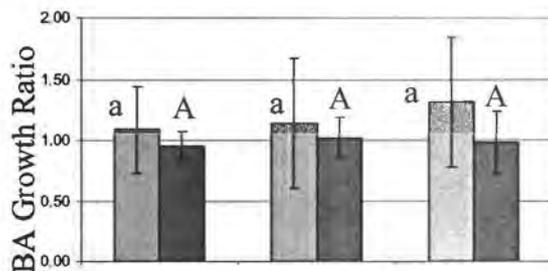
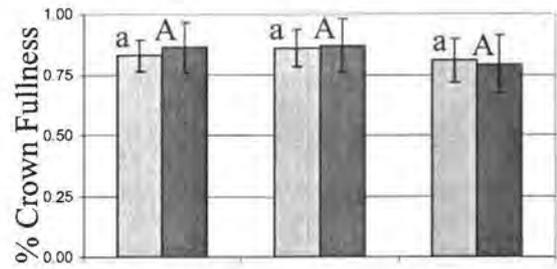
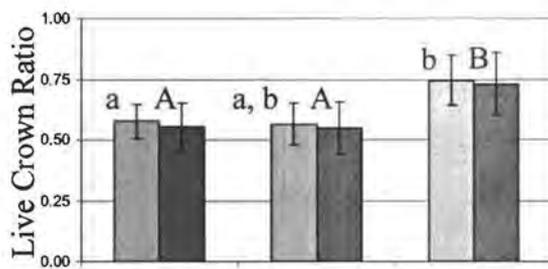
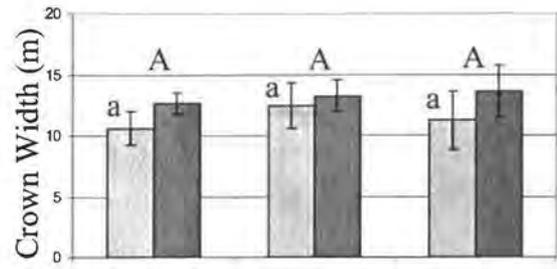
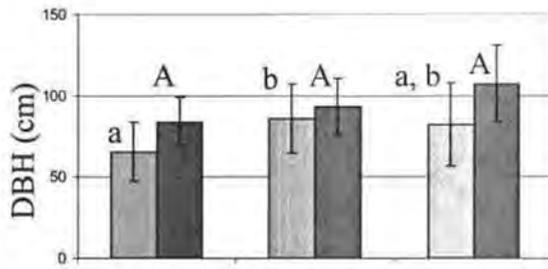


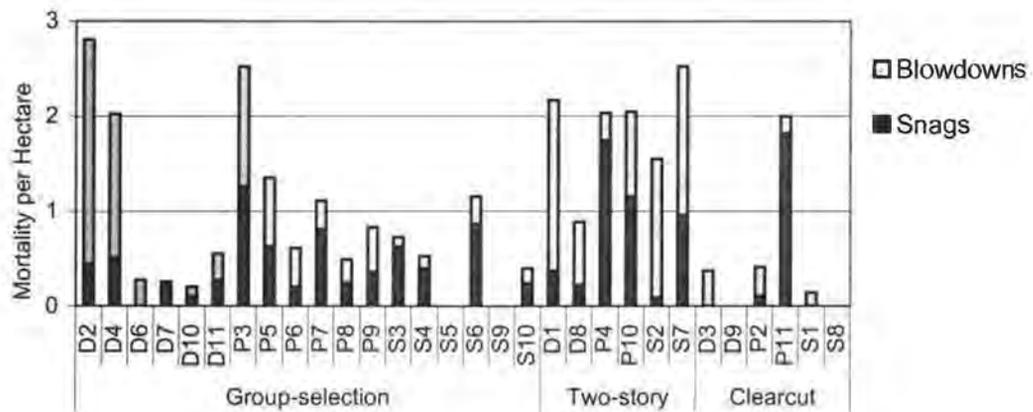
Figure 3.5. Mean DBH, live crown ratio, basal area growth, height, crown width, percent crown fullness, and epicormic branching ratio of all survey trees (> 10 cm DBH, n = 452 trees) and the largest 70% of survey trees (> 48 cm DBH, n = 192 trees) across 3 silviculture treatments (n = 18 group-selection, 6 two-story, and 6 clearcut stands) one decade following harvest. Basal area growth during the decade before and the decade after harvest is expressed as the ratio: post-/pre-harvest growth. Epicormic branching ratio = length of the tree bole below the live crown with epicormic branching/total tree height, and live crown ratio = live crown length/total tree height. Error bars represent 95% confidence intervals around means. Significant differences tested at $\alpha = 0.05$, as determined from Tukey's multiple comparison tests, are represented by different lowercase letters for all survey trees and uppercase letters for the largest 70% of survey trees.



All Trees (> 10 cm DBH)
 Largest 70% of Trees (> 48 cm DBH)

Group-selection Two-story Clearcut

Figure 3.6. Number of reserve green trees per hectare in each study stand in 2001 that died (blowdowns and snags) across 3 silviculture treatments (n = 18 group-selection, 6 two-story, and 6 clearcut stands) that were implemented between 1989 and 1991 in the McDonald-Dunn Research Forest, Oregon. Stands are listed by block (D = Dunn, P = Peavy, and S = Lewisburg Saddle) and number.



CHAPTER 4

CONCLUSIONS

Based on the several-fold increase in nest cavities and an increase in the number of species that nested in the created CFIRP snags over the past 6 years, and higher mean cavities per created snag compared to natural snags in this and another study in the Oregon Coast Range, topping conifers in either clustered or scattered arrangements appears to provide valuable habitat for cavity-nesting birds nesting during the first decade after tree death. Crown removal during topping provides the benefit of development of decay in the upper bole that facilitates cavity excavation where nests are most commonly placed. Also, topping may provide long-standing habitat because absent crowns reduce snag wind resistance, and thus snags are less susceptible to blowdown. However, if topping fails to kill the tree because of retained live branches, the resulting structure does not provide favorable nest sites compared to topped trees that die. Although, because this research shows created snags without dead branches were readily used for nesting, removal of live branches following topping would be beneficial to ensure tree death and development of decay that allows nest cavity excavation.

Differential harvest intensities and patterns in dense, mature conifer stands appear to affect stand structural diversity in a way that can influence cavity-nesting bird nesting in snags. Higher levels of nesting, greater species richness, and higher species diversity of cavity nesters in two-story and clearcut stands can likely be attributed to the open-canopies that promote increased stand structure compared to

group-selection stands with closed canopies. Open canopies allow increased light to reach the understory, stimulating vegetative growth and providing insect gleaning substrates for some cavity-nesting birds. Furthermore, increased light exposure to retained trees can promote longer crowns, due to reduced crown recession, and stimulate epicormic branching. Both live tree crowns and epicormic branches provide additional habitat for insects eaten by some cavity-nesting birds. Lastly, extensive and uniform harvest of timber in two-story and clearcut stands can result in higher new snag recruitment, relative to group-selection stands, providing additional and foraging opportunities, particularly for woodpeckers, and nest sites.

Although two-story and clearcut treatments appear to promote cavity-nesting bird habitat, the value of group-selection harvests should not be underestimated. Closed canopies in group-selection stands can provide conditions utilized by cavity-nesting species associated with intact forests, such as the pileated woodpecker when forest ages near 200 years old. Furthermore, closed-canopy stands may deter exotic European starlings that have previously been reported to out-compete native cavity-nesting species for nest sites.

Although stand density reductions are sometimes used to increase tree growth, silvicultural treatments in this study applied to mature conifer stands do not appear to meet this goal within the first decade after harvest. However, despite the lack of growth differences across treatments, partial harvests in the CFIRP

stands increased stand structural diversity that is a common goal of uneven-aged forest management plans that are increasingly used to benefit wildlife in the Pacific Northwest.

BIBLIOGRAPHY

Adams, P. W., A. L. Fling, and R. L. Fredriksen. 1991. Long-term patterns in soil moisture and revegetation after a clearcut of a Douglas-fir forest in Oregon. *Forest Ecology and Management* 41(4):249-263.

Adkisson, C. S. 1988. Cavity-nesting birds of North America: past history, present status, and future prospects. *Bird Conservation* 3:85-100.

Anderson, D. R., K. P. Burnham, and W. L. Thompson. 2000. Null hypothesis testing: problems, prevalence, and an alternative. *Journal of Wildlife Management* 64(4):912-923.

Anderson, D. R., W. A. Link, D. H. Johnson, and K. P. Burnham. 2001. Suggestions for presenting the results of data analyses. *Journal of Wildlife Management* 65(3):373-378.

Aubry, K. B., M. P. Amaranthus, C. B. Halpern, J. D. White, B. L. Woodard, C. E. Peterson, C. A. Lagoudakis, and A. J. Horton. 1999. Evaluating the effects of varying levels and patterns of green-tree retention: experimental design of the DEMO study. *Northwest Science* 73:12-26.

Aubry, K. B. and C. M. Raley. 2002. Selection of nest and roost trees by pileated woodpeckers in coastal forests of Washington. *Journal of Wildlife Management* 66(2):392-406.

Avery, T. E. and H. E. Burkhart. 1994. *Forest measurements*. Fourth edition. McGraw Hill, Boston Massachusetts, USA.

Bailey, J. D. and J. C. Tappeiner. 1998. Effects of thinning on structural development in 40- to 100-year-old Douglas-fir stands in western Oregon. *Forest Ecology and Management* 108(2):99-113.

Batschelet, E. 1981. *Circular statistics in biology*. Academic Press, London, England.

Barber, D. R., T. E. Martin, M. A. Melchiors, R. E. Thill, and T. B. Wigley. Nesting success of birds in different silvicultural treatments in southeastern U.S. pine forests. *Conservation Biology* 15(1):196-207.

Barbour, R. J., S. Johnston, J. P. Hayes, and G. F. Tucker. 1997. Simulated stand characteristics and wood product yields from Douglas-fir plantations managed for ecosystem objectives. *Forest Ecology and Management* 91:205-219.

Berg, D. R., T. K. Brown, and B. Blessing. 1996. Silvicultural systems design with emphasis on the forest canopy. *Northwest Science* 70:31-36.

Birch, K. R. and K. N. Johnson. 1992. Stand-level wood-production costs of leaving live, mature trees at regeneration harvest in coastal Douglas-fir stands. *Western Journal of Applied Forestry* 7(3):65-68.

Bosch, J. M. and J. D. Hewlett. 1982. A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration. *Journal of Hydrology* 55(1):3-23.

Brandeis, T. J., M. Newton, G. M. Filip, and E. C. Cole. 2002. Cavity-nester habitat development in artificially made Douglas-fir snags. *Journal of Wildlife Management* 66(3):625-633.

Buermeyer, K. R. and C. A. Harrington. 2002. Fate of overstory trees and patterns of regeneration 12 years after clearcutting with reserve trees in southwest Washington. *Western Journal of Applied Forestry* 17(2):78-85.

Bull, E. L. and R. S. Holthausen. 1993. Habitat use and management of pileated woodpeckers in Northeastern Oregon. *Journal of Wildlife Management* 57(2):335-345.

Bull, E. L., R. S. Holthausen, and M. G. Henjum. 1990. Techniques for monitoring pileated woodpeckers. U.S. Department of Agriculture Forest Service General Technical Report PNW-GTR-269.

Bull, E. L. and J. A. Jackson. Pileated woodpecker. *Birds of North America* 148:1-21.

Bull, E. L., C. G. Parks, and T. R. Torgersen. 1997. Trees and logs important to wildlife in the interior Columbia river basin. U.S. Department of Agriculture Forest Service General Technical Report PNW-GTR-391.

Bull, E. L. and A. D. Partridge. 1986. Methods of killing trees for use by cavity nesters. *Wildlife Society Bulletin* 14(2):142-146.

Butts, S. R. and W. C. McComb. 2000. Associations of forest-floor vertebrates with coarse woody debris in managed forests of western Oregon. *Journal of Wildlife Management* 64(1):95-104.

- Cabe, P. R. 1993. European starling. Pages 1-24 in A. Poole and F. Gill, editors. *The birds of North America: life histories for the 21st century*. Smith-Edwards-Dunlap, Philadelphia, Pennsylvania, USA.
- Carey, A. B. 1996. Interactions of northwest forest canopies and arboreal mammals. *Northwest Science* 70:72-78.
- Carey, A. B. and R. O. Curtis. 1996. Conservation of biodiversity: a useful paradigm for forest ecosystem management. *Wildlife Society Bulletin* 24(4):610-620.
- Carey, A. B., M. M. Hardt, S. P. Horton, and B. L. Biswell. 1991. Spring bird communities in the Oregon Coast Range. Pages 123-141 in *Wildlife and vegetation of unmanaged Douglas-fir forests*. U.S. Department of Agriculture Forest Service General Technical Report PNW-GTR-285.
- Chambers, C. L., T. Carrigan, T. E. Sabin, J. Tappeiner, and W. C. McComb. 1997. Use of artificially created Douglas-fir snags by cavity-nesting birds. *Western Journal of Applied Forestry* 12:93-97.
- Chambers, C. L. and W. C. McComb. 1997. Effects of silvicultural treatments on wintering bird communities in the Oregon Coast Range. *Northwest Science* 71(4):298-304.
- Chambers, C. L., W. C. McComb, and J. C. Tappeiner. 1999a. Breeding bird responses to three silvicultural treatments in the Oregon Coast Range. *Ecological Applications* 9(1):171-185.
- Chambers, C. L., W. C. McComb, J. C. Tappeiner, L. D. Kellog, R. L. Johnson, and G. Spycher. 1999b. CFIRP: What we learned in the first ten years. *The Forestry Chronicle* 75(3):431-434.
- Christensen, N. L., A. M. Bartuska, J. H. Brown, S. Carpenter, C. D'Antonio, R. Francis, J. F. Franklin, J. A. MacMahon, R. F. Noss, D. J. Parsons, C. H. Peterson, M. G. Turner, and R. G. Woodmansee. 1996. The report of the Ecological Society of America committee on the scientific basis for ecosystem management. *Ecological Applications* 6(3):665-691.
- Cline, S. P., A. B. Berg, and H. M. Wight. 1980. Snag characteristics and dynamics in Douglas-fir forests, western Oregon. *Journal of Wildlife Management* 44(4):773-786.
- Cline, M. L., B. F. Hoffman, M. Cyr, and W. Bragg. 1991. Stand damage following whole-tree partial cutting in northern forests. *Northern Journal of Applied Forestry* 8(2):72-76.

- Collias N. E. and E. C. Collias. 1984. Nest building and bird behavior. Princeton University Press, New Jersey, USA.
- Collier, R. L. and E. C. Turnblom. 2001. Epicormic branching on pruned coastal Douglas-fir. *Western Journal of Applied Forestry* 16(2):80-86.
- Curtis, R. O. 1995. Extended rotations and culmination age of coast Douglas-fir: old studies speak to current issues. U.S. Department of Agriculture Forest Service PNW-RP-485.
- Curtis, R. O. and A. B. Carey. 1996. Managing for economic and ecological values in Douglas-fir forests. *Journal of Forestry* 94(9):4-7 and 35-37.
- Curtis, R. O. and D. D. Marshall. 1993. Douglas-fir rotations – time for reappraisal? *Western Journal of Applied Forestry* 8(3):81-85.
- Curtis, R. O. and D. L. Reukema. 1970. Crown development and site estimates in a Douglas-fir plantation spacing test. *Forest Science* 16(3):287-301.
- De'ath, G. and K. E. Fabricius. 2000. Classification and regression trees: a powerful yet simple technique for ecological data analysis. *Ecology* 81(11):3178-3192.
- Dickson, J. G., R. N. Conner, and J. H. Williamson. 1983. Snag retention increases bird use of a clear-cut. *Journal of Wildlife Management* 47(3):799-804.
- Drew, T. J. and J. W. Flewelling. 1979. Stand density management: an alternative approach and its application to Douglas-fir plantations. *Forest Science* 25(3):518-532.
- Eberhardt, L. L. 2003. What should we do about hypothesis testing? *Journal of Wildlife Management* 67(2):241-247.
- Edge, W. D. and J. M. Weikel. 2000. Monitoring avian response to density management. Cooperative Forest Ecosystem Research program (CFER) Annual Report. College of Agricultural Sciences and College of Forestry, Oregon State University, Corvallis, Oregon. December:31-32.
- Emmingham, B. 1998. Uneven-aged management in the Pacific Northwest. *Journal of Forestry* 96(7):37-39.
- Everett, R., J. Lehmkuhl, R. Schelhaas, P. Ohlson, D. Keenum, H. Riesterer, and D. Spurbeck. 1999. Snag dynamics in a chronosequence of 26 wildfires on the east

slope of the Cascade Range in Washington state, USA. *International Journal of Wildland Fire* 9(4):223-234.

Feare C. 1984. *The starling*. Oxford University Press, New York, New York, USA.

Ferrell, G. T. 1983. Growth classification systems for red fir and white fir in northern California. U.S. Department of Agriculture Forest Service General Technical Report PSW-72.

Franklin, J. F. 1989. Toward a new forestry. *American Forests* 95(11):37-44.

Franklin, J. F., D. R. Berg, D. A. Thornburg, and J. C. Tappeiner. 1997. Alternative silvicultural approaches to timber harvesting: variable retention systems. Pages 111-139 in K. A. Kohm and J. F. Franklin, editors. *Creating a forestry for the 21st century: the science of ecosystem management*. Island Press, Washington D.C., USA.

Franklin, J. F. and C. T. Dyrness. 1988. *Natural vegetation of Oregon and Washington*. Oregon State University Press, Corvallis, Oregon, USA.

Franklin, J. F., and R. T. T. Forman. 1987. Creating landscape patterns by forest cutting: Ecological consequences and principles. *Landscape Ecology* 1(1):5-8.

Franklin, J. F., H. H. Shugart, and M. E. Harmon. 1987. Tree death as an ecological process. *BioScience* 37(8):550-556.

Franklin, J. F., T. A. Spies, R. Van Pelt, A. B. Carey, D. A. Thornburgh, D. R. Berg, D. B. Lindenmayer, M. E. Harmon, W. S. Keeton, D. C. Shaw, K. Bible, and J. Chen. 2002. Disturbances and structural development of natural forest ecosystems with silvicultural implications, using Douglas-fir forests as an example. *Forest Ecology and Management* 155(3):399-423.

Gibbons, P. and D. B. Lindenmayer. 1997. *Conserving hollow-dependent fauna in timber-production forests*. Environmental Heritage Monograph, Number 3.

Grumbine, R. E. 1994. What is ecosystem management? *Conservation Biology* 8(1):27-38.

Hagar, J. C. 1999. Influence of riparian buffer width on bird assemblages in western Oregon. *Journal of Wildlife Management* 63(2):484-496.

Hagar, J. C., W. C. McComb, and W. H. Emmingham. 1996. Bird communities in commercially thinned and unthinned Douglas-fir stands in western Oregon. *Wildlife Society Bulletin* 24(2):353-366.

- Halaj, J., D. W. Ross, and A. R. Moldenke. 2000. Importance of habitat structure to the arthropod food-web in Douglas-fir canopies. *Oikos* 90(1):139-152.
- Hall, L. S., P. R. Krausman, and M. L. Morrison. 1997. The habitat concept and a plea for standard terminology. *Wildlife Society Bulletin* 25(1):173-182.
- Hallet, J. G., T. Lopez, M. A. O'Connell, and M. A. Borysewicz. 2001. Decay dynamics and avian use of artificially created snags. *Northwest Science* 75(4):378-386.
- Halpern, C. B. and T. A. Spies. 1995. Plant species diversity in natural and managed forests of the Pacific Northwest. *Ecological Applications* 5(4):913-934.
- Han, H-S, L. D. Kellog, G. M. Filip, and T. D. Brown. 2000. Scar closure and future timber value losses from thinning damage in western Oregon. *Forest Products Journal* 50(1):36-42.
- Hansell, M. 2000. Bird nests and construction behaviour. Cambridge University Press, New York, New York, USA.
- Hansen, A. J., W. C. McComb, R. Vega, M. G. Raphael, and M. Hunter. 1995. Bird habitat relationships in natural and managed forests in the west Cascades of Oregon. *Ecological Applications* 5(3):555-569.
- Harmon, M. E. 2001. Moving towards a new paradigm for woody detritus management. *Ecological Bulletins* 49:269-278.
- Harmon, M. E., J. F. Franklin, F. J. Swanson, P. Sollins, S. V. Gregory, J. D. Lattin, N. H. Anderson, S. P. Cline, N. G. Aumen, J. R. Sedell, G. W. Lienkaemper, K. Cromak, J. R., and K. W. Cummins. 1986. Ecology of coarse woody debris in temperate ecosystems. Pages 133-302 in A. MacFadyen and E. D. Ford, editors. *Advances in Ecological Research*, volume 15. Academic Press, London, England.
- Harr, R. D. 1983. Potential for augmenting water yield through forest practices in western Washington and western Oregon. *Water Resources Bulletin* 19(3):383-393.
- Harrington, C. A. and D. L. Reukema. 1983. Initial shock and long-term stand development following thinning in a Douglas-fir plantation. *Forest Science* 29(1):33-26.

Hartsough, B. 2003. Economics of harvesting to maintain high structural diversity and resulting damage to residual trees. *Western Journal of Applied Forestry* 18(2):133-142.

Hayes, J. P., S. S. Chan, W. H. Emmingham, J. C. Tappeiner, L. D. Kellogg, and J. D. Bailey. 1997. Wildlife response to thinning in young forests in the Pacific Northwest. *Journal of Forestry* 95(8):28-33.

Hayes, J. P. and J. Weikel. 2000. Bird response to thinning. Cooperative Forest Ecosystem Research program Annual Report. College of Agricultural Sciences and College of Forestry, Oregon State University, Corvallis, Oregon. December:29-30.

Howard, A. F. 1996. Damage to residual trees from cable yarding when partial cutting second-growth stands in coastal British Columbia. *Canadian Journal of Forest Research* 26(8):1392-1396.

Huff, M. H., K. A. Bettinger, H. L. Ferguson, M. J. Brown, and B. Altman. 2000. A habitat-based point-count for terrestrial birds, emphasizing Washington and Oregon. U.S. Department of Agriculture Forest Service General Technical Report PNW-GTR-501.

Hurlbert, S. H. 1984. Pseudoreplication and the design of ecological field experiments. *Ecological Monographs* 54(2):187-211.

Hunter, J. E. and M. L. Bond. 2001. Residual trees: wildlife associations and recommendations. *Wildlife Society Bulletin* 29(3):995-999.

Ingold, D. J. 1994. Influence of nest-site competition between European starlings and woodpeckers. *Wilson Bulletin* 106(2):227-241.

Ingold, D. J. 1996. Delayed nesting decreases reproductive success in northern flickers: implications for competition with European starlings. *Journal of Field Ornithology* 67(2):321-326.

Ishii, H. and N. McDowell. 2002. Age-related development of crown structure in coastal Douglas-fir trees. *Forest Ecology and Management* 169(3):257-270.

Ishii, H. and M. E. Wilson. 2001. Crown structure of old-growth Douglas-fir in the western Cascade Range, Washington. *Canadian Journal of Forest Research* 31(7):1250-1261.

Johnson, D. H. 1999. The insignificance of statistical significance testing. *Journal of Wildlife Management* 63(3):763-772.

- Johnson, D. H., and T. A. O'Neil. 2000. Wildlife-habitat relationships in Oregon and Washington. Oregon State University Press, Corvallis, Oregon, USA.
- Johnson, E. V. 2000. Woodpecker drumming. *Bird Watcher's Digest*. January:68-75.
- Kaufman, K. 1996. Lives of North American birds. Houghton Mifflin Company, Boston, Massachusetts, USA.
- Kellogg, L. D., P. Bettinger, and R. M. Edwards. 1996. A comparison of logging planning, felling, and skyline yarding costs between clearcutting and five group-selection harvesting methods. *Western Journal of Applied Forestry* 11(3):90-96.
- Knopf, L. K., R. R. Johnson, T. Rich, F. B. Samson, and R. C. Szaro. 1988. Conservation of riparian ecosystems in the United States. *Wilson Bulletin* 100(2):272-284.
- Krebs, C. J. Ecological methodology. Second edition. 1999. Addison Welsey Longman. Menlo Park, California, USA.
- Larson, J. B. 1995. Ecological stability of forests and sustainable silviculture. *Forest Ecology and Management* 73:85-96.
- Latham, P. and J. Tappeiner. 2002. Response of old-growth conifers to reduction in stand density in western Oregon forests. *Tree Physiology* 22:137-146.
- Lehmkuhl, J. F., R. L. Everett, R. Schellhaas, P. Ohlson, D. Keenum, H. Riesterer, and D. Spurbeck. 2003. Cavities in snags along a wildlife chronosequence in eastern Washington. *Journal of Wildlife Management* 67(1):219-228.
- Li, P. and T. E. Martin. 1991. Nest-site selection and nesting success of cavity-nesting birds in high elevation forest drainages. *The Auk* 108(2):405-418.
- Loefering, J. P. and R. G. Anthony. 1999. Distribution, abundance, and habitat association of riparian-obligate and -associated birds in the Oregon Coast Range. *Northwest Science* 73(3):168-185.
- Lundquist, R. W. and J. M. Mariani. 1991. Nesting habitat and abundance of snag-dependent birds in the southern Washington Cascade Range. Pages 221-239 in *Wildlife and vegetation of unmanaged Douglas-fir forests*. U.S. Department of Agriculture Forest Service General Technical Report PNW-GTR-285.
- Maguire, C. C. and C. L. Chambers, editors. *In press*. College of Forestry Integrated Research Project: Ecological and socioeconomic responses to

alternative silvicultural treatments. Oregon State University, College of Forestry, Forestry Research Lab Publication #3582.

Maguire, D. A. and D. W. Hann. 1987. A stem dissection technique for dating branch mortality and reconstructing past crown recession. *Forest Science* 33(4):858-871.

Maguire, D. A. and A. Kanaskie. 2002. The ratio of live crown length to sapwood area as a measure of crown sparseness. *Forest Science* 48(1):93-100.

Mallow, C. 1998. The zeroth problem. *The American Statistician* 52(1):1-9.

Mannan, R. W., E. C. Meslow, and H. M. Wight. 1980. Use of snags by birds in Douglas-fir forests, western Oregon. *Journal of Wildlife Management* 44(4):787-797.

Marshall, D. D., J. F. Bell, and J. C. Tappeiner. 1992. Levels-of-growing-stock cooperative study in Douglas-fir: Report No. 10 – the Hoskins study, 1963-83. U.S. Department of Agriculture Forest Service Pacific Northwest Research Station Research Paper PNW-RP-448.

Martin, T. E. and G. R. Geupel. 1993. Nest-monitoring plots: methods for locating nests and monitoring success. *Journal of Field Ornithology* 64(4):507-519.

Marzluff, J. M., M. G. Raphael, and R. Sallabanks. 2000. Understanding the effects of forest management on bird species. *Wildlife Society Bulletin* 28(4):1132-1143.

Matzka, P. J. and L. D. Kellogg. 2003. Harvest system selection and design for damage reduction in noble fir stands: a case study on the Warm Springs Indian Reservation, Oregon. *Western Journal of Applied Forestry* 18(2):118-126.

Mayfield, H. F. 1975. Suggestions for calculating nest success. *Wilson Bulletin* 87(4):456-466.

McClain, K. M., D. M. Morris, S. C. Hills, and L. J. Buse. 1994. The effects of initial spacing on growth and crown development for planted northern conifers: 37-year results. *The Forestry Chronicle* 70(2):174-182.

McEllin, S. M. 1979. Nest sites and population demographics of white-breasted and pigmy nuthatches in Colorado. *Condor* 81:348-352.

Mikusiński, G. M. Gromadzki, and P. Chylarecki. Woodpeckers as indicators of forest bird diversity. *Conservation Biology* 15(1):208-217.

- Miller, M. and B. Emmingham. 2001. Can selection thinning convert even-age Douglas-fir stands to uneven-age structures? *Western Journal of Applied Forestry* 16(1):35-43.
- Minore, D. 1979. Comparative autecological characteristics of northwestern tree species – a literature review. U.S. Department of Agriculture Forest Service Pacific Northwest Forest and Range Experiment Station General Technical Report PNW-87.
- Mitchell, M. S., R. A. Lancia, and J. A. Gerwin. 2001. Using landscape-level data to predict the distribution of birds on a managed forest: effects of scale. *Ecological Applications* 11(6):1692-1708.
- Moore, J. R., D. A. Maguire, D. L. Phillips, and C. B. Halpern. 2002. Effects of varying levels and patterns of green-tree retention on amount of harvesting damage. *Western Journal of Applied Forestry* 17(4):202-206.
- Moorman, C. E., and D. D. Guynn, Jr. 2001. Effects of group-selection opening size on breeding bird habitat use in a bottomland forest. *Ecological Applications* 11(6):1680-1691.
- Morrison, M. L. and E. C. Meslow. 1983. Bird community structure on early-growth clear-cuts in western Oregon. *The American Midland Naturalist* 110(1):129-137.
- Morrison, M. L. and M. G. Raphael. 1993. Modeling the dynamics of snags. *Ecological Society of America* 3(2):322-330.
- Neitro, W. A., V. W. Binkley, S. P. Cline, R. W. Mannan, B. G. Marcot, D. Taylor, and F. F. Wagner. 1985. Snags (wildlife trees). Pages 129-167 in E. R. Brown, editor. *Management of wildlife and fish habitats in forests of western Oregon and Washington. Part 1: chapter narratives.* Portland, Oregon, U.S. Department of Agriculture Forest Service Pacific Northwest Region.
- Newton, M. and E. C. Cole. 1987. A sustained-yield scheme for old-growth Douglas-fir. *Western Journal of Applied Forestry* 2(1):22-25.
- O'Hara, K. L. 1988. Stand structure and growing space efficiency following thinning in an even-aged Douglas-fir stand. *Canadian Journal of Forest Research* 18(7):859-866.
- Ohmann, J. L., W. C. McComb, and A. A. Zumrawi. 1994. Snag abundance for primary cavity-nesting birds on nonfederal forest lands in Oregon and Washington. *Wildlife Society Bulletin* 22(4):607-620.

- Ohmart, R. D. 1994. The effects of human-induced changes on the avifauna of western riparian habitats. *Studies in Avian Biology* 15:273-285.
- Olden, J. D. and D. A. Jackson. 2000. Torturing data for the sake of generality: How valid are our regression models? *Ecoscience* 7(4):501-510.
- Oregon Climate Service. 2003. <http://www.ocs.orst.edu/>
- Parks, C. G. and D. C. Shaw. 1996. Death and decay: a vital part of living canopies. *Northwest Science* 70:46-53.
- Peet, R. K. and N. L. Christensen. 1987. Competition and tree death. *BioScience* 37(8):586-595.
- Perry, D. A. 1998. The scientific basis of forestry. *Annual Review of Ecology and Systematics* 29:435-66.
- Peterson, B. and G. Gauthier. 1985. Nest site use by cavity-nesting birds of the Cariboo Parkland, British Columbia. *Wilson Bulletin* 97(3):319-331.
- Poage, N. J. and J. C. Tappeiner II. 2002. Long-term patterns of diameter and basal area growth of old-growth Douglas-fir trees in western Oregon. *Canadian Journal of Forest Research* 32(7):1232-1243.
- Ramsey F. L. and D. W. Schafer. 1997. *The statistical sleuth*. Duxbury Press, California, USA.
- Raphael, M. G. and M. White. 1984. Use of snags by cavity-nesting birds in the Sierra Nevada. *Wildlife Monograph* 86:1-66.
- Rocklage, A. M. and J. T. Ratti. 2000. Avian use of recently evolved riparian habitat on the Lower Snake River, Washington. *Northwest Science* 74(4):286-293.
- Rolstad, J. I. Gjerde, V. S. Gundersen, and M. Saetersdal. 2002. Use of indicator species to assess forest continuity: a critique. *Conservation Biology* 16(1):253-257.
- Rose, C. L. 1996. Forest canopy-atmosphere interactions. *Northwest Science* 70:7-14.
- Ross, D. W. and C. G. Niwa. 1997. Using aggregation and antiaggregation pheromones of the Douglas-fir beetle to produce snags for wildlife habitat. *Western Journal of Applied Forestry* 12(2):52-54.
- SAS Institute System. 1999. SAS Institute Incorporated. Cary, North Carolina, USA.

- Sallabanks, R., E. B. Arnett, and J. M. Marzluff. 2000. An evaluation of research on the effects of timber harvest on bird populations. *Wildlife Society Bulletin* 28(4):144-155.
- Salwasser, H. 1990. Gaining perspective: forestry for the future. *Journal of Forestry* 88:32-38.
- Schreiber, B. and D. S. deCalesta. 1992. The relationship between cavity-nesting birds and snags on clearcuts in western Oregon. *Forest Ecology and Management* 50:299-316.
- Sharpe, F. 1996. The biologically significant attributes of forest canopies to small birds. *Northwest Science* 70:86-93.
- Shaw, D. C. and K. Bible. 1996. An overview of forest canopy ecosystem functions with reference to urban and riparian systems. *Northwest Science* 70:1-6.
- Showalter, C. R. and R. C. Whitmore. 2002. The effect of gypsy moth defoliation of cavity-nesting bird communities. *Forest Science* 48(2):273-281.
- Smith, D. M., B. C. Larson, M. J. Kelty, P. M. S. Ashton. 1997. *The practice of silviculture: applied forest ecology*. John Wiley and Sons, New York, New York, USA.
- Spies, T. A. and J. F. Franklin. 1991. The structure of natural young, mature, and old-growth Douglas-fir Forests in Oregon and Washington. Pages 91-109 *in* *Wildlife and vegetation of unmanaged Douglas-fir forests*. U.S. Department of Agriculture Forest Service General Technical Report PNW-GTR-285.
- Spies, T. A., J. F. Franklin, and T. B. Thomas. 1988. Coarse woody debris in Douglas-fir forests of western Oregon and Washington. *Ecology* 69(9):1689-1702.
- Starkey, E. E and J. C. Hagar. 2000. Trophic relationships among birds, arthropods, and shrubs. Cooperative Forest Ecosystem Research program (CFER) Annual Report. College of Agricultural Sciences and College of Forestry, Oregon State University, Corvallis, Oregon. December:35-39.
- Steidl, R. J., J. P. Hayes, and E. Schaubert. 1997. Statistical power analysis in wildlife research. *Journal of Wildlife Management* 61(2):270-279.
- Suzuki, N. and J. P. Hayes. 2003. Effects of thinning on small mammals in Oregon coastal forests. *Journal of Wildlife Management* 67(2):352-371.

Swanson, F. J. and J. F. Franklin. 1992. New forestry principles from ecosystem analysis of Pacific Northwest forests. *Ecological Applications* 2(3):262-274.

Swihart, R. K. and P. M. Waser. 2002. Gray matters in ecology: dynamics of pattern, process, and scientific progress. *Bulletin of the Ecological Society of America* 83(2):149-155.

Tappeiner, J. C., D. Huffman, D. Marshall, T. A. Spies, and J. D. Bailey. 1997. Density, ages, and growth rates in old-growth and young-growth forests in coastal Oregon. *Canadian Journal of Forest Research* 27(5):638-648.

Tittler, R., S. J. Hannon, and M. R. Norton. 2001. Residual tree retention ameliorates short-term effects of clear-cutting on some boreal songbirds. *Ecological Applications* 11(6):1656-1666.

Torgersen, T. R. and E. L. Bull. 1995. Down logs as habitat for forest-dwelling ants – the primary prey of pileated woodpeckers in northeastern Oregon. *Northwest Science* 69(4):294-303.

Van Pelt, R. and M. P. North. 1996. Analyzing canopy structure in Pacific Northwest old-growth forests with a stand-scale crown model. *Northwest Science* 70:15-30.

Veblen, T. T., D. Kulakowski, K. S. Eisenhart, and W. L. Baker. 2001. Subalpine forest damage from a severe windstorm in northern Colorado. *Canadian Journal of Forest Research* 31(12):2089-2097.

Weikel, J. M. and J. P. Hayes. 1999. The foraging ecology of cavity-nesting birds in young forests of the northern Coast Range of Oregon. *The Condor* 101:58-66.

Weikel, J. M. and J. P. Hayes. 2001. Habitat use by snag-associated species: a bibliography for species occurring in Oregon and Washington. Research contribution 33, Forest Research Laboratory, Oregon State University, Corvallis, Oregon: <http://www.fsl.orst.edu/cfer/snags/bibliography.html>

Weitzel, N. H. 1988. Nest-site competition between the European starling and native breeding birds in northwestern Nevada. *The Condor* 90(2):515-517.

Williamson, R. L. 1982. Response to commercial thinning in a 110-year-old Douglas-fir stand. U.S. Department of Agriculture Forest Service Pacific Northwest Forest and Range Experimental Station Research Paper PNW-296.

Williamson, R. L. and F. E. Price. 1971. Initial thinning effects in 70- to 150-year-old Douglas-fir – western Oregon and Washington. U.S. Department of

Agriculture Forest Service Pacific Northwest Forest and Range Experimental Station Research Paper PNW-117.

Winchester, N. N. and R. A. Ring. 1996. Northern temperate coastal sitka spruce forests with special emphasis on canopies: studying arthropods in an unexplored frontier. *Northwest Science* 70:94-103.

Wunder, L. and A. B. Carey. 1996. Use of the forest canopy by bats. *Northwest Science* 70:79-85.

Youngblood, A. P. 1991. Radial growth after a shelterwood seed cut in a mature stand of white spruce in interior Alaska. *Canadian Journal of Forest Research* 21(3):410-413.

Youngblood, A. 2000. Damage to residual trees and advance regeneration from skyline and forwarder yarding in mixed-conifer stands of northeastern Oregon. *Western Journal of Forestry* 15(2):101-107.

Zarnowitz, J. E. and D. A. Manuwal. 1985. The effects of forest management on cavity-nesting birds in Northwestern Washington. *Journal of Wildlife Management* 49(1):255-263.

Zar, J. H. 1999. *Biostatistical analysis*. Fourth edition. Prentice-Hall, New Jersey, USA.

Zenner, E. K. 2000. Do residual trees increase structural complexity in Pacific Northwest coniferous forests? *Ecological Applications* 10(3):800-810.