Recommendations and Supporting Analysis of Conservation Opportunities for the Marbled Murrelet Long-Term Conservation Strategy

Prepared for:
Washington State Department of Natural Resources
Olympia, Washington

September 2008

Suggested Citation

Raphael, M. G., S. K. Nelson, P. Swedeen, M. Ostwald, K. Flotlin, S. Desimone, S. Horton, P. Harrison, D. Prenzlow Escene, and W. Jaross. 2008. Recommendations and Supporting Analysis of Conservation Opportunities for the Marbled Murrelet Long-Term Conservation Strategy. Washington State Department of Natural Resources, Olympia, WA.

Recommendations and Supporting Analysis of Conservation Opportunities for the Marbled Murrelet Long-Term Conservation Strategy

Prepared for:
Washington State Department of Natural Resources
Olympia, Washington

Prepared by:
The Marbled Murrelet Science Team
M. G. Raphael, S. K. Nelson, P. Swedeen, M. Ostwald, K. Flotlin, S. Desimone, S. Horton,
P. Harrison, D. Prenzlow Escene, and W. Jaross

In Association With:
Hamer Environmental, L.P.
Mt. Vernon, Washington
and
EDAW, Inc.
Seattle, Washington

September 2008

WASHINGTON STATE DEPARTMENT OF
Natural Resources

DOUG SUTHERLAND
Commissioner of Public Lands

September 9, 2008

Dear Reader:

The Washington State Department of Natural Resources (DNR) is proud to present a technical report prepared by the Marbled Murrelet Science Team for the management of marbled murrelet habitat on DNR-managed forests in Southwest Washington and on the Olympic Peninsula titled, *Recommendations and Supporting Analysis of Conservation Opportunities for the Marbled Murrelet Long-Term Conservation Strategy*. The report was released on the internet in February 2008 while waiting for two chapters to be completed. The completed report is now final and updated online.

When DNR completed its Habitat Conservation Plan in 1997, it was not able to include a Long-Term Conservation Strategy for the marbled murrelet due to the lack of sufficient scientific knowledge regarding habitat and nesting criteria. Instead, an interim strategy was created to guide the collection of data to inform the subsequent development of a Long-Term Conservation Strategy.

In 2004, DNR convened a team of professionals to compile expert opinion, data, and research on marbled murrelet habitat conservation. These specialists, known within this report as the Science Team, were asked to develop a set of recommendations for DNR to consider when developing a Long-Term Conservation Strategy for the marbled murrelet on DNR-managed forestlands.

The attached report, which embodies the Science Team's recommendations and their supporting analysis, is a thoughtful and innovative piece of scientific work unlike that done by any other landowner for the conservation of this federally threatened species. The Science Team members, all marbled murrelet experts with varied backgrounds in research, monitoring and management, worked for almost four years to fulfill their mandate. I believe you will be impressed with the quality of their work.

This report supplies a landscape-level examination of conservation opportunities for DNR to consider in their crafting of a Long-Term Conservation Strategy. It includes the definition of appropriate biological goals for habitat conservation, an evaluation and rationale for important landscapes for support of those biological goals, and some preliminary forest modeling to demonstrate tools for DNR to use in evaluating alternative approaches to a Long-Term Conservation Strategy.

This report details recommendations developed by the Science Team for DNR's consideration; it is not a draft strategy. The development of a proposed Long-Term Conservation Strategy will be done by DNR with input from the U.S. Fish and Wildlife Service, and will be informed by additional analysis and public input. Opportunities for public input will be provided through the environmental review process under the National Environmental Policy Act and State Environmental Policy Act.

I greatly appreciate the time and work that DNR's team members devoted to this important effort, and the tireless and rigorous scientific contributions that the Science Team provided. Their work gives DNR the scientific foundation for a conservation strategy that will make a contribution to the conservation of marbled murrelet habitat in western Washington.

Sincerely,

Bruce Mackey
DNR Land Steward

SUMMARY OF RECOMMENDATIONS

The Science Team reviewed the objectives for the marbled murrelet conservation strategy in the Washington Department of Natural Resources' 1997 Habitat Conservation Plan (HCP). From these commitments, the Team identified the biological goals for the Long-Term Conservation Strategy to be to manage forest habitat to contribute to 1) a stable or increasing population; 2) an increasing geographic distribution; and 3) a population that is resilient to disturbance.

The Science Team recommends that DNR manage 176,000 acres of DNR-managed lands on the Olympic Peninsula and in Southwest Washington for the development and maintenance of high-quality nesting habitat for the marbled murrelet. The Science Team uses the term "high-quality nesting habitat" to denote nesting habitat that has the highest likelihood of supporting successfully reproductive marbled murrelets in a landscape. Such habitat is characterized by the Science Team as forest stands that 1) have very large, tall trees with broad, deep crowns that support potential nest platforms; 2) have multiple canopy layers and canopy gaps, and; 3) are situated within a secure landscape that minimizes predation and allows for the successful fledging of young. The Team recommends that identified areas be actively managed through silviculture, emphasizing the goal of habitat development.

Throughout the area of the proposed Long-Term Conservation Strategy, the Science Team recommends that DNR defer all sites currently identified as occupied (55,000 acres) from harvest for the duration of the HCP.

The Science Team proposes distinct landscape approaches for the Southwest Washington, Olympic Experimental State Forest and Straits Analysis Units. In Southwest Washington, nine landscapes comprising 66,000 acres are identified where specific "marbled murrelet management areas" (MMMAs) are delineated. Those MMMAs are found in the Salmon Creek, Skamokawa, Browning, Elochoman, Chehalis, Grays, Humptulips, Nemah and Lebam blocks. Within each MMMA, 100 percent of the area is recommended to be managed with the goal of creating high-quality nesting habitat.

In the Olympic Experimental State Forest (OESF), recommended conservation emphasis differs among the 11 landscape planning units (LPUs). The greatest emphasis on conservation is placed in the Dickodochtedor, Goodman Creek, and Kalaloch LPUs, where 39,000 acres are delineated into MMMAs that will be managed to achieve and maintain at least 50 percent of those areas as high-quality nesting habitat. In the other eight LPUs, varying conservation emphases are recommended based on specific landscape configuration, forest conditions, and other management considerations in those individual landscapes. The Science Team also recommends that all designated "old forest" in the OESF, about 44,000 acres, be deferred from harvest for the duration of the HCP in support of nesting habitat for the marbled murrelet.

In the Straits Analysis Unit, due to the presence of high-quality nesting habitat on federal lands, it is proposed that DNR maintain and buffer all occupied sites as the only conservation measure employed.

Across all three analysis units, in areas without specific recommended conservation emphasis, management will increase marbled murrelet nesting habitat through the implementation of other conservation objectives.

Using quantitative methods, the Science Team evaluated two simplified forest land management scenarios for their ability to maximize over the life of the HCP the quality and quantity of marbled murrelet habitat on DNR-managed land on the Olympic Peninsula and in southwest Washington. These two scenarios, "No Management" and "Habitat Management", simulated forest growth and consequent development of marbled murrelet habitat. Analysis suggests that DNR's policies, in concert with the specific approach to marbled murrelet conservation, will result in improved inland habitat conditions in the Southwest Washington and Olympic Experimental State Forest Analysis Units. Projected habitat conditions improve under both scenarios, with DNR-managed lands doubling their potential capability to provide habitat for marbled murrelets in both analysis units. The Habitat Management scenario creates more potential habitat capability in Southwest Washington than the No Management scenario over the life of the HCP, while both scenarios perform equally well in the Olympic Experimental State Forest. Additional analysis is required in order to fine tune habitat development modeling, which will be undertaken during the development of alternatives to be considered by the Department of Natural Resources and the U.S. Fish and Wildlife Service during the development of the Long-Term Conservation Strategy.

ACKNOWLEDGEMENTS

AUTHORS AND PRINCIPAL CONTRIBUTORS

Principal Authors

Dr. Martin G. Raphael	U.S. Forest Service Pacific Northwest Research Station
Kim Nelson	Oregon State University
Dr. Paula Swedeen	Consultant
Mark Ostwald	U.S. Fish and Wildlife Service
Kimberly Flotlin	U.S. Fish and Wildlife Service
Steve Desimone	Washington Department of Fish and Wildlife
Dr. Scott Horton	Washington Department of Natural Resources
Peter Harrison	Washington Department of Natural Resources
Danielle Prenzlow Escene	Washington Department of Natural Resources
Weikko Jaross	Washington Department of Natural Resources

Project Managers

Peter Harrison	Science Team Lead
	Washington Department of Natural Resources
Corina Logan	Project Coordinator
	Washington Department of Natural Resources
Andrew Hayes	Project Manager
	Washington Department of Natural Resources

GIS Support

Christina Kellum	Washington Department of Natural Resources
Rebecca Niggemann	Washington Department of Natural Resources
Chris Snyder	Washington Department of Natural Resources
Ned Wright	Washington Department of Natural Resources

DOCUMENT PREPARATION

Tom Hamer	Hamer Environmental, L.P.
Nathalie Denis	Hamer Environmental, L.P.
Thomas Mohagen	Hamer Environmental, L.P.
Erin Colclazier	Hamer Environmental, L.P.
Jake Verschuyl	Hamer Environmental, L.P.
Jim Keany	EDAW, Inc.
Amber Martin	EDAW, Inc.
Julie Nichols	EDAW, Inc.
Christy Seifert	EDAW, Inc.
Angela Cahill	Washington Department of Natural Resources
Cassandra Koerner	Washington Department of Natural Resources

ACKNOWLEDGEMENTS

We thank Zach Peery, Alan Burger, and Daniel Rosenberg for their invaluable reviews.

COVER PHOTO CREDITS

Tree: Steve Curry 2005

Marbled murrelet at-sea: Rich MacIntosh

Marbled murrelet nesting: Tom Hamer

TABLE OF CONTENTS

EXECUTIVE SUMMARY……………………………………………………………………………ES-1

1.0 INTRODUCTION 1-1

1.1 Interim Conservation Strategy 1-4
1.2 Developing a Long-Term Conservation Strategy 1-6

2.0 MARBLED MURRELET ECOLOGY AND LIFE HISTORY 2-1

2.1 Species Description and Taxonomy 2-1
2.2 Geographic Distribution 2-5
2.3 Movement, Dispersal, Site Fidelity, and Philopatry 2-7
2.4 Flight Distance and Behavior 2-10
2.5 Food Habits and Foraging Behaviors 2-11
2.6 Population Ecology 2-13
2.7 Habitat Loss and Fragmentation 2-31
2.8 Conclusion 2-39

3.0 RECOMMENDED LANDSCAPE CONSERVATION APPROACH... 3-1

I INTRODUCTION 3-1
II DNR MANAGEMENT GUIDANCE 3-1
III CONSERVATION OBJECTIVES.. 3-2
IV POPULATION-BASED CONSERVATION APPROACH FOR DNR-MANAGED FORESTLANDS 3-3
3.1 Land Designations for Habitat Conservation 3-9
3.2 Conservation Approach for a Marbled Murrelet Long-Term Conservation Strategy in Southwest Washington 3-12
3.3 Conservation Approach for a Marbled Murrelet Long-Term Conservation Strategy in the Olympic Experimental State Forest 3-32
3.4 Conservation Approach for a Marbled Murrelet Long-Term Conservation Strategy in the Straits 3-58

4.0 HABITAT ASSESSMENT METHODS 4-1

I ESTIMATING POTENTIAL MARBLED MURRELET POPULATION RESPONSES TO CURRENT AND PROJECTED FOREST HABITAT 4-1
4.1 Population Responses to Habitat 4-1
4.2 An Index of the Potential Influence of Habitat Quality and Quantity on Marbled Murrelet Populations in Washington 4-2
4.3 The Relationship of Habitat Area with Marbled Murrelet Abundance 4-3
4.4 The Relationship of the Structure and Composition of Forest Stands with Their Potential Contribution to Carrying Capacity for Marbled Murrelets 4-4
4.5 Estimating Current and Future Marbled Murrelet Habitat 4-9
4.6 Projecting Marbled Murrelet Habitat Development on DNR-Managed Lands 4-10
4.7 Summary of the Projected Current and Future Contribution of Forest Stands to Marbled Murrelet Carrying Capacity 4-15
4.8 Edge Effects on Quality of Marbled Murrelet Habitat and Its Potential Influence on Carrying Capacity 4-17
4.9 The Habitat Capability (*K'*) Equation 4-18
4.10 The Influence of Distance from Marine Habitat on the Quality of Inland Marbled Murrelet Habitat and its Effects on Carrying Capacity 4-19

II METHODS FOR PROJECTING THE DEVELOPMENT OF MARBLED MURRELET HABITAT UNDER THE SCIENCE TEAM'S RECOMMENDED CONSERVATION APPROACH 4-19
4.11 Goals and Objective Criteria 4-20
4.12 Model Structure 4-20
4.13 Model Development 4-21
4.14 Management Scenarios: Silvicultural Activities and Projected Forest Responses 4-22
4.15 Model Limitations 4-25
4.16 Management Scenario Analysis Results 4-26

5.0 HABITAT ASSESSMENT RESULTS: PROJECTIONS OF MARBLED MURRELET HABITAT AND POTENTIAL POPULATION RESPONSE RESULTING FROM THE SCIENCE TEAM'S CONSERVATION RECOMMENDATIONS 5-1

5.1 Comparison of Current and Projected Future Marbled Murrelet Habitat and Its Potential for Population Support among Analysis Units and of DNR's Relative Role within Analysis Units 5-2
5.2 Projected Rate of Habitat Development on DNR-Managed Lands 5-8
5.3 A Comparison of the No Management and Habitat Management Scenarios 5-11
5.4 A Comparison of Marbled Murrelet Habitat on DNR-Managed Lands within and outside Marbled Murrelet Management Areas 5-12
5.5 Summary and Discussion 5-15

6.0 CONCEPTS IN ADAPTIVE MANAGEMENT 6-1
6.1 Introduction 6-1
6.2 Characteristics of DNR's Marbled Murrelet Long-Term Conservation Strategy 6-3
6.3 Management Approaches 6-7
6.4 Adaptive Management for the Long-Term Conservation Strategy 6-9
6.5 Potential Topics for Adaptive Management 6-14

7.0 LITERATURE CITED 7-1

APPENDICES
APPENDIX A: DNR Marbled Murrelet Summit Meeting Attendees
APPENDIX B: Forest Stand Classification Crosswalk
APPENDIX C: Management Scenario Analysis Assumptions and Methods
APPENDIX D: Science Team Recommendations: Roads, Yarding and Salvage in Occupied Sites
APPENDIX E: Science Team Recommendations: Performance Criteria for Buffers Around Occupied Sites
APPENDIX F: Evaluation of Survey Efforts for DNR Surveys
APPENDIX G: Comprehensive Summary of Results from the Management Scenario Analysis
APPENDIX H: Marbled Murrelet Potential Habitat Capability (*K′*) Model Sensitivity Analysis

FIGURES

Figure 1-1. DNR-Managed Lands Covered by the Habitat Conservation Plan 1-2
Figure 1-2. DNR Marbled Murrelet Long-Term Conservation Strategy Process Flow Chart....1-3
Figure 2-1. Marbled Murrelet Adult in Breeding Plumage....2-2
Figure 2-2. Marbled Murrelet After-Hatch-Year Bird in Winter Plumage....2-3
Figure 2-3. Juvenile (Hatch-Year) Marbled Murrelet Just Before Fledging from the Nest....2-3
Figure 2-4. Distribution of Breeding and Non-Breeding (At-Sea) Marbled Murrelets in North America 2-6
Figure 2-5. Three-State Marbled Murrelet Range, U.S. Fish and Wildlife Service Conservation Zones Boundaries, and Land Ownership 2-17
Figure 2-6. Marbled Murrelet Conservation Zone One and the Three Primary Sampling Units Used to Estimate Population Size for the Northwest Forest Plan Effectiveness Monitoring Program 2-28
Figure 2-7. Marbled Murrelet Conservation Zone Two and the Two Primary Sampling Units Used to Estimate Population Size for the Northwest Forest Plan Effectiveness Monitoring Program 2-29
Figure 2-8. Relationship of Estimated Mean At-Sea Marbled Murrelet Population Size with Adjacent Potential Marbled Murrelet Nesting Habitat within the Conservation Zones, with Segment Numbers Denoting Conservation Zones and Segments within Zones. 2-32
Figure 2-9. Recent Trends in Washington Timber Harvests on Public and Private Lands....2-33
Figure 2-10. Recent Trends in Washington Timber Harvests on Public Lands....2-34
Figure 3-1. Planning Area Considered by the Science Team, Including Marbled Murrelet Analysis Units and DNR HCP Planning Units. 3-6
Figure 3-2. Major Public Lands in Each Analysis Unit within the Planning Area Considered by the Science Team....3-7
Figure 3-3. Geographic Planning Blocks for the Southwest Washington Analysis Unit....3-18
Figure 3-4. Overall Scorecard Results by Geographic Planning Block for the Southwest Washington Analysis Unit....3-19
Figure 3-5. Proposed Science Team Land Allocations for Marbled Murrelet Management Areas in the Nemah Planning Block 3-21
Figure 3-6. Proposed Science Team Land Allocations for Marbled Murrelet Management Areas in the Browning Planning Block....3-22
Figure 3-7. Proposed Science Team Land Allocations for Marbled Murrelet Management Areas in the Salmon Creek Planning Block 3-24
Figure 3-8. Proposed Science Team Land Allocations for Marbled Murrelet Management Areas in the Elochoman Planning Block....3-25
Figure 3-9. Proposed Science Team Land Allocations for Marbled Murrelet Management Areas in the Skamokawa Planning Block 3-27

FIGURES (CONTINUED)

Figure 3-10. Proposed Science Team Land Allocations for Marbled Murrelet Management Areas in the Humptulips Planning Block 3-28
Figure 3-11. Proposed Science Team Land Allocations for Marbled Murrelet Management Areas in the Grays Planning Block 3-29
Figure 3-12. Proposed Science Team Land Allocations for Marbled Murrelet Management Areas in the Chehalis Planning Block 3-30
Figure 3-13. Proposed Science Team Land Allocations for Marbled Murrelet Management Area in the Lebam Planning Block 3-31
Figure 3-14. Olympic Experimental State Forest Landscape Planning Units within the OESF Analysis Unit 3-33
Figure 3-15. Proposed Science Team Land Allocations for Upper Clearwater LPU 3-40
Figure 3-16. Proposed Science Team Land Allocations for Willy-Huel LPU 3-41
Figure 3-17. Proposed Science Team Land Allocations for Reade Hill LPU 3-43
Figure 3-18. Proposed Science Team Land Allocations for Queets LPU 3-45
Figure 3-19. Proposed Science Team Land Allocations for Copper Mine LPU 3-47
Figure 3-20. Proposed Science Team Land Allocations for Upper Sol Duc LPU 3-49
Figure 3-21. Proposed Science Team Land Allocations for Clallam LPU 3-51
Figure 3-22. Proposed Science Team Land Allocations for Sekiu LPU 3-52
Figure 3-23. Proposed Science Team Land Allocations for Dickodochtedor LPU 3-54
Figure 3-24. Proposed Science Team Land Allocations for Goodman Creek LPU 3-55
Figure 3-25. Proposed Science Team Land Allocations for Kalaloch LPU 3-56
Figure 3-26. Overview of the Proposed Science Team Land Allocations for the North Portion of the Straits Analysis Unit 3-60
Figure 3-27. Overview of the Proposed Science Team Land Allocations for the East Portion of the Straits Analysis Unit 3-61
Figure 4-1. Model-Averaged Predicted Probability of Marbled Murrelet Occupancy Compared with the Interaction of Platforms per Acre and Canopy Layers. 4-6
Figure 4-2. Development Stages for a Stand of Naturally Regenerated Mixed-Species/Western Hemlock with a Western Hemlock 50-Year Site Index of 110 4-13
Figure 4-3. Science Team Assumptions Regarding the Rate at which Transitions Occur among Categories of P_{stage} Values for Marbled Murrelet Habitat Quality in Western Hemlock and Douglas-Fir Dominated Stands 4-15
Figure 4-4. Stand Density Management Diagram. 4-25

FIGURES (CONTINUED)

Figure 5-1. The Estimated Current and Projected Future Area of Forest Cover That Has Potential to Provide Marbled Murrelet Nesting Habitat (Figure 5-1A) and the Estimated Capability of That Habitat to Support Marbled Murrelet Populations Based on Its Quality and Abundance (Figure 5-1B) Across all Ownerships within Each Analysis Unit (under the Habitat Management Scenario). 5-3

Figure 5-2. The Current and Projected Future Capability of Forests Managed by DNR, Federal Agencies, and Other Landowners to Support Marbled Murrelet Populations (*K′*) and Pattern of Land Ownership (Expressed as a Percentage of Total Landscape) in the SWWA, Straits, and OESF Analysis Units (under the Habitat Management Scenario). 5-4

Figure 5-3. The Relative Current and Projected Future Capability of Forests Managed by DNR, Federal Agencies, and Other Landowners to Support Marbled Murrelet Populations (Averaged over the Area of that Ownership or *K′*/1000 Acres [405 Hectares]) in the SWWA, Straits, and OESF Analysis Units (under the Habitat Management Scenario). 5-5

Figure 5-4. The Current and Projected Future Capability of DNR-Managed Forests, Classified by Stand Development Stage (Brodie et al. 2004), to Support Marbled Murrelet Populations (*K′*) in the SWWA, Straits, and OESF Analysis Units (under the Habitat Management Scenario). 5-9

Figure 5-5. The Current and Projected Future Capability of DNR-Managed Interior Forest Habitat (More than 164 Feet [50 Meters] from Edges) to Support Marbled Murrelet Populations (*K′*) in the SWWA, Straits, and OESF Analysis Units (under the Habitat Management Scenario) (Figure 5-5A). The Proportion of Total *K′* Provided by DNR-Managed Interior Forest Habitat in the SWWA , Straits, and OESF Analysis Units (under the Habitat Management Scenario) (Figure 5-5B).. 5-10

Figure 5-6. The Current and Projected Future Capability of DNR-Managed Forests to Support Marbled Murrelet Populations (*K′*) in the SWWA and OESF Analysis Units for the No Management and Habitat Management Scenario. 5-11

Figure 5-7. The Current and Projected Future Capability of DNR-Managed Forests to Support Marbled Murrelet Populations (*K′*) within and outside MMMAs in the SWWA and OESF Analysis Units (under the Habitat Management Scenario) 5-13

Figure 5-8. The Current and Projected Future Capability of DNR-Managed Forests, Classified by Stand Development Stage (Brodie et al. 2004, Appendix B) to Support Marbled Murrelet Populations (*K′*) within and outside MMMAs in the SWWA and OESF Analysis Units (under the Habitat Management Scenario) 5-14

TABLES

Table 1-1. Marbled Murrelet Science Team Members 1-7

Table 2-1. Chronology of Breeding for the Marbled Murrelet Showing Approximate Dates of Each Phase of Breeding for Each State or Province. 2-14

Table 3-1. Abundance of Federally Managed and DNR-Managed Lands and Marbled Murrelet Forest Habitat in the Marbled Murrelet Analysis Units 3-8

Table 3-2. Definitions for Habitat Terms Used in this Document 3-10

Table 3-3. Definitions for Terms Used Throughout This Document to Delineate the Landscape 3-13

Table 3-4. Scorecard Category Definitions, Formulas, and Weights 3-16

Table 3-5. Properties of Landscape Planning Units (LPUs) in the Olympic Experimental State Forest Analysis Unit 3-36

Table 3-6. Conservation Approaches and Recommendations—Upper Clearwater and Willy-Huel LPUs. 3-39

Table 3-7. Conservation Approaches and Recommendations—Reade Hill LPU 3-42

Table 3-8. Conservation Approaches and Recommendations—Queets LPU 3-44

Table 3-9. Conservation Approaches and Recommendations—Copper Mine LPU 3-46

Table 3-10. Conservation Approaches and Recommendations—Upper Sol Duc LPU 3-48

Table 3-11. Conservation Approaches and Recommendations—Clallam and Sekiu LPUs 3-50

Table 3-12. Conservation Approaches and Recommendations—Dickodochtedor, Goodman Creek, and Kalaloch LPUs 3-53

Table 3-13. Olympic Experimental State Forest Landscape Planning Unit Habitat Calculations 3-58

Table 4-1. All Possible Logistic Models Fit to the Marbled Murrelet Survey Results, their ∆AIC Values, and a Normalized Measure of the Weight of Evidence that Model *i* was the Best among the Set (*w*) 4-5

Table 4-2. Projections of Forest Succession among Seral Stages for Previously Harvested Areas on Non-DNR-Managed Lands 4-10

Table 4-3. Structural Indicators and Estimated Proportions of Marbled Murrelet Carrying Capacity based on Stand Development Stages 4-11

Table 4-4. Summary Assumptions Regarding Marbled Murrelet Habitat Potential (P_{stage}) for Two Classifications of Forest Successional Stages 4-16

Table 5-1. Current and Projected Future Acreage of Forests Managed by DNR, Federal Agencies, and Other Landowners That Could Provide Habitat to Support Marbled Murrelet Populations in the SWWA, Straits, and OESF Analysis Units (under the Habitat Management Scenario). 5-6

TABLES (CONTINUED)

Table 5-2. The Current (2004) and Projected Future (2013, 2031, and 2067) Capability of Forests Managed by DNR, Federal Agencies, and Other Landowners to Support Marbled Murrelet Populations (*K′*) in the SWWA, Straits, and OESF Analysis Units (under the Habitat Management Scenario) 5-7
Table 5-3. Summary of the Current and Projected Future Condition of Marbled Murrelet Habitat in the SWWA, OESF, and Straits Analysis Units Relative to the Science Team's Biological Goals for Marbled Murrelet Conservation. 5-18
Table 6-1. Hypothesized Demographic and Ecological Mechanisms that Influence Risk and Demographic Performance, and Subsequent Models. 6-5

ACRONYMS AND ABBREVIATIONS

ASOS	Automated Surface Airways System
a-v	Audio-visual
BA	Biological assessment
BNR	Board of Natural Resources
CD	Climatological data
CI	Confidence interval
CWD	Coarse woody debris
dbh	Diameter at breast height
DEM	Digital Elevation Model
DFFC	Desired Future Forest Conditions
DNR	Washington State Department of Natural Resources
EIS	Environmental impact statement
ESA	Endangered Species Act
FEIS	Final environmental impact statement
FRIS	Forest Resource Inventory System
GIS	Geographic Information System
HCP	Habitat conservation plan
IVMP	Interagency Vegetation Mapping Project
LCD	Local climatological data
LIDAR	Light Detection and Ranging
LPU	Landscape Planning Unit
LTS	Large Tree Exclusion
LTCS	Long-Term Conservation Strategy
MMMA	Marbled Murrelet Management Area
mph	Miles per hour
NEPA	National Environmental Policy Act
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NSO	Northern spotted owl
NWS	National Weather Service
OESF	Olympic Experimental State Forest
PNWRS	Pacific Northwest Research Station
QMD	Quadratic mean diameter
RD	Relative density

ACRONYMS AND ABBREVIATIONS (CONTINUED)

RIU	Resource Inventory Units
SDMD	Stand density management diagram
SE	Standard error
SEPA	State Environmental Policy Act
SDS	Stand Development Stage
SHC	Sustainable Harvest Calculation
SWWA	Southwest Washington
TPA	Trees per acre
USC	United States Code
USFWS	U.S. Fish and Wildlife Service
WAC	Washington Administrative Code
WAU	Watershed Administrative Unit
WDFW	Washington Department of Fish and Wildlife
WRIA	Water Resource Inventory Area

EXECUTIVE SUMMARY

ES.1 PURPOSE

The purpose of this executive summary is to provide a complete guide to the contents of this document, including an overview of the background, methodology, analyses, and results. Unlike many executive summaries, it is technically detailed and written to provide an average interested reader with enough information to gain an understanding of its substantive content without reviewing the entire report.

ES.2 INTRODUCTION

Contributing to the conservation of endangered and threatened species and their habitat is a priority for the Washington State Department of Natural Resources (DNR) in its habitat conservation plan (HCP). The marbled murrelet (*Brachyramphus marmoratus*) was listed as a threatened species by the federal government in 1992, primarily because of the loss of older forest habitat. The greatest threat identified to marbled murrelets in Washington, Oregon, California, British Columbia, and Alaska is the loss of habitat-containing quality nesting sites, primarily older forests, as well as an increase in forest fragmentation which is thought to increase predation and decrease nesting success.

The HCP (DNR 1997a) required the development of a conservation strategy for the marbled murrelet; however, because of a lack of information on this species, DNR implemented an Interim Conservation Strategy (DNR 1997a) until a Long-Term Conservation Strategy (LTCS) could be created. This document was produced by a team of marbled murrelet scientists that was convened to bring together the current data, research, and expert opinion on habitat conservation and population biology of the marbled murrelet. The result is a set of recommendations for DNR to consider while it develops an LTCS for the marbled murrelet on DNR-managed forestlands. The purpose of this report is to provide the Science Team's research to DNR and present recommendations for marbled murrelet conservation on DNR-managed lands in southwest Washington and the Olympic Peninsula.

ES.3 BACKGROUND

A habitat conservation plan is a long-term management tool, authorized under the federal Endangered Species Act (ESA) (Title 16, Section 1531 et seq. of the United States Code [16 USC 1531 et seq.]). For DNR, an HCP allows timber harvesting and other land management activities to continue on forested state trust lands, while providing for species conservation as described in the ESA.

In 1997, DNR completed a final multi-species HCP for DNR-managed lands in order to be compliant with the ESA (DNR 1997a). The HCP covers approximately 1.8 million acres of DNR-managed lands, and provides mitigation for the incidental take of ESA-listed species, including the marbled murrelet, northern spotted owl (*Strix occidentalis caurina*), and several other species. DNR committed in its HCP "to develop a long-term conservation strategy for the habitat of the marbled murrelet that will provide minimization and mitigation for any incidental take of this species" (DNR 1997a, p. IV. 39) in the Olympic Experimental State Forest (OESF) and five westside planning units. The HCP states that DNR will:

> *"…[H]elp meet the recovery objectives of the U.S. Fish and Wildlife Service, contribute to the conservation efforts of the President's Northwest Forest Plan, and make a significant contribution to maintaining and protecting marbled murrelet populations in western Washington over the life of the HCP"*(DNR 1997a, p. IV.44).

However, the HCP did not contain an LTCS for marbled murrelets because of a lack of knowledge of the species' habitat use on DNR-managed lands, locations of nesting areas, and factors affecting the population, as well as the lack of a completed federal recovery plan. Without this knowledge, development of a credible LTCS to adequately aid in the conservation of marbled murrelet populations was not considered possible. Therefore, an Interim Conservation Strategy (DNR 1997a, pp. IV.39-45) was designed to protect marbled murrelet habitat on DNR-managed lands while DNR conducted studies and collected information on the biology and ecology of the species in each of the HCP planning units. After satisfactory completion of the Interim Conservation Strategy, DNR would develop and transition to the implementation of an LTCS. At the request of DNR management, this document provides recent research and expert opinion on the conservation biology of the marbled murrelet and develops a set of recommendations that provide the foundation for a credible, science-based LTCS that meets the requirements of DNR's HCP.

This document will provide DNR and the U.S. Fish and Wildlife Service (USFWS) the scientific information necessary to develop alternative approaches to the LTCS to be examined through the State Environmental Policy Act and National Environmental Policy Act processes. Those processes will provide decision makers with information about the potential environmental impacts of a proposal and the public with an opportunity to provide input on potential alternatives and the types of potential impacts that should be analyzed. The environmental impact statement (EIS) arising from this analysis will be used with other relevant information by DNR to propose an LTCS to USFWS.

The Board of Natural Resources will review the LTCS and final EIS, conduct an assessment of the impacts to the trusts, and identify a proposed LTCS for USFWS. Once identified, the LTCS for the marbled murrelet will be submitted to USFWS as part of the application for an amended incidental take permit for the marbled murrelet. USFWS will analyze the LTCS per the requirements specified in the ESA and HCP, and will write a biological opinion to analyze impacts on the species' population. If the amended permit is granted for the LTCS, it will allow implementation of this strategy on DNR-managed lands for the term of the HCP.

ES.4 INTERIM CONSERVATION STRATEGY

DNR's Interim Conservation Strategy for the marbled murrelet is described in the HCP (DNR 1997a) and involves several basic steps.

1. Identify and defer from harvest any part of a block of suitable habitat for the marbled murrelet.
2. Complete habitat relationship studies to determine the relative importance, based on occupancy by marbled murrelets, of the various habitats.
3. After the habitat relationship studies are completed, make available for timber harvest the lowest quality habitats, which are expected to contain a maximum of 5% of the occupied sites. All known occupied sites were protected.

4. Survey for occupancy by marbled murrelets in the higher quality habitat areas identified from the habitat relationships study; certain unoccupied habitats would then become available for timber harvest. Occupied habitat and some unoccupied habitat would be protected.
5. Develop an LTCS for the marbled murrelet on DNR-managed lands.

While these steps were being implemented, DNR participated in cooperative regional research efforts to understand more about the biology and ecology of the marbled murrelet.

DNR substantively completed these steps for four of the six westside HCP planning units—Columbia, South Coast, Straits, and OESF—which are the subject of these recommendations.

ES.5 DEVELOPING A LONG-TERM CONSERVATION STRATEGY

In January 2004, a Science Team (Table ES-1) was created to review current literature about the marbled murrelet, examine survey and research data collected by DNR and other researchers, and draft recommendations for conservation opportunities for an LTCS on DNR-managed lands in the Columbia, South Coast, Straits, and OESF Planning Units. The Science Team consisted of biologists with marbled murrelet expertise from research and academic institutions, USFWS, the Washington Department of Fish and Wildlife (WDFW), and DNR.

The Science Team held regular meetings beginning in January 2004. Data gathered during the Interim Conservation Strategy phases were reviewed and organized for further analysis, and the

Table ES-1. DNR Marbled Murrelet Science Team Members.

Name	Agency
Martin G. Raphael, Ph.D.	U.S. Forest Service, Pacific Northwest Research Station
S. Kim Nelson, M.S.	Oregon State University
Paula Swedeen, Ph.D.	Consultant
Mark Ostwald, B.S.	U.S. Fish and Wildlife Service
Kim Flotlin, B.S.	U.S. Fish and Wildlife Service
Steve Desimone, M.S.	Washington Department of Fish and Wildlife
Scott Horton, Ph.D.	Washington Department of Natural Resources
Peter Harrison, B.S.	Washington Department of Natural Resources
Danielle Prenzlow Escene, M.S.	Washington Department of Natural Resources
Weikko Jaross, M.S.	Washington Department of Natural Resources

team began to develop conservation opportunities for the LTCS. The Science Team's recommendations for conservation opportunities for an LTCS do not involve the North Puget and South Puget Planning Units because the interim strategy in those planning units is still underway.

This document describes conservation opportunities for marbled murrelet habitat on DNR-managed forested lands developed by the Science Team for the Columbia, South Coast, Straits, and OESF HCP Planning Units.

ES.6 LIFE HISTORY AND POPULATION STATUS OF THE MARBLED MURRELET

The marbled murrelet is a small, dove-sized seabird that nests in old-growth conifer forests along the Pacific coast of North America. These extremely secretive birds spend most of their lives in small groups or pairs, on protected coastal waters just beyond the breakers. They forage in nearshore waters using wing propulsion to "fly" underwater, chasing prey to depths of 164 feet.

Until 1974, little was known about the birds' nesting habits. Today, it is known that they nest as far as 50 miles inland in mature coniferous forests, usually 120 to 150 feet above ground. Because the nest itself is just a shallow depression in lichens or moss on a tree limb, they rely on tall, old trees with large limbs and a complex canopy to access and conceal their nests.

Marbled murrelet populations range along the Pacific coast from the Aleutian Islands in Alaska to the Baja Peninsula in Mexico. Historically, they inhabited the entire Washington coast and the Puget Sound region. From at-sea surveys, population estimates currently place the number of murrelets in Washington at around 9,800 birds. Major gaps in the at-sea distribution of murrelets in Washington occur in the southern Puget Sound and along the southwestern coast (north of the Columbia River, off the coast of Grays Harbor and Willapa Bay).

The marbled murrelet populations of Washington, Oregon, and California were federally listed as threatened in 1992. The listing decision was based on threats to the marbled murrelet that included loss of nesting habitat from timber harvest and mortality from gill-net fishing and oil spills at sea. Estimates indicate that the number of marbled murrelet individuals is declining at a rate of about 4 to 8% per year (Beissinger and Nur 1997).

ES.7 RECOMMENDED LANDSCAPE CONSERVATION APPROACH

DNR Management Guidance

DNR management tasked the Science Team with developing recommendations that would provide the foundation for a credible, science-based LTCS that would meet DNR's obligations under the HCP. The Science Team developed the conservation recommendations without consideration for DNR's fiduciary responsibility to the trusts, with the exception of special considerations for Wahkiakum and Pacific Counties. The Science Team received special guidance from DNR management for Wahkiakum and Pacific Counties, as they rely primarily on revenue generated from DNR-managed trust lands for their operations budget (Daniels 2004). A special effort was made to recommend marbled murrelet conservation measures that reflect DNR's responsibility to consider potential revenue impacts to those two smaller trust beneficiaries. The financial analyses and impacts will be addressed for all DNR-managed lands during DNR's EIS development, primarily through the alternatives in the draft and final EISs.

Conservation Objectives

The Science Team's objectives were based on two recovery principles: "to stabilize and then increase the population size, changing the current downward trend to an upward (improving) trend throughout the listing range" and "to provide conditions in the future that allow for a reasonable likelihood of continued existence of viable populations" (USFWS 1997, p. 112). DNR defined its goal to contribute to the above USFWS recovery objectives and "*…make a significant contribution to maintaining and protecting marbled murrelet populations in western Washington over the life of the HCP"* (DNR 1997a, p. IV.44). The team adopted biological goals that reflect those principles at appropriate scales for the abundance and distribution of DNR-managed forestlands in Washington. The Science Team recommends that DNR manage forest habitat to contribute to the following three biological goals: a stable or increasing population, an increasing geographic distribution, and thus a population that is resilient to disturbances. Because DNR manages forestland and not wildlife, DNR is able to contribute to the USFWS recovery plan and population goals for the marbled murrelet through the maintenance and creation of the birds' nesting habitat.

The Science Team's conservation objectives set the foundation for the following recommendations and analyses developed by the Science Team. The objectives of the analyses applied to the Science Team's recommendations are to:

1. Present objective, repeatable, quantitative comparisons of current and projected forest habitat for marbled murrelets on DNR-managed and other lands.
2. Illustrate potential marbled murrelet population responses to current and projected habitat using an index of carrying capacity.

This information will prove valuable for DNR and USFWS managers as they evaluate the overall effects of different management alternatives and their contributions to HCP conservation objectives for the marbled murrelet.

ES.8 POPULATION-BASED CONSERVATION APPROACH FOR DNR-MANAGED FORESTLANDS

The abundance and distribution of marbled murrelets and their potential inland habitat vary regionally within Washington, as do the distribution and relative abundance of DNR-managed lands. To determine the association between marbled murrelets and their habitat distribution on state forestlands, DNR agreed to consider and develop marbled murrelet conservation plans unique to each of six ecologically-based HCP planning units (DNR 1997a), four of which are considered in this document (Figure ES-1):

1. Columbia
2. South Coast
3. Olympic Experimental State Forest (OESF)
4. Straits

Based on similar distribution and quantity of DNR-managed lands, and the abundance of inland habitat and marbled murrelets, the Columbia and South Coast Planning Units (west of Interstate 5, south of Olympic National Forest, and south of Quinault Indian Reservation) were combined into one, and are referred to as the Southwest Washington (SWWA) Analysis Unit (see Figure ES-1). SWWA is the term used in the following conservation approach and model analyses sections of this report. Within SWWA the Science Team focused conservation efforts on DNR-managed lands within approximately 40 miles of the Pacific coast (see Figure ES-1). The OESF and Straits Planning Units (hereafter also referred to as analysis units) have distinctive characteristics and retain separate identities.

In the OESF and Straits Analysis Units, the fairly abundant existing marbled murrelet habitat is concentrated largely on federal lands, with habitat on DNR-managed lands occurring approximately in proportion to its abundance (Table ES-2). This contrasts sharply with SWWA, where there is little federal land or federally managed habitat. Although DNR-managed lands are relatively scarce, making up only 13% of the total area, they contain 28% of the habitat in the analysis unit (Table ES-2).

Table ES-2. Abundance of Federally Managed and DNR-Managed Lands, and Marbled Murrelet Forest Habitat by Analysis Unit.

Geographic Area	Total			Federally Managed[1]				DNR-Managed			
	Area[2]	Habitat[2,3]	% of total	Area[2]	% of Total	Habitat[2,3]	% of Total Habitat	Area[2]	% of Total	Habitat[2,3]	% of Total Habitat
SWWA	2,530	268	11	1.5	0	0.7	0	324	13	74	28
OESF	1,299	421	32	523	40	266	63	271	21	83	20
Straits	1,178	377	32	704	60	284	75	118	10	46	12
Olympic Peninsula[4]	2,932	948	32	1,530	52	675	71	389	13	129	14

[1] Includes lands managed by National Park Service and U.S. Forest Service. Lands managed by other federal agencies are not included.
[2] Thousands of acres.
[3] Habitat estimates are Biomapper estimates from Raphael et al. (2006) who used this program to build an Ecological Niche Factor Analysis Model (ENFA) of marbled murrelet habitat suitability. Model inputs were GIS-based rasters of ecogeographical variables (forest cover derived from satellite imagery, as well as topography, solar radiation, and distance to coastline) and species presence data. Habitat estimates are based on an ENFA habitat suitability index greater than 60.
[4] Entire Olympic Peninsula: OESF, Straits, plus Other Olympic Peninsula (see Figure ES-1).
Note: analysis unit and ownership areas are from DNR's GIS data (July 20, 2005). Percentages do not sum to 100 because tribal lands, privately managed lands, and some federally managed lands are not included.

The breeding-season marine distribution and abundance of marbled murrelets on the Olympic Peninsula and in SWWA generally corresponds with the inland distribution of habitat. The majority of the marbled murrelet numbers from survey counts (Hull et al. 2001 [at-sea and inland surveys], Miller et al. 2006 [at-sea surveys]: approximately 90%) occur within 40 miles of the Olympic Peninsula, a reasonable commuting distance for nesting birds, while less than 10% of the offshore birds counted occur adjacent to SWWA (Miller et al. 2006). Additionally, more general range-wide assessments (USFWS 1997, McShane et al. 2004) identified SWWA as an

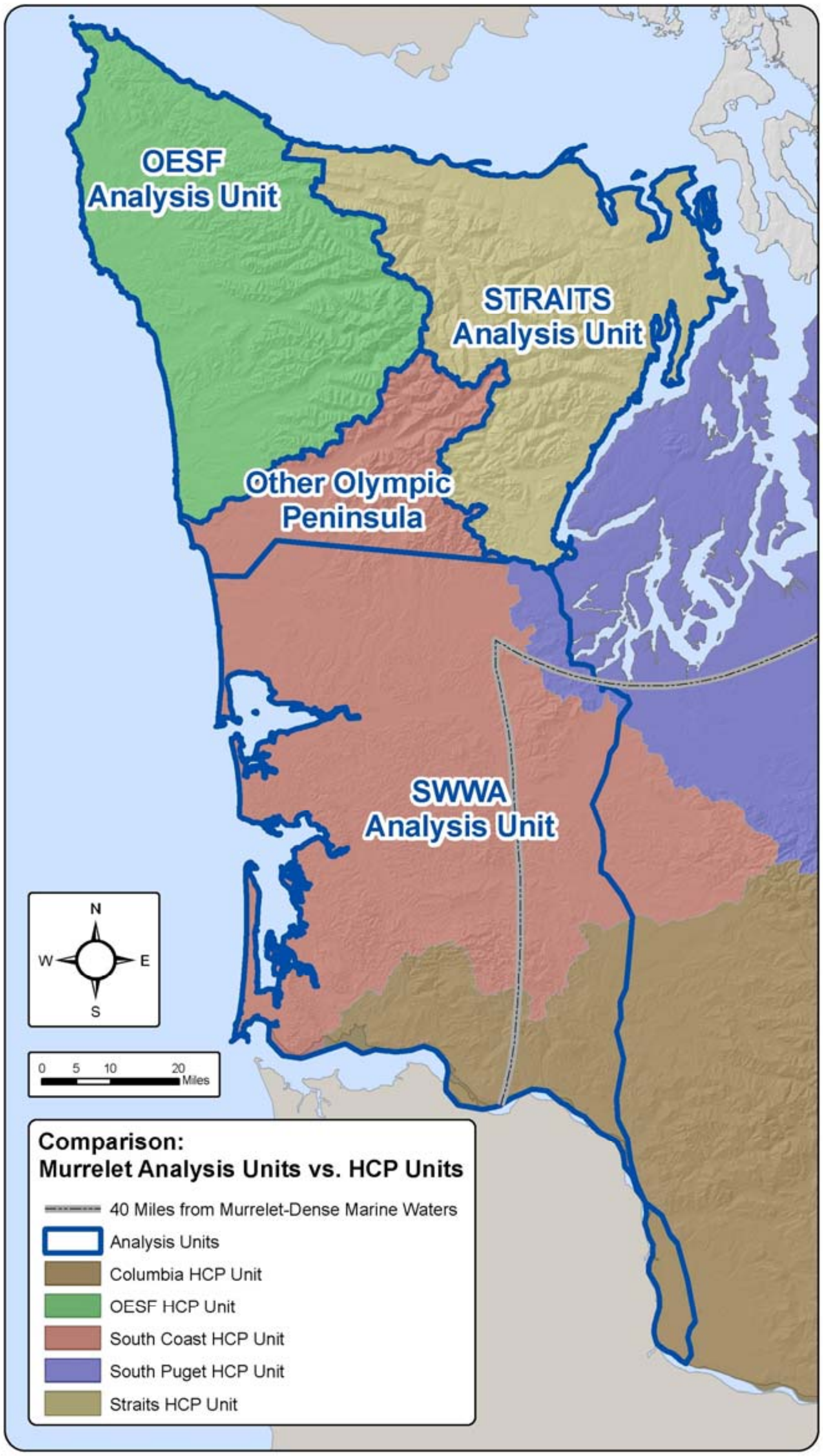


Figure ES-1. Planning Area Considered by the Science Team, Including Marbled Murrelet Analysis Units and DNR HCP Planning Units (Murrelet-Dense Marine Waters are Defined in Section 3.2b).

area of low density in the distribution of marbled murrelets and their inland habitat. Thus, SWWA is an important area in which to address the conservation goal of increasing the geographic distribution by increasing inland nesting habitat.

The differences in current habitat and federal land distribution led to three specific strategic approaches to marbled murrelet conservation that acknowledged how conservation efforts in each analysis unit could help achieve objectives for population stability.

- In SWWA, DNR-managed lands contain 28% of the existing inland habitat base for a depressed marbled murrelet population (Table ES-2). Substantial habitat restoration across much of the DNR-managed land base is central to achieving conservation objectives (USFWS 1997, McShane et al. 2004).
- In the OESF, where DNR-managed lands in the low-elevation Sitka spruce zone have the potential to increase the number of forest types occupied by marbled murrelets, explicit efforts at habitat restoration through active silviculture in distinct DNR-managed areas are a key component of the recommended conservation approach.
- In the Straits, where DNR-managed lands contribute less to the land and habitat base, a relatively minimal approach is appropriate—occupied sites identified during comprehensive inland surveys were mapped and designated for conservation management.

The landscape-level conservation approach, methodology, and rationale are presented in the above sequence.

Land Designations for Habitat Conservation

The Science Team recommends the employment of three basic management approaches to creating and maintaining habitat in the three analysis units (SWWA, OESF and Straits).

In areas where potential and known marbled murrelet nesting habitat is well developed and needs to simply be retained on the landscape in support of the stated biological goals, the Science Team proposes deferral of those lands from harvest for the life of the conservation strategy. These include all currently known occupied sites and old forest stands in the OESF. The Science Team is not recommending that DNR continue identifying additional occupied sites once the LTCS is completed.

Areas of the landscape that have the ability to provide future potential nesting habitat have been identified and proposed to be actively managed as Marbled Murrelet Management Areas (MMMAs). Some proportion or all of DNR-managed lands within their boundaries (depending on the analysis unit) would have as their management goal high-quality nesting habitat.

Marbled murrelet nesting habitat is defined as large trees with sizeable nesting platforms supporting high levels of moss, and generally occurring in old-growth forests with low amounts of edge (Nelson et al. 2006). Based on current data and knowledge, there is no explicit way of identifying these features on DNR-managed land. For the purposes of this report, forest stand development stages (Brodie et al. 2004, see also Appendix B) are used as a surrogate measure for nesting habitat. Under this classification system, the more complex, older stages—Large Tree Exclusion, Understory Development, Botanically Diverse, Niche Diversification, and Fully Functional—are classified as "potential marbled murrelet habitat."

It is envisioned that active management techniques will be applied to accelerate the development of non-habitat to stimulate the development of suitable marbled murrelet habitat where silviculturally appropriate. This aspect of the Science Team's conservation approach was developed to emphasize marbled murrelet conservation in a geographic area where it could be most effective in meeting the biological goals and gaining the largest benefit for marbled murrelet habitat conservation. The Science Team recommends deferral of all known occupied marbled murrelet sites located inside proposed MMMAs.

In some cases, the Science Team has recommended moderated forest management to complement deferred areas and habitat areas within MMMAs. In these areas, retention of forest structure around areas being recommended specifically for habitat creation and maintenance is proposed. These include areas not required for meeting habitat thresholds in MMMAs and buffers around occupied sites and old forest.

Finally, the Science Team anticipates that other conservation strategies being implemented in fulfillment of the HCP on DNR-managed lands will complement the recommended marbled murrelet conservation measures. Conservation measures including the northern spotted owl strategy, riparian forest restoration strategy, and efforts to protect unstable landforms, to name a few, are expected to develop a matrix of complex forest structure on the landscape and support marbled murrelet biological goals.

Conservation Approach for a Marbled Murrelet Long-Term Conservation Strategy in Southwest Washington

SWWA serves an important distributional role in the listed range of the marbled murrelet (USFWS 1997, McShane et al. 2004). This area, close to coastal waters, has very little forested federal ownership (Table ES-2); thus, non-federal forests are critical to marbled murrelet conservation. DNR-managed forestlands in this landscape provide a significant and vital opportunity for maintenance of local breeding populations and are crucial to meeting the biological goals stated above.

Within SWWA, ownership blocks were examined for their potential to contribute to the objectives of the LTCS (population stability, distribution, and resilience). A scorecard ranking exercise was used to achieve an objective, replicable means of identifying high-priority areas in which to invest DNR's efforts at marbled murrelet conservation.

The Scorecard

The Science Team used a scorecard to rank the potential conservation value of geographic land blocks and to inform their proposals regarding the size and locations of MMMAs. The Science Team defined 20 metrics, including marbled murrelet detections, habitat data, and other ecological and topographic data deemed important to marbled murrelet conservation (see below). Values for the metrics were calculated relative to the maximum value for all blocks and rescaled to range from 0 to 10. Each metric was assigned a weight by the Science Team to reflect its overall importance in estimating potential conservation value. The sum of the 20 weighted category scores resulted in an overall score for each block.

Marbled Murrelet Management Areas in SWWA

Seventeen ownership blocks of DNR-managed lands were delineated by the Science Team and subsequently reviewed and edited by the local biologists (Figure ES-2). These ownership blocks (referred to as planning blocks) were delineated as logical groupings of DNR-managed lands.

The overall scores ranged from 8.41 for the Nemah block to 0.88 for the Lake Creek block (Figure ES-3). The top five blocks down to Skamokawa were considered the highest priority. The second six blocks, including Humptulips through Pe Ell, were considered a secondary priority, except Capitol which contained no occupied sites and is not proposed for conservation

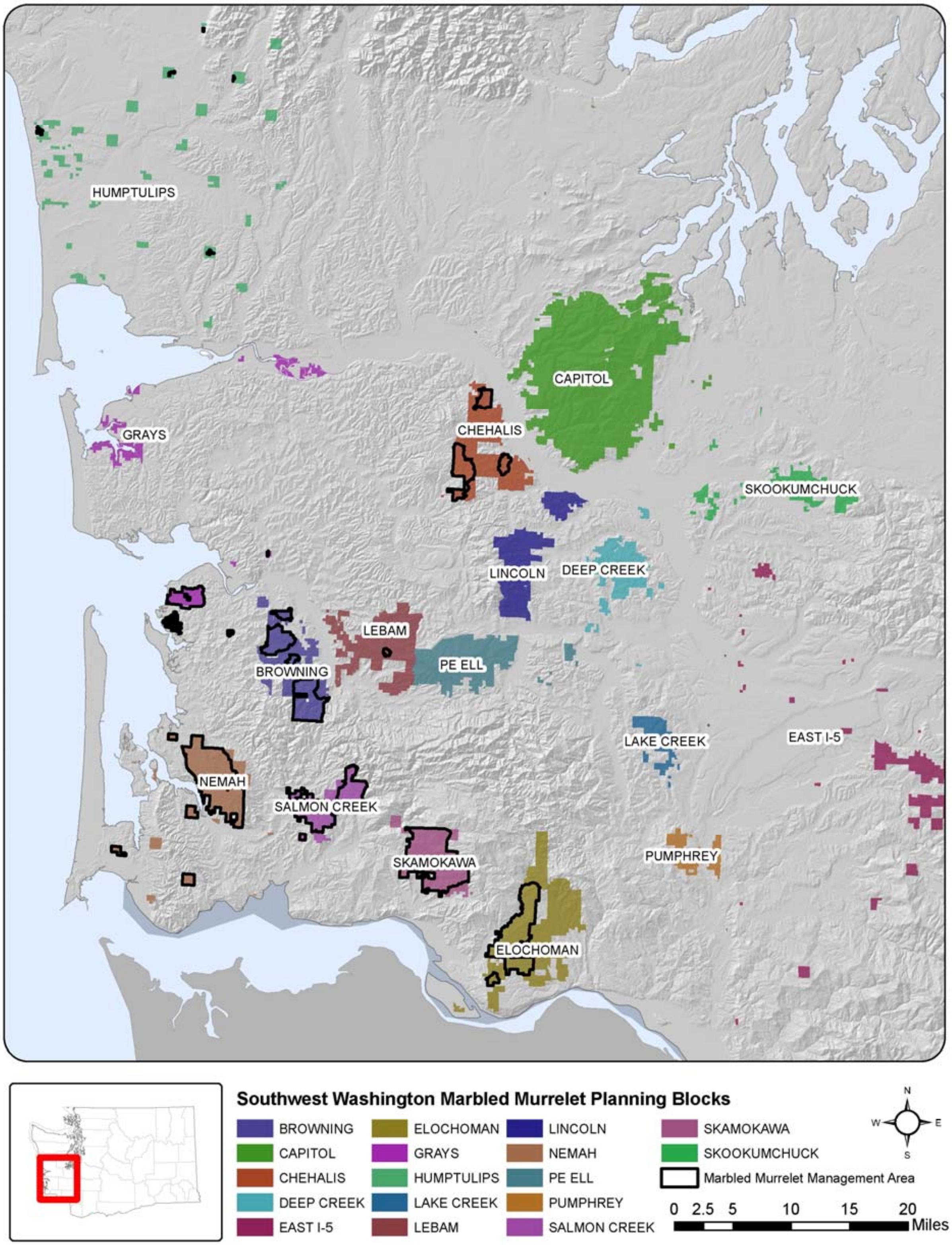


Figure ES-2. Geographic Planning Blocks for the Southwest Washington Analysis Unit.

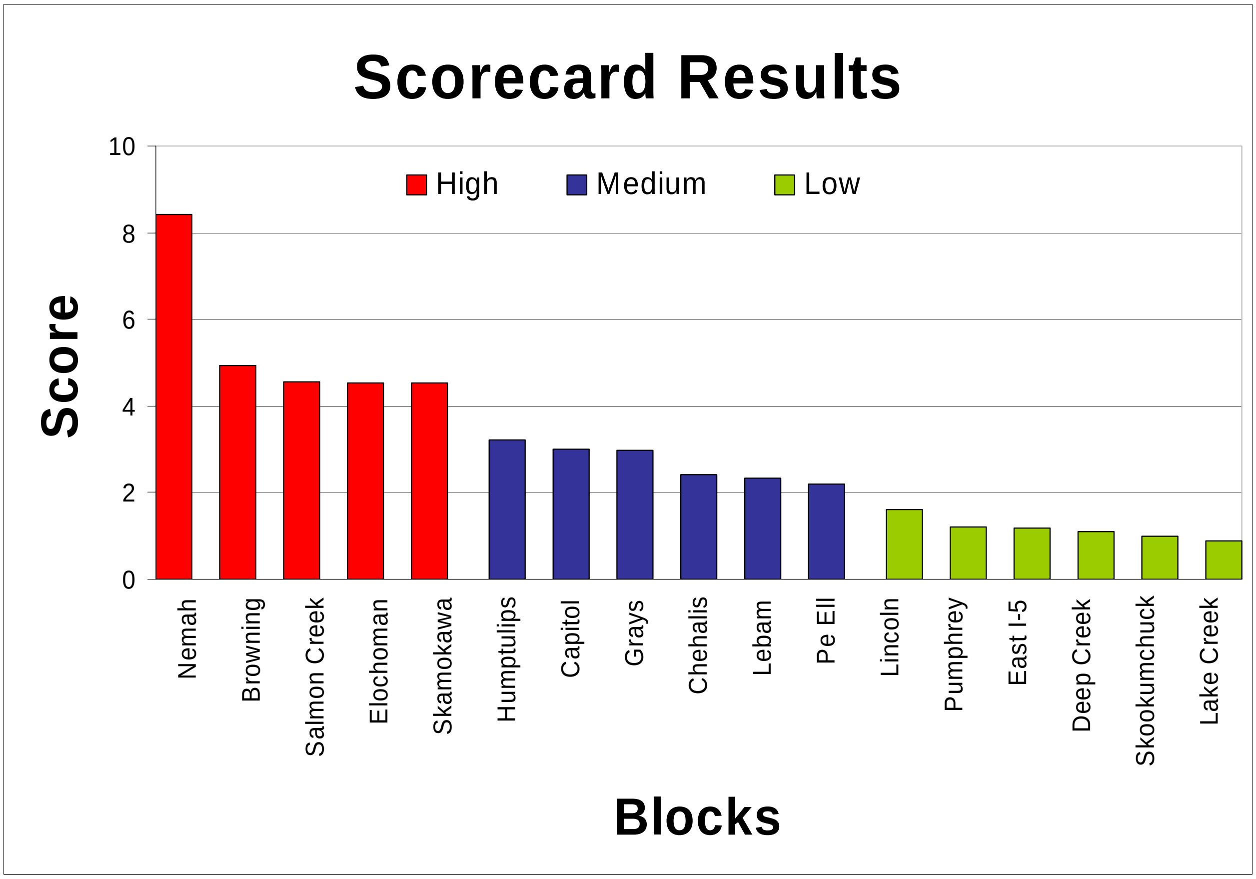


Figure ES-3. Overall Scorecard Results by Geographic Planning Block for the Southwest Washington Analysis Unit.

emphasis. The bottom six blocks from Lincoln to Lake Creek were considered the lowest priority, do not contain occupied sites, and therefore are not recommended for conservation emphasis in this report.

Delineation of Marbled Murrelet Management Areas

The Science Team delineated MMMAs in SWWA in an iterative process that:

- Used the scorecard exercise to help consider the relative importance of each planning block to the goals of the LTCS.
- Examined amounts and locations of past and current marbled murrelet activity.
- Reviewed amounts and locations of mature forest conditions.
- Considered the size and configuration of each block within the matrix of privately managed forests.

- Considered the financial impacts on beneficiaries of Pacific County and Wahkiakum County forest board lands.

Figure ES-2 provides an overview map of the location of the proposed MMMAs. Chapter 3.0 describes the MMMAs in detail and includes maps of their locations.

Conservation Approach for a Marbled Murrelet Long-Term Conservation Strategy in the Olympic Experimental State Forest

The OESF Analysis Unit has unique conservation strategies as part of its mandate to learn how to achieve integration of old forest ecosystem functions with commercial forestry on state trust lands (DNR 1997a). The management strategy of the OESF is that of an “unzoned forest” (i.e., land management decisions are guided by earth, biological, and other sciences) to achieve multiple objectives across 11 intermediate-scale landscape planning units (LPUs) (Figure ES-4).

Biological Goals for Marbled Murrelet Conservation in the Context of the OESF

Marbled murrelets have been observed moving throughout the waters off the Olympic Peninsula, not just off the areas of adjacent habitat (Bloxton and Raphael 2007). These long-distance movements suggest that habitat abundance in the Straits and OESF Analysis Units should be considered in the context of the entire Olympic Peninsula. Table ES-2 shows that DNR-managed lands comprise 13% of the Olympic Peninsula (389,000 of 2.9 million acres), which is dominated by federal lands, most with congressional or administrative designations that emphasize conservation of old forests. In this context, DNR habitat conservation in the OESF can provide only a relatively minor contribution to regional carrying capacity base for marbled murrelets (Table ES-5 and discussion in Chapter 5.0). DNR has already committed to increase the amount of old forest and to improve its function across the OESF through other DNR policies and objectives, most notably northern spotted owl and riparian management commitments in the HCP, adding incrementally to the carrying capacity of the Olympic Peninsula for marbled murrelets. The Science Team assumes that the areas under protection by the other conservation strategies will remain protected throughout the life of the HCP. The Science Team recommends that, if other conservation strategies change such that they discontinue benefits to the marbled murrelet, policy be examined to maintain protection of areas important to the marbled murrelet.

DNR-managed lands exist in a variety of settings, with a variety of land uses (e.g., timber management, surface mines, transportation network, leased communication sites, recreation and natural areas) that likely result in a wide range of fragmentation effects on the quality of nesting habitat. Thus, it is likely that habitat in the OESF will be variable in its success at contributing to the goal of population stability. Areas that will be managed for contiguous blocks of old forest will provide a higher contribution than areas where ownership patterns or management policies result in smaller patches of habitat.

From the conservation biology principle of "spreading the risk" (Den Boer 1981), perhaps the most important role the OESF can play, in addition to the maintenance of high-quality habitat (including occupied sites) is to broaden the ecological distribution of marbled murrelets on the Olympic Peninsula. Federal lands are scarce in the low-elevation Sitka spruce zone (Franklin and Dyrness 1988), and private land managers are unlikely to restore substantial marbled murrelet habitat capability within the OESF Analysis Unit; thus, DNR's OESF conservation efforts in this low-elevation Sitka spruce zone will be disproportionately important. The Sitka spruce element of the OESF has the greatest potential to contribute to a resilient marbled murrelet population.

Approaches to Marbled Murrelet Conservation in the OESF

The 11 LPUs in the OESF (Figure ES-4) vary in their overall size, area of DNR-managed lands, and context; and in the amount, distribution, and condition of existing forest cover.

The strategic approach of Everett and Lehmkuhl (1999) suggests using two basic approaches to achieve the biological goals for marbled murrelet conservation in an unzoned OESF. While marbled murrelet conservation will occur in all LPUs, the two approaches represent opposite ends of a gradient. At one end, marbled murrelet conservation would occur through existing policy and procedures (e.g., riparian and northern spotted owl conservation strategies); at the other end, LPUs exist where marbled murrelet conservation would be emphasized as a guiding element in landscape design and management.

Guiding Elements for Landscape Design within the 11 Landscape Planning Units for Marbled Murrelet Conservation in an Unzoned OESF

The following four marbled murrelet conservation objectives are recommended for use in landscape design and management in an unzoned OESF.

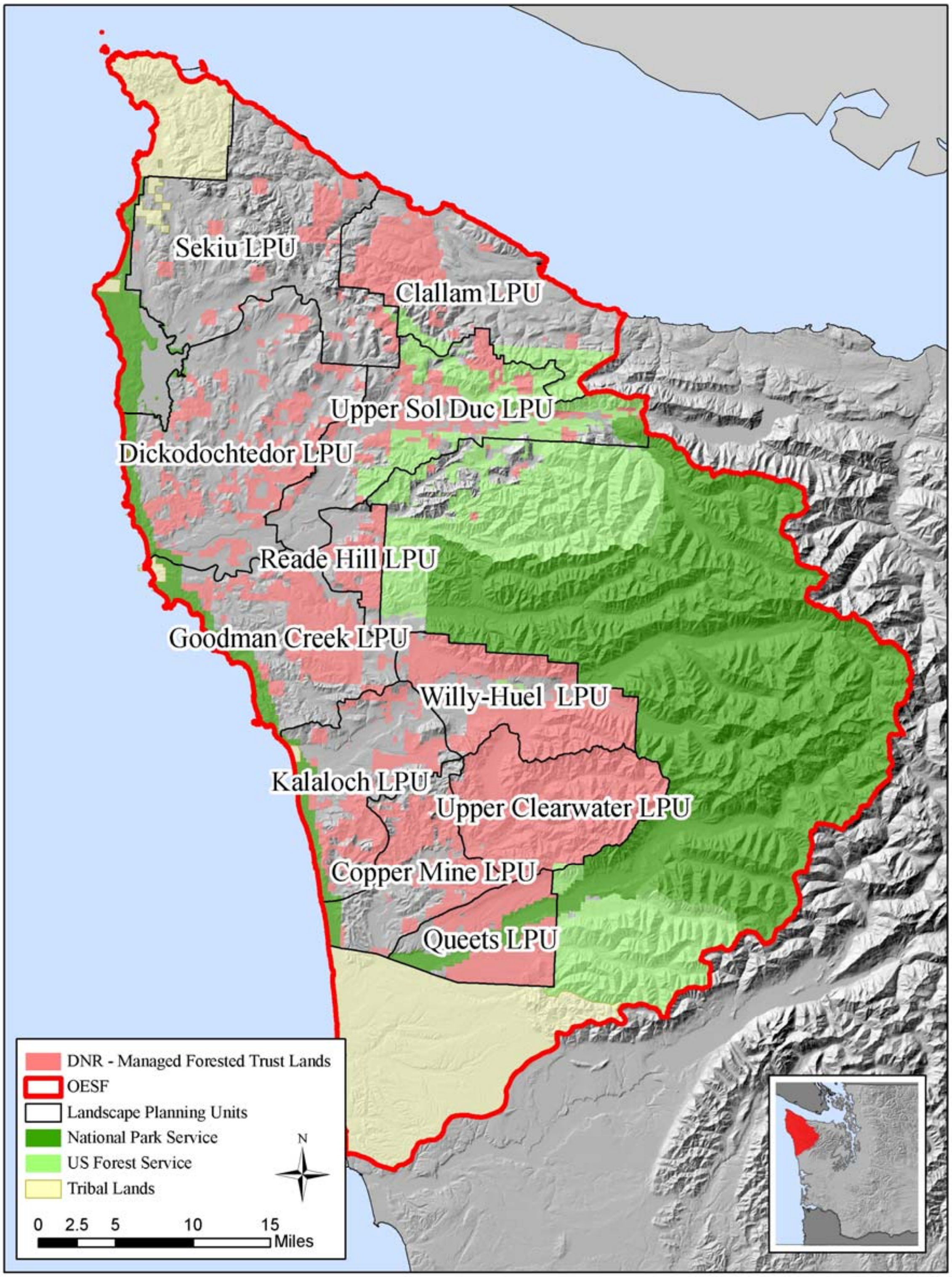


Figure ES-4. Olympic Experimental State Forest Landscape Planning Units within the OESF Analysis Unit.

1. ***Conservation through existing policy and procedure model (Upper Clearwater and Willy-Huel LPUs)*: ** The conservation through existing policy and procedure model is proposed for large contiguous blocks of DNR-managed lands adjacent to large federal reserves, such as the Upper Clearwater and Willy-Huel LPUs. These LPUs are at middle to upper elevations, with high densities of dissected, unstable landforms, and contain high densities of existing marbled murrelet habitat. Maturation and generally more conservative management of adjacent stands will result in diminishing negative edge effects during the lengthy period of habitat restoration in riparian and unstable areas. Retention of current nesting habitat, habitat restoration, and overall maturation of early-seral forests in these landscapes which will diminish fragmentation effects are, in combination, predicted to help achieve the goals of population stability and increasing size.

2. ***Intermediate approach for smaller landscapes (Reade Hill, Copper Mine, and Queets LPUs)*:** One type of intermediate approach is proposed for smaller landscapes at generally lower elevations and lesser, but still significant, amounts of old forests. Active management to limit fragmentation around existing stands of suitable structure in Reade Hill and Copper Mine, and broader areas of the Queets LPU, is hypothesized to improve the goal of population stability.

3. ***Intermediate approach for the northern landscapes (Upper Sol Duc, Clallam, and Sekiu LPUs)*:** Another intermediate approach is in the northern LPUs with very little older forest remaining: Upper Sol Duc, Clallam, and Sekiu. These LPUs are largely in lower to middle elevations and vary in the size of DNR-managed blocks and their adjacency to federal reserves. Additionally, riparian and unstable areas adjacent to current habitat will buffer suitable habitat as they mature. Current nesting habitat will incur diminishing fragmentation effects over time. Similar to the first conservation objective (conservation through existing policy and procedure model), marbled murrelet conservation will largely be a product of existing management policy and procedures for other objectives in these LPUs, but the nature of these landscapes (fragmented ownership, and amount, distribution, and condition of existing habitat) is such that they will likely contribute less to the biological goals than the Upper Clearwater and Willy-Huel LPUs.

4. ***Emphasis on marbled murrelet conservation model (Dickodochtedor, Goodman Creek, and Kalaloch LPUs)*****:** The emphasis on marbled murrelet conservation model will apply in the Sitka spruce zone of three coastal plain LPUs with some existing older forest: Dickodochtedor, Goodman Creek, and Kalaloch. To limit potential negative fragmentation effects, MMMAs were located adjacent to federal lands or in areas with a high density of DNR-managed lands, and avoided areas of higher human impact with enriched corvid populations. Active management in the emphasis areas is hypothesized to improve their contribution to achieving the goal of population stability, while their location in the Sitka spruce zone is intended to contribute to distribution and resilience goals.

The specific elements of these approaches are detailed and mapped for each of the 11 LPUs in chapter 3.0.

Conservation Approach for a Marbled Murrelet Long-Term Conservation Strategy in the Straits Analysis Unit

Non-federal lands in the Straits Analysis Unit occur in a narrow peripheral band, approximately four to nine miles wide, on the northern and eastern Olympic Peninsula. DNR-managed lands (118,000 acres) comprise approximately one-fourth of the non-federal land base in the analysis unit (Figures ES-5A and ES-5B).

Marbled murrelets have been observed moving throughout the waters surrounding the Olympic Peninsula and engaging in very long commuting flights (over 50 miles one-way) between nesting and foraging areas (Bloxton and Raphael 2006, 2007). These long-distance movements suggest that marbled murrelet nesting habitat in the Straits Analysis Unit should be considered in the context of the entire Olympic Peninsula. The nature and abundance of existing potential marbled murrelet habitat on federal and DNR-managed forests, as well as results of comprehensive inland surveys for marbled murrelets on DNR-managed lands (Harrison et al. 2003), suggest that state forests currently provide only a relatively minor contribution to the carrying capacity for marbled murrelets in the Straits Analysis Unit. The habitat known to be occupied on DNR-managed lands in the Straits Analysis Unit occurs predominantly in smaller, isolated stands compared to the adjacent, extensive old-growth forests found on federal lands. Additionally, the quality of these occupied stands is almost exclusively second growth Douglas-fir forest. Consequently, the Science Team recommended that all currently known occupied marbled murrelet sites be

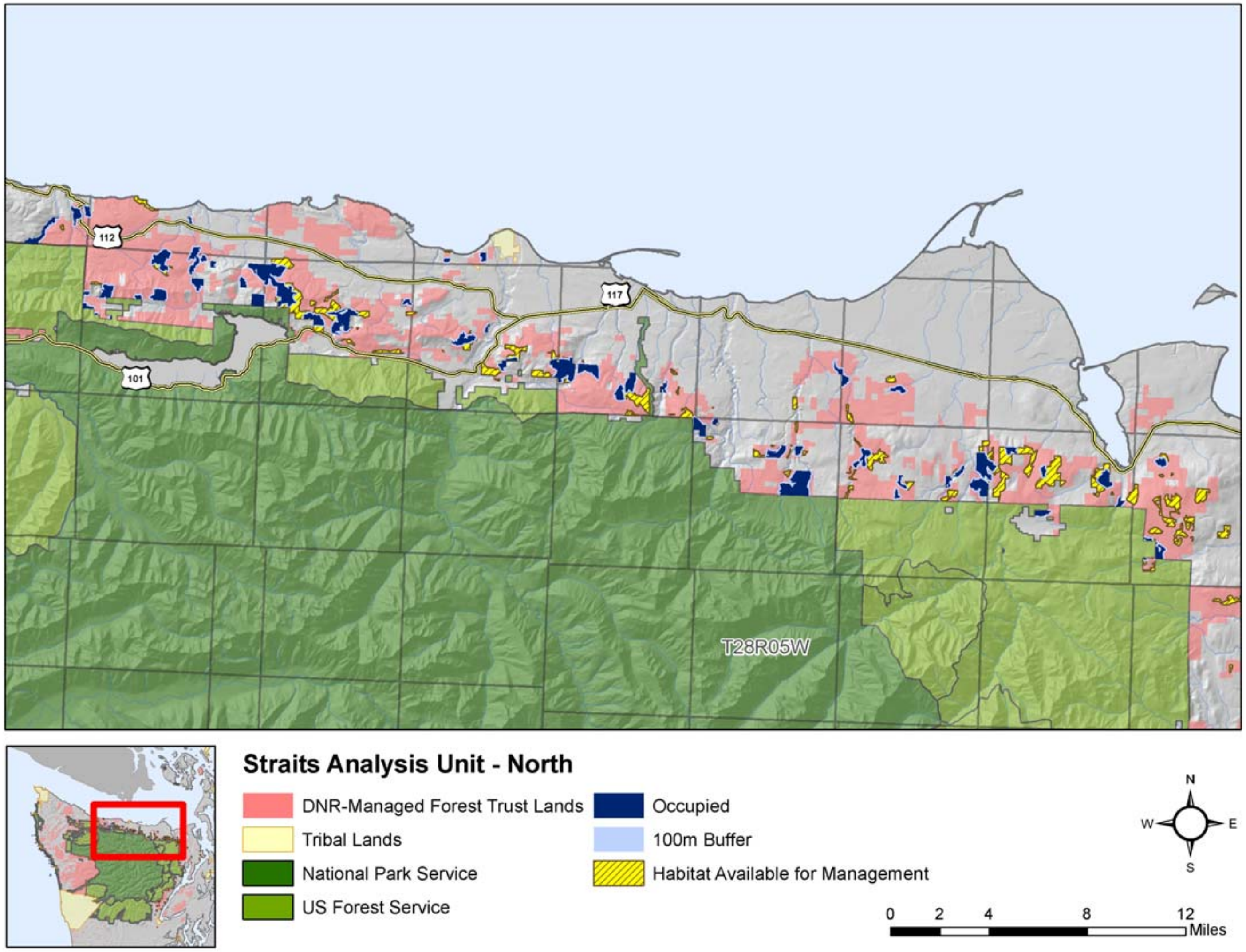


Figure ES-5A. Overview of the Proposed Science Team Land Allocations for the North Portion of the Straits Analysis Unit.

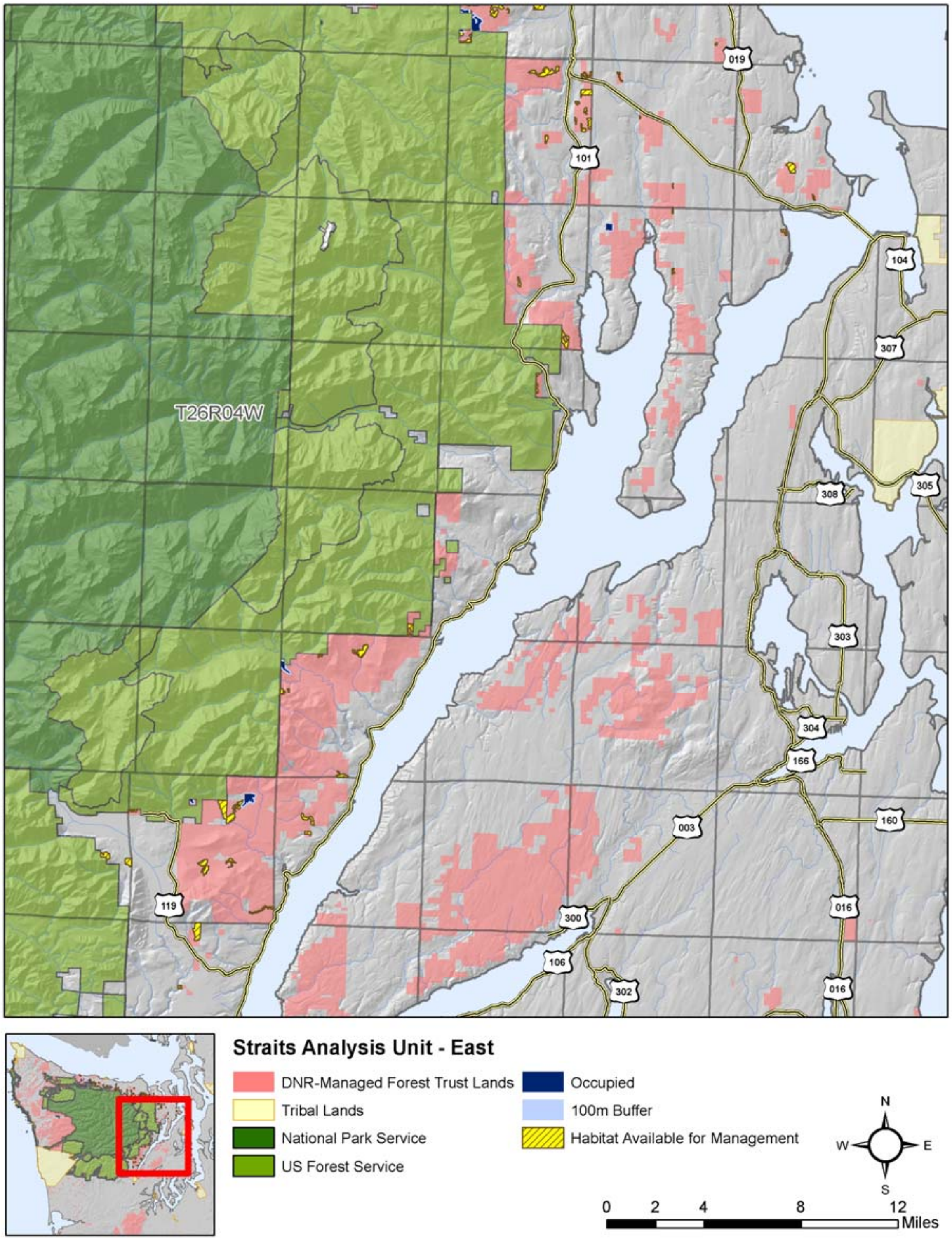


Figure ES-5B. Overview of the Proposed Science Team Land Allocations for the East Portion of the Straits Analysis Unit.

managed to retain habitat capability and be buffered with closed canopy forest strips at least 328-feet wide and does not recommend further measures to meet their conservation objectives.

ES.9 METHODS FOR ESTIMATING POTENTIAL MARBLED MURRELET POPULATION RESPONSES TO CURRENT AND PROJECTED FOREST HABITAT

Introduction

This section documents the Science Team's methods to describe the potential for current and projected forest habitat to support populations of marbled murrelets. These methods were applied to the Science Team's recommended conservation approach to conduct the analyses presented in chapter 5.0, although any alternative recommendations for marbled murrelet conservation can be evaluated using these methods. The objectives of these analyses are to present objective, repeatable, quantitative comparisons of current and projected forest habitat for marbled murrelets on DNR-managed and other lands; and to illustrate potential responses of marbled murrelets to current and projected habitat using an index for carrying capacity.

An Index to the Potential Influence of Habitat Quality and Quantity on Marbled Murrelet Populations in Washington

The index incorporates four elements of marbled murrelet relationships with forest habitat:

- Broad-scale correspondence of numbers of marbled murrelets to area of habitat.
- The gradient in habitat quality caused by variation in stand structure and composition.
- The apparent reduction in habitat quality by edge effects.
- The influence of distance from their marine habitat.

These elements can be expressed as mathematical relationships among area, structure, composition, and context of forest stands across the plan area to predict the capability of current and projected future habitat to support marbled murrelet populations. However, the index should not be considered an explicit prediction of current or future marbled murrelet numbers; rather, it should be viewed as an objective, repeatable, qualitative index that can be used to judge relative conservation values of DNR-managed lands as well as all other lands across the plan area. Chapter 4.0 describes the rationale, derivation, and application of this index.

The Relationship of Habitat Area with Marbled Murrelet Abundance

Raphael et al. (2006) estimated that, on average, 396 acres of nesting habitat were available per marbled murrelet detected by radar during their 2002 study. Using radiotelemetry studies of inland flight behavior by marbled murrelets by Peery et al. (2004b) suggests that approximately 43% of the population is likely to be detected with radar; thus, *K* (carrying capacity) is approximately 170 acres (i.e., 396 acres * 0.43) of potential nesting habitat per marbled murrelet.

Estimating Current and Future Marbled Murrelet Habitat

Current conditions were estimated using 2004 forest inventory data for DNR-managed lands and Interagency Vegetation Mapping Project (IVMP) data (collected from 1992 to 1996), classified as described in chapter 4.0 and projected to 2004 for other ownerships. Future conditions were evaluated in the years 2013, 2031, and 2067 using growth and harvest projections from DNR's 2004 sustainable harvest calculation preferred alternative (DNR 2004b).

Land cover estimates for many non-DNR-managed lands were largely held static through these projections, assuming that these areas reflected a natural disturbance regime, so that the 1992–1996 satellite images broadly represented future conditions as well.

Forest succession was projected for several portions of the analysis landscape according to a series of assumptions detailed in chapter 4.0. Areas where clearcut, early- and mid-seral conifer stands existed would advance to late-seral development (Green et al. 1993) according to growth projections of model stands in the analysis area.

Summary of the Projected Current and Future Contribution of Forest Stands to Marbled Murrelet Carrying Capacity

The series of relationships and assumptions described lead to a set of explicit assumptions regarding the predicted values of marbled murrelet habitat quality, or "P_{stage}" values, which vary according to three dimensions: land ownership, existing versus projected land cover, and the application of a variety of projected management regimes for DNR-managed lands. The P_{stage} values that are assumed to result from the relationship with these dimensions are summarized in Table ES-3.

Table ES-3. Summary Assumptions Regarding Marbled Murrelet Habitat Potential (P_{stage}) for Two Classifications of Forest Successional Stages.

Stand Development Stages (Brodie et al. 2004)	Seral Stages (Green et al. 1993)	Relative Marbled Murrelet Habitat Potential (P_{stage})				
		Existing and Projected Future Conifer Stands on DNR-Managed Land	Existing Conifer Forest in Olympic National Park and Olympic National Forest	Other[1] Existing Conifer Forests	Projected Future Conifer Forests in Previously Harvested Areas of Olympic National Forest	Projected Future Riparian Conifer Forests in Previously Harvested Riparian Areas Outside of Olympic National Forest
Ecosystem Initiation	Nonconifer (in part)	0	0	0	0	0
Sapling Exclusion	Early-seral	0	0	0	0	0
Pole Exclusion	Mid-seral	0	0	0	0	0
Large Tree Exclusion	Late-seral	0.25	0.68[2]	0.31[2]	0.20[3]	0.13[3]
Understory Development	Late-seral	0.36	0.68	0.31	0.20	0.13
Botanically Diverse	Late-seral	0.47	0.68	0.31	0.20	0.13
Niche Diversification	Late-seral	0.62	0.68	0.31	0.20	0.13
Fully Functional	Late-seral	0.89	0.68	0.31	0.20	0.13

[1] Predominantly private and tribal land.
[2] See discussion for these calculations in section 4.4.
[3] See discussion for these calculations in section 4.5.
Note: assumptions on the influence of land ownership, existing versus projected land cover on non-DNR ownerships, and several potential forest management regimes for DNR-managed lands on P_{stage} are discussed in the preceding section.

Edge Effects on Quality of Marbled Murrelet Habitat and Its Potential Influence on Carrying Capacity

Based on the observed relationship of diminished nest success with stand edges (Manley and Nelson 1999), the Science Team determined to discount the predicted contribution of edge-influenced potential marbled murrelet habitat to carrying capacity (*K*). A 164-foot distance reflecting edge effects (Manley and Nelson 1999) and the values for low and high nest success hypothesized by McShane et al. (2004) (0.38 and 0.54, respectively) were used together to determine a discount factor, or P_{edge}, of 0.70 (0.38 / 0.54 = 0.70; i.e., success at edges is assumed to be 70% of forest interior values). This discount factor (0.70) was used to modify the predicted contribution to *K* of current or potential future edge-influenced habitat as $K_{edge} = K_{stage} * P_{edge}$. Predictions of *K* across edge and interior ($K_{interior}$=K_{stage}) habitat are summarized as $K' = K_{edge} + K_{interior}$. Thus for example, applying this concept to a 100-acre stand in the Botanically Diverse (Appendix B) stage (*P*=0.47) with 50 acres of interior and 50 acres of edge influence, K' = (170 acres / marbled murrelet) * [(0.47 * 50 acres) + (0.47 * 0.70 * 50 acres)] = 0.251 “marbled murrelet units.”

Areas of potential marbled murrelet habitat subject to edge effects were identified and summarized using the 82-foot resolution GIS grids that represented current and projected land cover. The land cover categories of Green et al. (1993) were the basis for determining edge-influenced areas of potential marbled murrelet habitat that occurred only in the late-seral category. Non-forest, non-conifer, and early-seral conifer were considered “edge-creating” categories. Among DNR’s stand development stage (SDS) categories, Ecosystem Initiation and Sapling Exclusion were considered edge-creating when adjacent to categories that provided some *K*.

The Influence of Distance from Marine Habitat on the Quality of Inland Marbled Murrelet Habitat and Its Effects on Carrying Capacity

Radiotelemetry studies in southwestern British Columbia (Hull et al. 2001) suggest that 40 miles is a reasonable one-way commuting distance for nesting marbled murrelets. The at-sea distribution of marbled murrelets during the breeding season (Miller et al. 2006) and results of DNR’s inland marbled murrelet surveys in the South Coast and Columbia HCP Planning Units (see Prenzlow Escene 1999 and Harrison et al. 2003 for survey reports) confirm that the value of inland habitat declines dramatically beyond 40 miles from marine foraging areas.

The Science Team applied an arbitrary discount factor of 0.25 to reflect the diminished potential contribution to *K'* of stands more than 40 miles from marine waters with an observed high density of marbled murrelets during the breeding season (Miller et al. 2006). Within the analysis areas, locations distant from marine foraging areas were exclusively in the far eastern portion of the SWWA Analysis Unit (Figure ES-1).

ES.10 METHODS FOR PROJECTING THE DEVELOPMENT OF MARBLED MURRELET HABITAT UNDER THE SCIENCE TEAM'S RECOMMENDED CONSERVATION APPROACH

As described previously, the Science Team designated MMMAs in the SWWA Analysis Unit. In the OESF, the Science Team designated the proposed areas in the Queets, Dickodochtedor, Goodman Creek, and Kalaloch LPUs as MMMAs for the purposes of examining current and projected forest habitat. The total area of all MMMAs is approximately 117,000 acres of forested state trust lands. These MMMAs were designated so that management within them would have the explicit objective of enhancing existing lower-quality habitat and developing new habitat in areas that have not been found to be occupied. This section summarizes the methods and assumptions used to project forest growth and response to silviculture in those MMMAs. The principal objective of this modeling exercise was to provide an objective, repeatable, quantitative assessment of the results of proactive silviculture intended to maximize the quality and quantity of marbled murrelet habitat, according to the unique conditions desired for each MMMA, within the 70 year term of the HCP. Since recommendations for the development of marbled murrelet habitat in the Straits Analysis Unit are to provide solely passive management, these exercises were not conducted there.

Goals and Objective Criteria

The goal of this exercise was to create as much potential nesting habitat for marbled murrelets as possible within the proposed area on DNR-managed land, as rapidly as possible within the seven-decade HCP agreement. Habitat was identified using the SDS criteria summarized in the previous section; thus, the solution led to the maximum *K* summed over all stands in the MMMAs in decade seven. For the purpose of demonstrating the process of applying these tools and interpreting the results, habitat was summed across all scales so that it was maximized within units of forest, blocks, or LPUs, and ultimately within and across analysis units.

Model Development

To frame what the Science Team recommended as "biologically appropriate silviculture," a series of preliminary modeling exercises examined several simplistic silvicultural approaches for achieving and improving nesting habitat. These exercises inspected outcomes of five hypothetical management approaches (scenarios) for achieving as much habitat as rapidly as possible: "No Management," "Light Thinning Only," "Heavy Thinning Only," "Conversion Only," and "Combination." The Combination approach found a solution that freely selected among the other approaches to maximize habitat. The silvicultural characteristics of each of these approaches are described in chapter 4.0.

Results of all five trial approaches demonstrated a steady increase in the abundance and quality of marbled murrelet habitat, but the scenarios could be lumped into two groups based on their performance. One group, consisting of No Management, Light Thinning Only, and Conversion Only, showed initial rapid gains in habitat, seen mainly in the first decade. Heavy Thinning and Combination comprised the other group, predicted to produce more high-quality habitat by decade seven.

Results of these initial trials were evaluated and integrated, acknowledging biophysical limitations on the effectiveness of silviculture, to form the Habitat Management scenario. Biophysical limitations refer to the capacity of the site's soil, light, and other nutrients to support a particular forest stand structure growing at a particular rate, as well as taking into consideration species composition, competition, and windthrow risk. All the listed silvicultural approaches were combined in the Habitat Management scenario to include considerations of how the interaction of stand density and the structural properties of trees could influence outcomes of silvicultural manipulations designed to create and/or improve marbled murrelet habitat. The No Management scenario was merely a simulation of forest development without active silvicultural intervention and was developed to provide a point of reference reflecting a preservation approach to habitat management.

ES.11 PROJECTS OF MARBLED MURRELET HABITAT AND POTENTIAL POPULATION RESPONSE TO THE SCIENCE TEAM'S CONSERVATION RECOMMENDATIONS

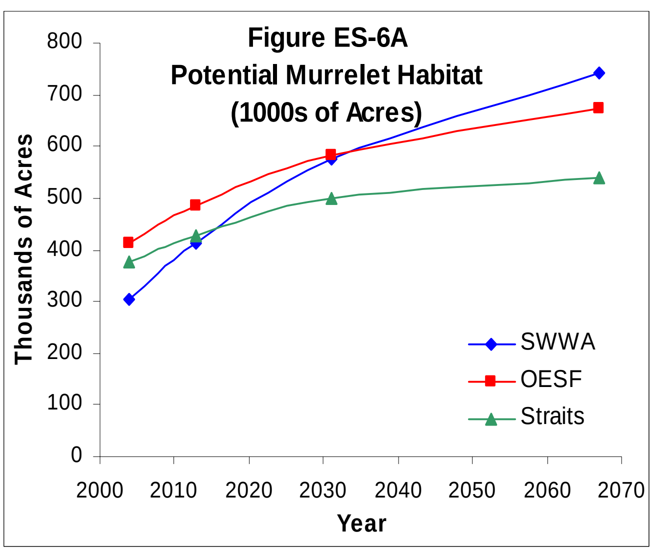
This section presents and discusses results from analyses of the current and projected future quantity and quality of marbled murrelet habitat and the potential for this habitat to contribute to the biological objectives for marbled murrelet conservation in the SWWA, OESF, and Straits Analysis Units. The analyses were intended 1) to provide objective, repeatable, quantitative comparisons of current and projected future forest habitat for marbled murrelets on DNR-managed and other lands; and 2) to estimate potential marbled murrelet population responses to current and projected future habitat under the Science Team's proposed approach using an index of the capability of forest habitat to support marbled murrelets (*K'*). *K'* is scaled to approximate DNR's current understanding of marbled murrelet population responses to forest habitat. Results from the *K'* analyses are presented in "marbled murrelet units." However, those values should not be viewed as explicit predictions of current or future marbled murrelet numbers. Rather, *K'* provides an objective, repeatable index that can be used to judge relative conservation values of future projected marbled murrelet habitat on DNR-managed lands and other lands across the area of analysis. This exercise may be used by DNR in the future to evaluate revisions to this approach or any alternative recommendations for the Marbled Murrelet LTCS.

Comparison of Current and Projected Marbled Murrelet Habitat and its Potential for Population Support Among Analysis Units and of DNR's Relative Role within Analysis Units

SUMMARY: DNR's current local-habitat contributions to populations of marbled murrelets depend on patterns of land ownership and land use within each analysis unit. In contrast, habitat quality depends on stand structure and edge effects. Currently, the OESF and Straits Analysis Units contribute more to the marbled murrelet population than the SWWA Analysis Unit; however, under the Science Team's conservation approach, the ability to support the population is likely to increase in all analysis units. This is especially true in SWWA because it has the greatest proportion of DNR ownership to overall land base and because it has high amounts of current edge habitat that can eventually be converted to high-quality habitat.

The quality and quantity of current and projected future marbled murrelet habitat differed markedly among the analysis units. Currently, habitat is most abundant in the OESF, followed by the Straits and then the SWWA Analysis Unit (Figure ES-6A; see section 4.4 for projected habitat calculation). However, since habitat is of higher quality in the largely native forests on federal lands on the Olympic Peninsula (see section ES-8), the OESF and Straits provide substantially greater support to the broader marbled murrelet population than do the managed forests in SWWA (Figure ES-6B). However, habitat capability (*K'*) is projected to increase at a slower rate than habitat area (Figures ES-6B and ES-6A, respectively) because projected increases in habitat area will largely occur in the lower-quality stages within the analysis period (Table ES-4). Thus projections for *K'* suggest that OESF, then Straits, will have much greater capability to support murrelets than SWWA over the life of the HCP (Figure ES-6B).

Forests managed by DNR comprise a minority of the land base in all analysis units, ranging from 10% in Straits to 21% in the OESF (Table ES-2). The relative contribution of DNR-managed forests to support local marbled murrelet populations depends on patterns of land ownership and land use within each analysis unit (Figure ES-7). In SWWA, where nearly all public forestlands occur on the 13% of the land base managed by DNR (Table ES-2), almost 40% of the current



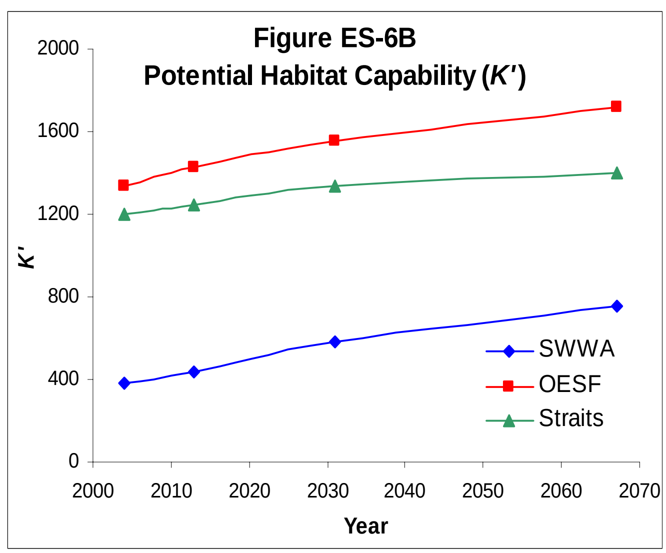


Figure ES-6. The Estimated Current and Projected Future Area of Forest Cover That Has Potential to Provide Marbled Murrelet Nesting Habitat (Figure ES-6A) and the Estimated Capability of That Habitat to Support Marbled Murrelet Populations Based on Its Quality and Abundance (Figure ES-6B) across All Ownerships within Each Analysis Unit (Under the Habitat Management Scenario).

habitat capability is on those DNR-managed lands (Figure ES-7). DNR-managed forests make such a significant contribution to *K'* because the abundance and quality of habitat on DNR-managed lands is relatively greater, particularly than that of other landowners (Table ES-4). This trend also holds for projected future forests. This abundance and quality of potential habitat can be seen when viewed as averaged over area by ownership. When averaged on a per-1000 acre basis, DNR-managed forests provide substantially more potential habitat capability than other landowners, with federal lands providing the most projected benefit on a per-area basis, particularly in the OESF Analysis Unit. The Olympic Peninsula is dominated by public forestlands, with the federally managed Olympic National Park and Olympic National Forest comprising half the land base (Table ES-2). Those federal lands provide the majority of support for marbled murrelet populations in the Straits and the OESF (Figure ES-7, Table ES-4).

Under the Science Team's recommended conservation approach, marbled murrelet habitat and its estimated capability to support marbled murrelet populations is projected to increase in all analysis units, assuming that marbled murrelets move into and successfully nest in newly created habitat. Those projections, illustrated in Figures ES-6 and ES-7, are based on the Habitat Management scenario for MMMAs on DNR-managed land; at the scale of these analyses, differences between No Management and Habitat Management are not discernable and therefore were not shown graphically. The relative difference in these increases is greatest in SWWA, where *K'* is projected to nearly double by 2067 (Table ES-5) because of the combined effects of new management practices on private forestlands (i.e., Forest and Fish Rules [Washington State Forest Practices Board 2002], which mandate managing streamside forests for future conditions that could potentially provide some capability as marbled murrelet habitat), management of state forests under current DNR policies, and the Science Team's recommended approach for marbled murrelet conservation.

Table ES-4. Current and Projected Future Acreage of Forests Managed by DNR, Federal Agencies, and Other Landowners That Could Provide Habitat to Support Marbled Murrelet Populations in the SWWA, Straits, and OESF Analysis Units (under the Habitat Management Scenario; See Appendix B for a Description of Stand Development Stages). Numbers Represent Thousands of Acres.

Landowner	Cover Type	SWWA				Straits				OESF			
		2004	2013	2031	2067	2004	2013	2031	2067	2004	2013	2031	2067
		Thousands of Acres											
DNR-Managed Lands	Large Tree Exclusion	51.1	38.7	28.5	25.8	8.5	7.7	5.2	5.9	8.2	8.4	7.5	37.2
	Understory Development	43.7	41.4	43.0	45.5	21.3	18.2	13.5	21.0	10.2	10.0	10.2	18.7
	Botanically Diverse	29.5	25.2	31.6	30.2	21.6	17.0	17.5	16.6	20.5	18.9	19.3	23.6
	Niche Diversification	0.9	3.4	19.4	33.5	0.2	1.5	8.8	2.4	26.9	23.7	31.0	32.9
	Fully Functional	0.1	0.2	0.4	22.0	0.0	0.0	0.0	7.5	5.6	14.1	17.7	30.6
Federal Lands	Existing Late-Seral	0.5	0.5	0.5	0.5	286.2	286.2	286.2	286.2	282.6	282.6	282.6	282.6
	Projected Late-Seral	-	0.4	0.9	1.0	-	55.3	106.1	125.9	-	43.6	83.9	98.3
Other Landowners	Existing Late-Seral	179.5	179.5	179.5	179.5	38.0	38.0	38.0	38.0	59.5	59.5	59.5	59.5
	Projected Late-Seral	-	121.8	270.8	400.1	-	4.0	23.2	34.6	-	23.7	69.5	88.1

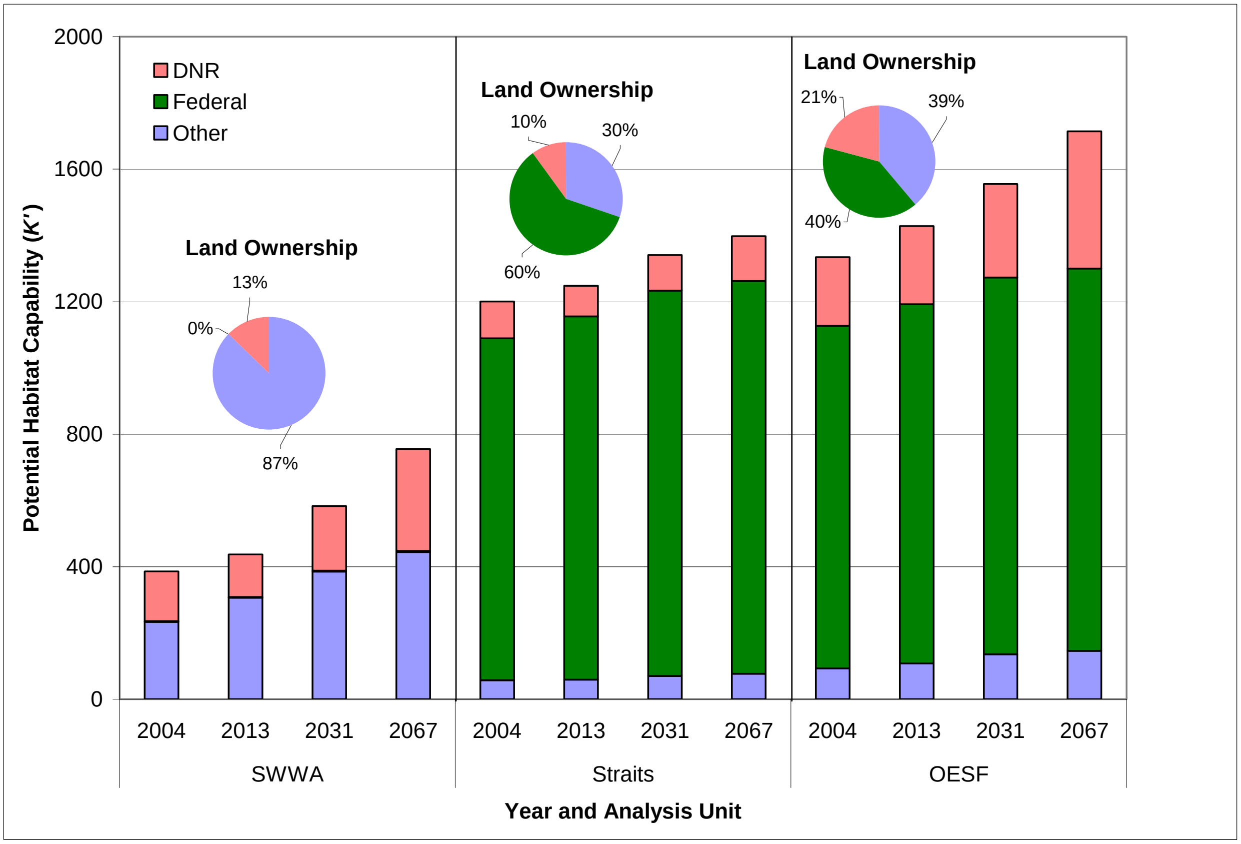


Figure ES-7. The Current and Projected Future Capability of Forests Managed by DNR, Federal Agencies, and Other Landowners to Support Marbled Murrelet Populations (*K'*) and Pattern of Land Ownership (Expressed as a Percentage of Total Landscape) in SWWA, Straits, and OESF Analysis Units (Under the Habitat Management Scenario).

Projected habitat quality is influenced mostly by stand structure; however, edge effects were also assumed to be detrimental. Habitat near edges currently provides the greatest contribution to K' in SWWA (33%) relative to Olympic Peninsula areas, where edge habitat contributes about one-fourth the projected habitat capability, with 21% and 26% for the OESF and Straits, respectively. Interior (non-edge) habitat is projected to increase in abundance in all areas by 73% (SWWA), 61% (OESF), and 52% (Straits) with associated increases in K' from interior forests. In concert with all projected changes across the landscape, a slight decrease in the proportional abundance of edge habitat is projected on the Olympic Peninsula, so that by 2067, interior habitat will increase to provide 80% and 77% of K' in the OESF and Straits, respectively, and 61% in SWWA. Edge habitat is projected to provide a greater proportion of K' in SWWA by 2067, with 39% of the substantially greater habitat capability resulting largely from the increased abundance of high-edge habitat projected to develop in riparian forests.

Table ES-5. The Current (2004) and Projected Future (2013, 2031, and 2067) Capability of Forests Managed by DNR, Federal Agencies, and Other Landowners to Support Marbled Murrelet Populations (*K'*) in the SWWA, Straits, and OESF Analysis Units (under the Habitat Management Scenario). (Note: Overall *K'* is High for Other Land Ownerships Due to the Substantial Number of Acres of Land in this Category [See Table 3-1].)

Land Ownership	Potential Habitat Capability (*K'*)											
	SWWA				Straits				OESF			
	2004	2013	2031	2067	2004	2013	2031	2067	2004	2013	2031	2067
DNR	151	128	195	308	111	92	107	135	207	236	282	414
Federal[1]	2	2	3	3	1,033	1,097	1,163	1,186	1,035	1,085	1,137	1,154
Other	233	306	385	444	56	59	70	76	92	107	135	146
Total	386	437	582	754	1,200	1,248	1,340	1,397	1,335	1,428	1,555	1,714

[1] Includes lands managed by National Park Service and U.S. Forest Service. Lands managed by other federal agencies are not included.

Projected Rate of Habitat Development on DNR-Managed Lands

SUMMARY: The general trends projected through 2067 show increasing overall habitat capability, as well as increasing habitat abundance and population support provided by higher quality habitat. This general boost in the amount of quality marbled murrelet habitat, particularly interior forest habitat, is in response to management practices both within MMMAs and elsewhere.

The increase in habitat capability projected on DNR-managed lands in all three analysis units was relative to each unit's habitat abundance and land management objectives in concert with those of other landowners (Figure ES-7). Section 5.3 in chapter 5.0 compares the projected outcomes of No Management and Habitat Management. Projected effects of Habitat Management are illustrated in Figure ES-8, showing the trend of increasing overall habitat capability, as well as the increasing abundance (see Table ES-4) and role in population support provided by presumed higher quality habitat.

The initial negative trends in *K'* for SWWA and the Straits (Figure ES-8) are the outcomes projected from timber harvests in areas not proposed to be designated to contribute to conservation, and would be managed according to DNR's broader policies under the Policy for Sustainable Forests (DNR 2006b) and the HCP (DNR 1997a) as a result of the LTCS. Although some projected marbled murrelet habitat is also predicted to be harvested in the OESF under this approach, the context of DNR-managed lands and objectives specific to the OESF are such that habitat development was projected to be the dominant process over all time steps reported from the analyses (Figure ES-8). By 2067, *K'* on DNR-managed lands is projected to double in SWWA and the OESF, and increase by 22% in the Straits (Table ES-5). Most of those increases are projected to occur as the amount and quality of marbled murrelet habitat improves in response to management practices (Figure ES-8) both within MMMAs and elsewhere.

Management in MMMAs and otherwise on DNR-managed lands was projected to result in long-term increases in the overall habitat capability of interior forest habitat, especially in SWWA and the OESF because of the focus on marbled murrelet conservation and other conservation objectives in these analysis units (Figure ES-9A). The proportion of habitat capability occurring in this potentially more secure landscape context (i.e. interior forest) remained fairly constant over time (Figure ES-9B). The temporary decreases in interior habitat due to increased edge in

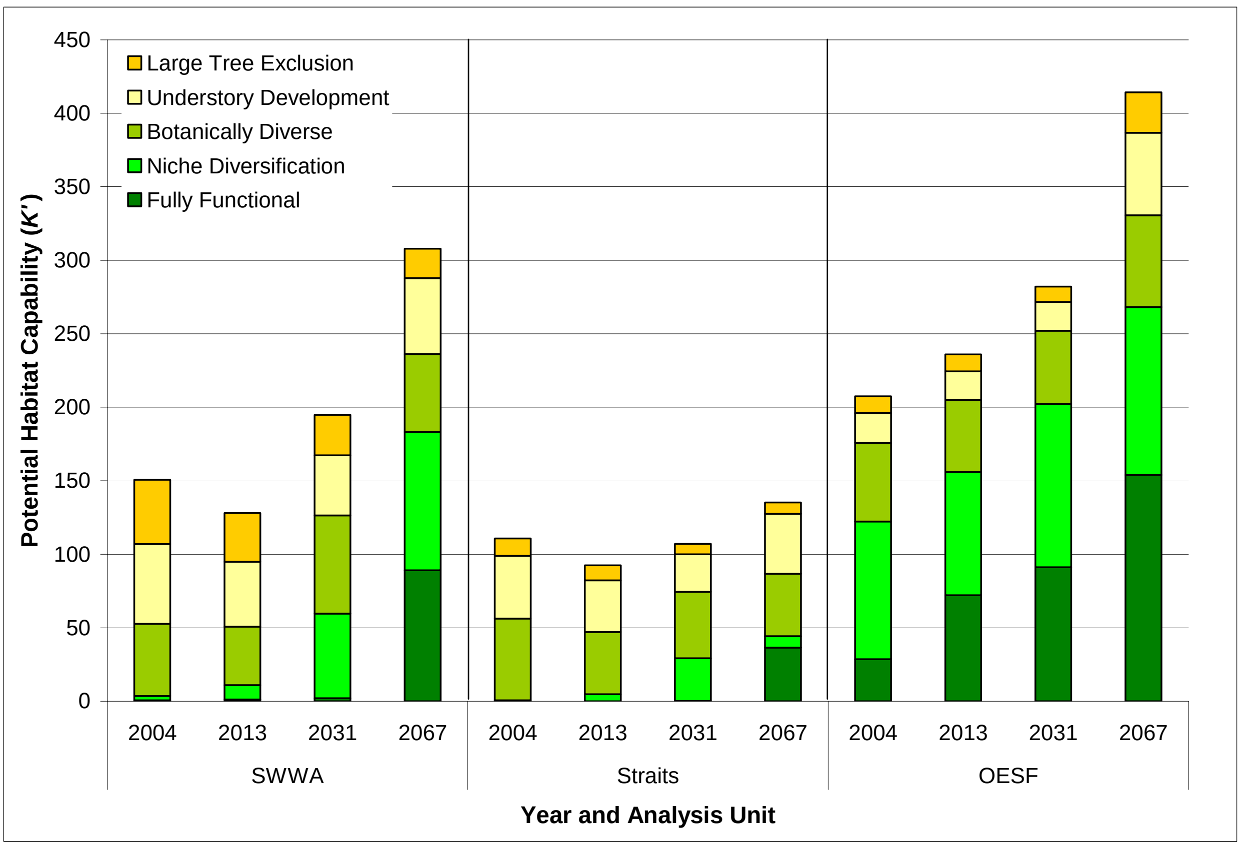
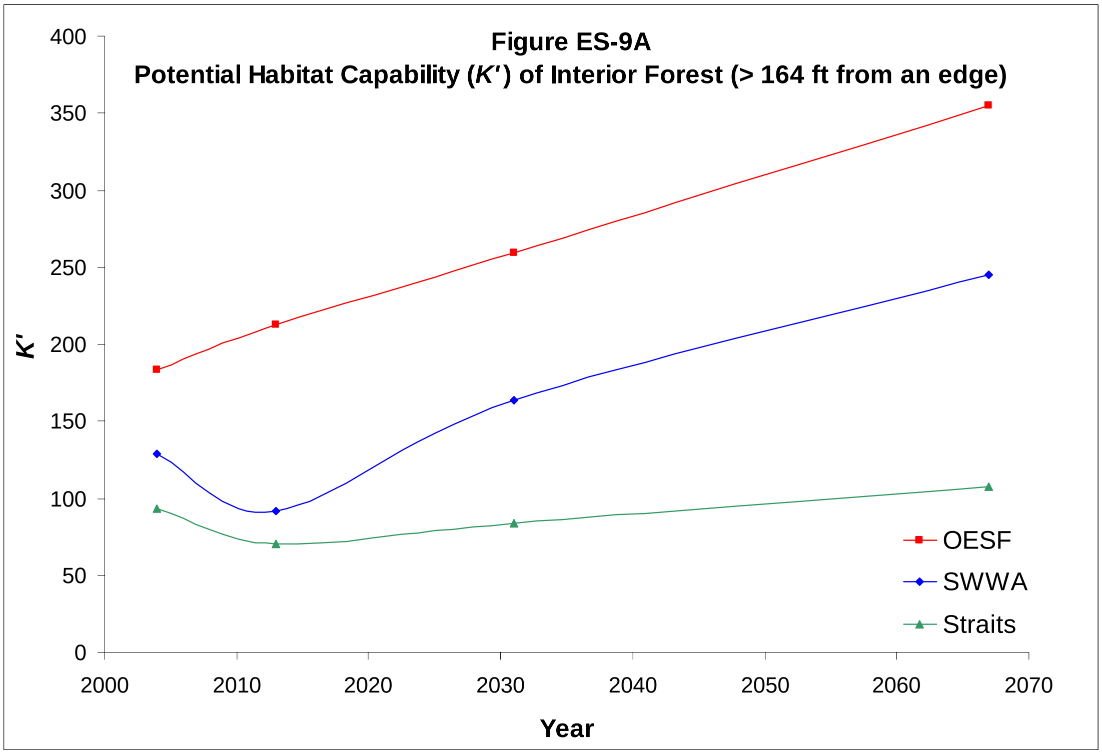


Figure ES-8. The Current and Projected Future Capability of DNR-Managed Forests, Classified by Stand Development Stage (Brodie et al. 2004), to Support Marbled Murrelet Populations (*K'*) in the SWWA, Straits, and OESF Analysis Units (under Habitat Management Scenario).



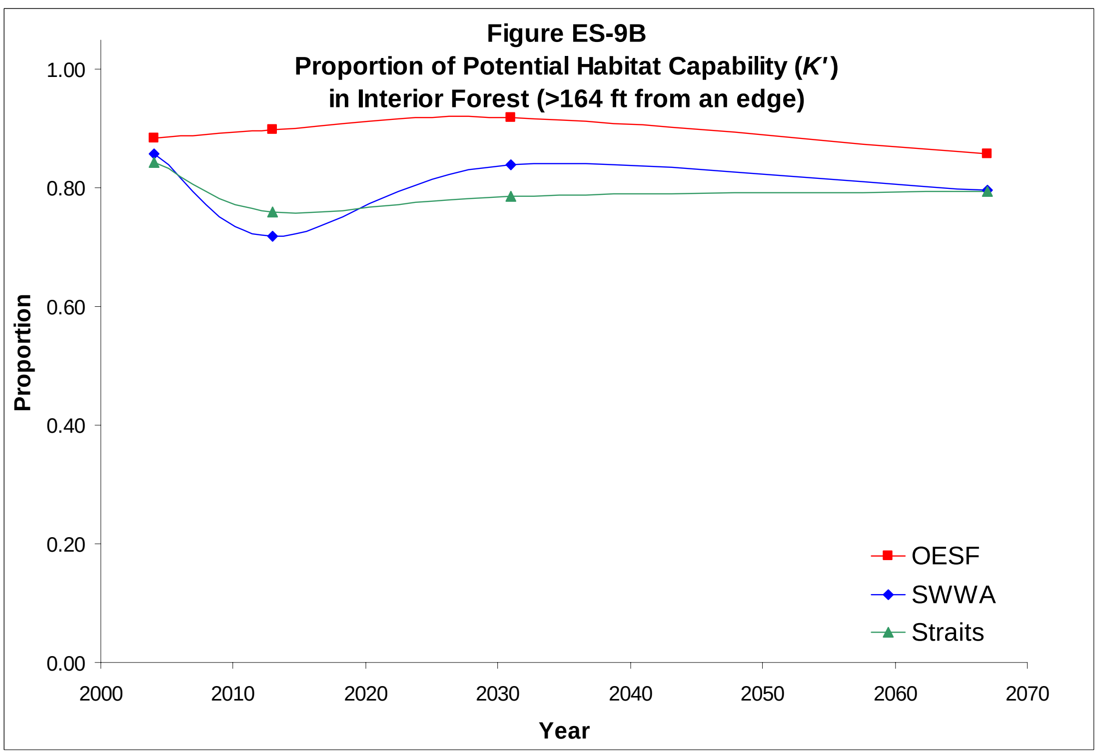


Figure ES-9. The Current and Projected Future Capability of DNR-Managed Interior Forest Habitat (more than 164 Feet from Edges) to Support Marbled Murrelet Populations (*K′*) in the SWWA, Straits, and OESF Analysis Units (under the Habitat Management Scenario) (Figure ES-9A). The Proportion of Total *K′* Provided by DNR-Managed Interior Forest Habitat in the SWWA, Straits, and OESF Analysis Units (under the Habitat Management Scenario) (Figure ES-9B).

the Straits and SWWA are the projected outcome of timber harvests in areas not recommended to be designated for conservation emphasis as noted in the previous paragraph.

A Comparison of the No Management and Habitat Management Scenarios

SUMMARY: Both the No Management and Habitat Management scenarios implement the Science Team's goals for marbled murrelet conservation, but they differ in their simulated management approaches, portraying passive and active silvicultural applications, respectively. The projections show very little difference in their projected outcomes for marbled murrelet populations, although higher quality habitat developed at an increased rate under the Habitat Management simulation.

Both the No Management and Habitat Management scenarios reflect the habitat objectives and geography of the Science Team's recommended approach to long-term marbled murrelet conservation. They differed only in their simulated management approaches, portraying a passive and active application of silviculture within the MMMAs designated in SWWA and the OESF. Projected management and its outcomes did not differ between those scenarios across the remainder of DNR-managed lands in those analysis units. That is, 66,000 of 324,000 acres in SWWA and 50,000 of 271,000 acres in the OESF were designated as MMMAs. These lands were the basis for the comparisons reported here against the background of implementing DNR policies and mandates over the rest of state forests in those analysis units.

Projections of the scenarios demonstrated very little difference in their projected outcomes for marbled murrelet populations (Figure ES-10). The most pronounced difference is for SWWA in 2067, when *K'* is projected to be 308 under Habitat Management compared to 275 under No Management. Within the MMMAs, the difference between No Management and Habitat Management were more pronounced. Projections for *K'* in 2067 were 130 and 158, respectively, or 22% greater with Habitat Management. In the OESF, the No Management scenario projected a slightly greater *K'* in 2067; 422 versus 414 for Habitat Management. This is a confounding projected outcome, and seems unlikely in view of management applied specifically for the purpose of accelerated habitat development under the Habitat Management scenario and habitat gains projected in SWWA. This phenomenon requires further investigation to explore the causes of this result in order to inform future modeling efforts. Habitat Management projected

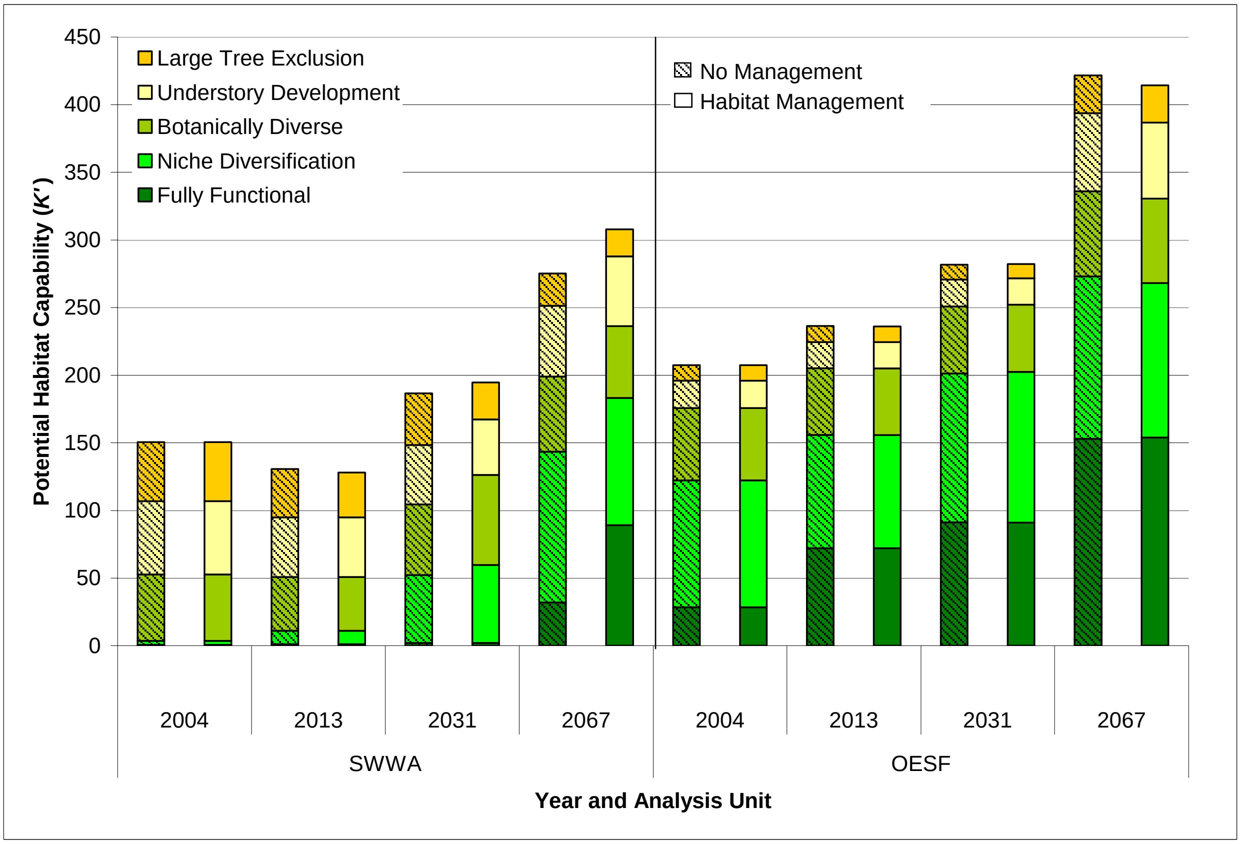


Figure ES-10. The Current and Projected Future Capability of DNR-Managed Forests to Support Marbled Murrelet Populations (*K'*) in SWWA and OESF Analysis Units for the No Management and Habitat Management Scenarios.

somewhat greater edge effects, with 80% versus 81% of *K'* from interior habitat in SWWA, and 86% versus 90% in the OESF.

<u>A Comparison of Marbled Murrelet Habitat on DNR-Managed Lands within and outside Marbled Murrelet Management Areas</u>

> *SUMMARY: Currently, both SWWA and the OESF provide a small proportion of the total area's habitat capability on DNR-managed lands. The focus of retaining and/or developing high-quality marbled murrelet habitat within MMMAs was expected by the Science Team to increase habitat quality and increase habitat abundance as a function of the amount and quality of habitat existing or projected to exist within them. Active silvicultural treatments (Habitat Management) are projected to increase these values and their capability to support marbled murrelet populations, particularly in interior forests.*

The role of MMMAs in supporting marbled murrelet populations is a function of the amount and quality of habitat existing, or projected to exist, within them. Their relative roles within the SWWA and OESF Analysis Units differ because the Science Team proposes designation of a larger percentage of the existing habitat in SWWA as MMMAs. The development of high-quality nesting habitat throughout entire MMMAs was designated as the primary objective for 66,000 acres in SWWA (20% of the total DNR-managed land area). In OESF, 50,000 acres (18% of the total DNR-managed land area) were designated as MMMAs with the primary objective being the development of high-quality nesting habitat in at least half of the area included in the designation (resulting in approximately 25,000 acres or 9% of the OESF managed for high-quality nesting habitat). Currently, both SWWA and OESF areas designated as MMMAs provide a small portion of the habitat's total capability on DNR-managed lands: 17% and 18%, respectively (Figure ES-11). Active silviculture (as exemplified by the Habitat

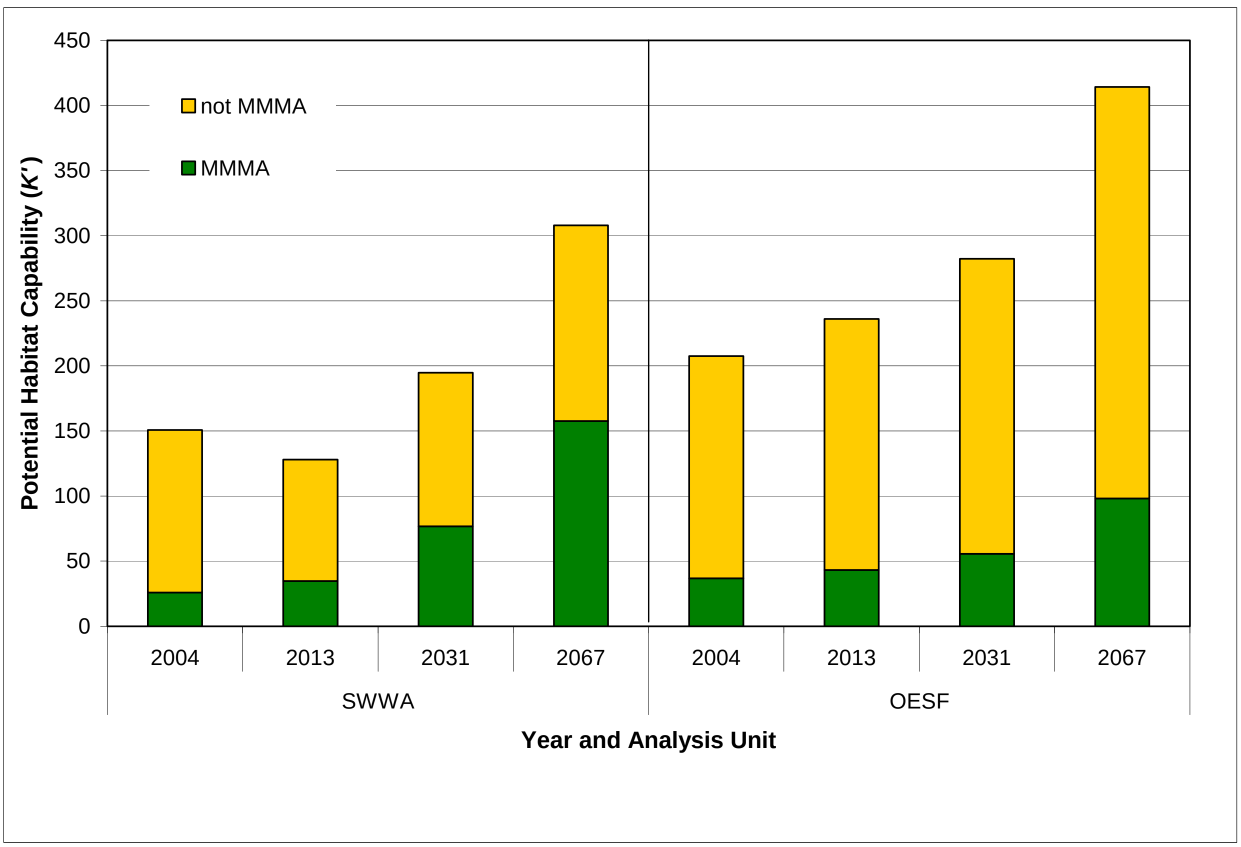


Figure ES-11. The Current and Projected Future Capability of DNR-Managed Forests to Support Marbled Murrelet Populations (*K'*) within and Outside MMMAs, in the SWWA and OESF Analysis Units under the Habitat Management Scenario.

Management scenario) to achieve the Science Team's objectives for these areas is projected to increase their capability to support marbled murrelet populations, such that by 2067, MMMAs in SWWA are projected to provide 51% of *K'* (which will have more than doubled since 2004) for DNR-managed lands in SWWA (Figure ES-11). In the OESF, habitat capability in the MMMAs is projected to increase nearly threefold by 2067 (37 to 98), comprising 24% of the overall *K'* in DNR-managed forests within the analysis unit (Figure ES-11).

The focus on retaining and/or developing high-quality marbled murrelet habitat within MMMAs was projected to increase habitat quality and increase habitat abundance, which led to the substantial increases in the projected values of *K'* between 2004 and 2067. In SWWA, the proportion of *K'* provided by higher quality habitat, including the Botanically Diverse, Niche Diversification and Fully Functional stand development stages (SDS), was 42% in MMMAs and 33% on other DNR-managed lands in 2004 (Figure ES-12). Projected increases in habitat quality

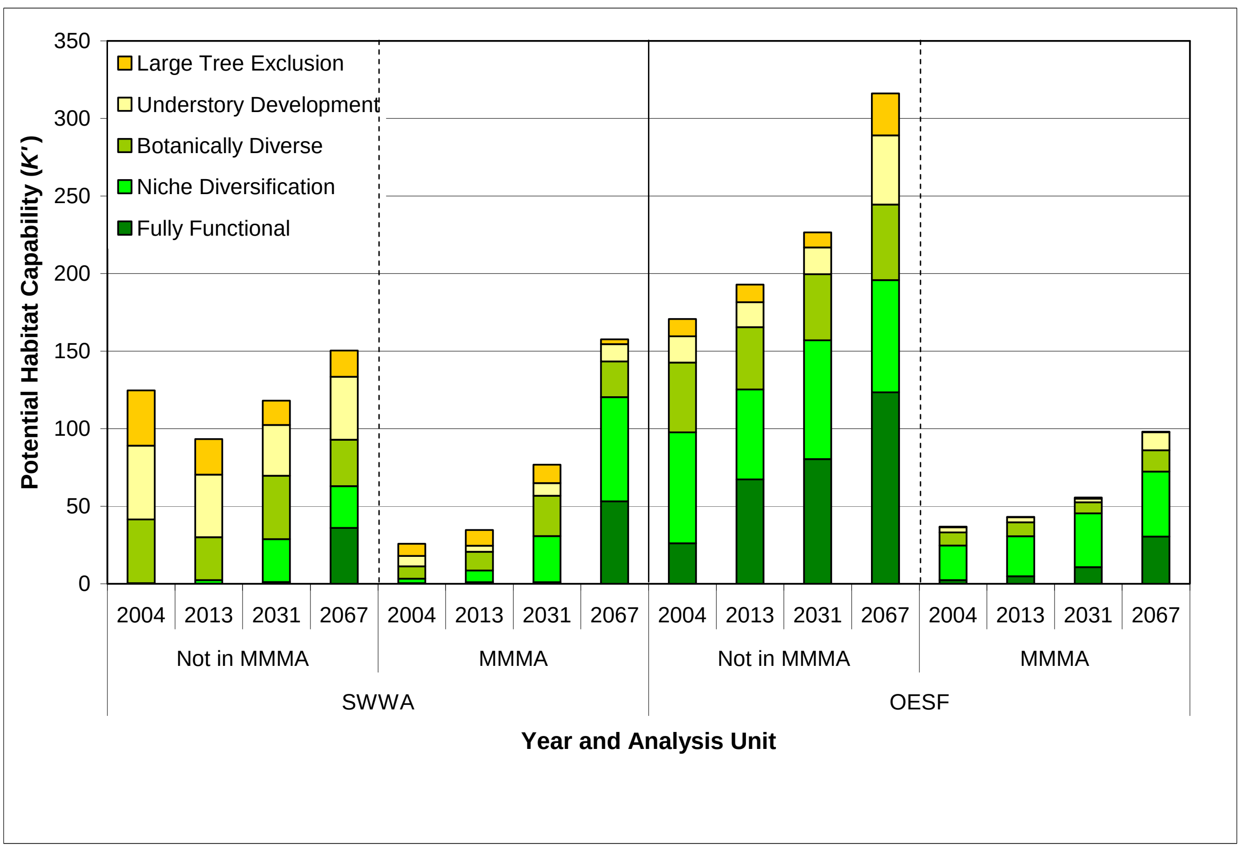


Figure ES-12. The Current and Projected Future Capability of DNR-Managed Forests, Classified by Stand Development Stage (Brodie et al. 2004, Appendix B), to Support Marbled Murrelet Populations (*K'*) within and Outside MMMAs in the SWWA and OESF Analysis Units (under the Habitat Management Scenario).

and abundance resulted in the majority of *K'* being provided by those higher quality stages by 2067, particularly in the MMMAs where 91% of the habitat capability was projected to be found in higher quality habitat. Overall management objectives in the OESF were more similar within and outside MMMAs, thus the striking changes projected for SWWA were not seen there. Habitat development was projected to increase the abundance of habitat in MMMAs, but the higher quality SDS categories provided similar proportions of *K'* in 2004 (86%) and 2067 (89%) (Figure ES-11). Edge effects were integrated with the influence of stand structure (SDS categories) in estimating future habitat capability; however, the effect of management on intentionally reducing edge effects in MMMAs was evident in the projected increases in *K'* provided from interior forests. In SWWA, *K'* of interior forests in MMMAs increased by 618% compared to its 2004 level, while it remained unchanged on state forests outside those areas. In the OESF MMMAs, *K'* of interior forests increased by 148% compared to an 81% increase in other DNR-managed forests in the area.

Summary and Discussion

Chapter 4.0 provides a discussion of the hypotheses and assumptions that are the basis for the analyses in this report. A brief review of those hypotheses and assumptions, as well as the uncertainty around them, can help the reader interpret the results from both a quantitative and qualitative perspective. Below is a brief summary of how knowledge and hypotheses regarding marbled murrelet biology and forest ecology were translated into specific assumptions concerning how forest habitat supports marbled murrelet populations and how forest succession, with and without active silvicultural intervention, influences the development of marbled murrelet habitat.

1. **Habitat area—**The assumption that 170 acres of suitable forest habitat provides sufficient opportunities to support one nesting marbled murrelet is substantiated by inland studies using radar to estimate marbled murrelet numbers and radiotelemetry to assess inland behavior (Burger 2002, Raphael et al. 2002a, Peery et al. 2004, Bloxton and Raphael 2007), as well as by estimates of marbled murrelet numbers on adjacent marine foraging areas (Miller et al. 2006). However, it is likely there is a fine-grained variability in this relationship that is overlooked by the simple assumption used in these analyses.

2. **Stand characteristics—**The abundance of potential nesting platforms and the presence of complex canopy structure are well known as essential elements of marbled murrelet nesting habitat (Grenier and Nelson 1995, Hamer and Nelson 1995). The assumed relationship of habitat value with stand structure and composition as within Table ES-3 was derived from empirical studies of marbled murrelet behavior in DNR-managed stands (Prenzlow Escene 1999), but the generalization that used SDS categories as surrogates for those structural elements has not been validated with field studies. It is likely that Table ES-3 depicts general trends in potential habitat value (Prenzlow Escene et al. 2006), but the precise numerical estimates should be considered as working hypotheses. Additionally, recent studies have located marbled murrelet nests in what appear to be unsuitable land cover categories (Hamer and Nelson 1995, Bradley and Cooke 2001, M. Raphael pers. comm.), though these nests were generally in old forests, rather than heavily managed forest landscapes. These discoveries probably reflect the inability of coarse-grained (i.e., stand-level) classifications to identify the specific, rare structural elements used as nest substrates by those birds (McShane et al. 2004).

3. **Forest succession—**The dynamics of succession in forest stands, with and without silvicultural intervention, have been well studied (Shugart 2003). Forest growth models can be sufficiently predictive (Vanclay and Skovsgaard 1997); therefore, they are widely used for effectively developing and implementing plans to manage forest properties for multiple objectives (Guisan and Zimmermann 2000). Projections for DNR-managed stands were based on data from high-resolution inventories of the forests (DNR's Forest Resource Inventory System [FRIS]) and well-supported forest growth models (DNR 2004b). However, as the predictions from those models become increasingly specific (i.e., for individual stands as opposed to averages taken across multiple stands), they can become increasingly uncertain (Heuvelink 1998).

4. **Edge effects—**Negative edge effects have been observed at marbled murrelet nests, and the rates of high and low nest success used to model edge effects were developed from field studies (Manley and Nelson 1999, Nelson and Hamer 1995b). However, research on actual and simulated marbled murrelet nests demonstrates that edge effects are probably the result of several complex, interacting phenomena that are not adequately represented by the simple model employed in these analyses (Nelson and Hamer 1995b, Raphael et al. 2002b).

Projections of the amounts of edge are fairly robust because they are based on the current landscape data on other ownerships (Interagency Vegetation Mapping Project) and projections of growth and harvest on DNR-managed lands (DNR 2004a), but there is substantial uncertainty as to the generality of the model that predicts their suitability as habitat. Some of this uncertainty may be resolved by ongoing and future research (see chapter 6.0).

5. **Distance from marine foraging areas—**Research on marbled murrelet behavior suggests there is a threshold distance between nesting and foraging areas beyond which the value of nesting habitat is markedly diminished (Hull et al. 2001). However, the assumption used in these analyses is merely an "educated guess" that reasonably conforms to observed patterns. It remains to be refined by ongoing research.

Thus, results of these analyses are best considered broadly. Smaller differences (e.g., on the order of 10%) are probably more meaningful when they are based on analyses across large areas, such as entire analysis units. Likewise, differences of that order in current or projected future conditions are likely to be less meaningful when measured across smaller analysis areas (e.g., individual SDS categories within MMMAs). Although there is uncertainty in the modeling assumptions, the fact that they were applied equally in the analyses allows the results to be directly compared. The best use of these results may be as relative comparisons:

- What are the relative roles of the analysis units and the landowners within them in regional marbled murrelet conservation?
- What broad trends are expected in marbled murrelet habitat within each analysis unit?
- Will DNR policies and the Science Team's recommendations meet their goals for marbled murrelet conservation?
- Is active silvicultural intervention an appropriate tactic for achieving marbled murrelet conservation goals?
- Are MMMAs an appropriate strategy for achieving marbled murrelet conservation goals?

The presentations of results earlier in this chapter were made with these types of comparisons in mind, although the text, tables, and figures allow the reader to evaluate projections at finer scales, if so desired. Table ES-6 summarizes current and projected future conditions relative to the Science Team's biological goals for marbled murrelet conservation on DNR-managed lands.

In short, DNR's broader policies, in concert with the specific approach to marbled murrelet conservation suggested by the Science Team and current policies of federal and other landowners, will result in improved inland habitat conditions, which are likely to support those biological goals. However, the portion of the marbled murrelet population nesting in SWWA will likely remain less secure than that portion using the Olympic Peninsula because of the lack of habitat on federal lands in SWWA.

Table ES-6. Summary of the Current and Projected Future Condition of Marbled Murrelet Habitat in the SWWA, OESF, and Straits Analysis Units Relative to the Science Team's Biological Goals for Marbled Murrelet Conservation This Summary Includes State, Federal, and Non-Federal Lands.

	SWWA		**OESF**		**Straits**	
	2004	**2067**	**2004**	**2067**	**2004**	**2067**
Population Size (Measured by Habitat Capability)	Small (K'≈386)	Moderate (95% increase)	Large (K'≈1,335)	Large (28% increase)	Large (K'≈1,200)	Large (16% increase)
Population Stability	Much habitat in high-edge situation, potential threat to stability	73% increase in K' from interior habitat but still high proportion of edge	Much habitat in interior forests, potentially supporting more stable population	61% increase in K' from interior habitat, improved potential for stable population	Much habitat in interior forests, potentially supporting more stable population	52% increase in K' from interior habitat, improved potential for stable population
Distribution	SWWA is a gap in broad distribution of habitat, few habitat concentrations within SWWA	Improved habitat distribution within SWWA and for rangewide population	Good, but ecological gap in distribution, little habitat in low elevation forest communities	Improved ecological distribution, K' increased 166% in MMMAs	Good	Good
Resilience	Probably low	Improved but less than Olympic Peninsula areas	Probably fairly high	Further improved	Probably fairly high	Further improved

The Science Team's conservation emphasis in SWWA is an effort to meet their translation of biological goals for the marbled murrelet. The geography and extent of DNR-managed lands as well as the relatively few acres of federally managed forests limit those efforts, but even with those limitations the strategy was projected to make substantial progress toward those goals, with DNR-managed lands providing a disproportionately large share (41%) of future habitat capability because of increased amounts and quality of habitat on state forests. About half of the future habitat capability on those DNR-managed lands will occur in the 20% of state forests designated as MMMAs. Forest growth modeling suggested that appropriate active management does not appear to affect the future development of habitat and may improve its effectiveness.

In the OESF and Straits Analysis Units, the Science Team suggested relatively lower levels of focal management for marbled murrelet conservation because of the context of DNR-managed lands in a landscape dominated by federal forest reserves, and because the existing OESF northern spotted owl conservation strategy greatly supports marbled murrelet habitat. Considering DNR-managed lands as a whole, the Straits and OESF Analysis Units contribute to the broader trend of projected improvement in habitat capability. This is particularly true in the OESF, where high-quality marbled murrelet habitat is a relatively larger proportion of the DNR-managed land base and where intentional management for marbled murrelet habitat restoration is part of the Science Team's recommended conservation approach. MMMAs in the OESF were likely to achieve the designated objective of increasing habitat capability in low elevation forest communities. The total habitat capability was projected to increase by 166% (Table ES-6) from active silviculture that included management for multiple objectives.

The management scenario analysis results indicate that there are a variety of ways to achieve equivalent levels of marbled murrelet habitat conservation. Each scenario has its own set of unique hypotheses and assumptions. Thoughtful evaluation of the most biologically relevant hypotheses and a minimal set of necessary assumptions required to enact the selected conservation strategy will ensure its success.

1.0 INTRODUCTION

A habitat conservation plan (HCP) is a long-term management tool, authorized under the federal Endangered Species Act (ESA) (Title 16, Section 1531 et seq. of the United States Code [16 USC 1531 et seq.]). For DNR, an HCP allows timber harvesting and other land management activities to continue on forested state trust lands, while providing for species conservation as described in the ESA. The HCP offsets harm to a threatened or endangered species as a result of land management activities with a plan that implements conservation on lands covered by that HCP. DNR is issued an "incidental take permit" by the United States Fish and Wildlife Service (USFWS) that allows limited accidental harm to a species or its habitat, known as "take", in exchange for the conservation provisions detailed in the HCP.

In 1997, DNR completed a multi-species HCP for state trust lands in order to be compliant with the ESA (DNR 1997a). The HCP covers approximately 1.8 million acres (728,000 hectares) of state trust lands (Figure 1-1), and provides mitigation for the incidental take of ESA-listed species, including the marbled murrelet (*Brachyramphus marmoratus*), northern spotted owl (*Strix occidentalis caurina*), and several other species. DNR committed in its HCP "to develop a long-term conservation strategy for the habitat of the marbled murrelet that will provide minimization and mitigation for any incidental take of this species" (DNR 1997a, p. IV.39) in the Olympic Experimental State Forest (OESF) and five westside planning units. The HCP states that DNR will:

"…[H]elp meet the recovery objectives of the U.S. Fish and Wildlife Service, contribute to the conservation efforts of the President's Northwest Forest Plan, and make a significant contribution to maintaining and protecting marbled murrelet populations in western Washington over the life of the HCP" (DNR 1997a, p. IV.44).

However, the HCP did not contain a Long-Term Conservation Strategy (LTCS) for marbled murrelets because of a lack of knowledge of the species' habitat use on DNR-managed lands, locations of nesting areas, and factors affecting the population, as well as the lack of a completed federal recovery plan. Without this knowledge, development of a credible LTCS to adequately aid in the conservation of marbled murrelet populations was not considered possible. Therefore, an Interim Conservation Strategy (DNR 1997a, pp. IV.39-45) was designed to protect marbled murrelet habitat on DNR-managed lands while DNR conducted studies and collected

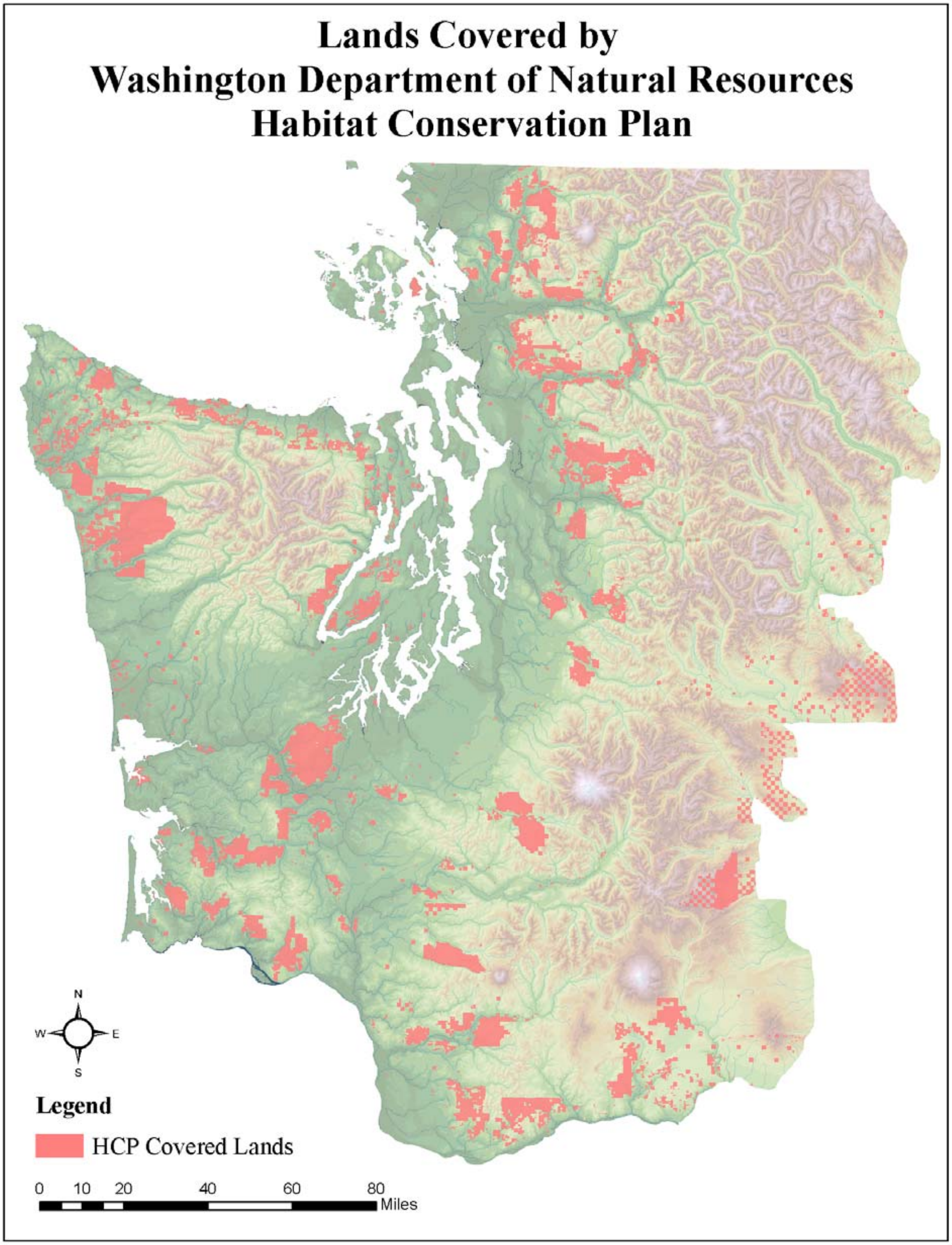


Figure 1-1. DNR-Managed Lands Covered by the Habitat Conservation Plan.

information on the biology and ecology of the species in each of the HCP planning units (Figure 3-1). Following satisfactory completion of the Interim Conservation Strategy, DNR would then develop and implement the LTCS.

At the request of DNR management, this document provides an overview of recent research and expert opinion on marbled murrelet habitat conservation and details a set of recommendations that provide the foundation for a credible, science-based LTCS that meets DNR's HCP requirements.

This document will provide DNR and USFWS the scientific information necessary to develop alternative approaches to the LTCS to be examined through the State Environmental Policy Act and National Environmental Policy Act processes. Those processes will provide decision makers with information about the potential environmental impacts of a proposal, and the public with an opportunity to provide input on potential alternatives and the types of potential impacts that should be analyzed. The environmental impact statement (EIS) arising from this analysis will be used with other relevant information by DNR to propose an LTCS (Figure 1-2).

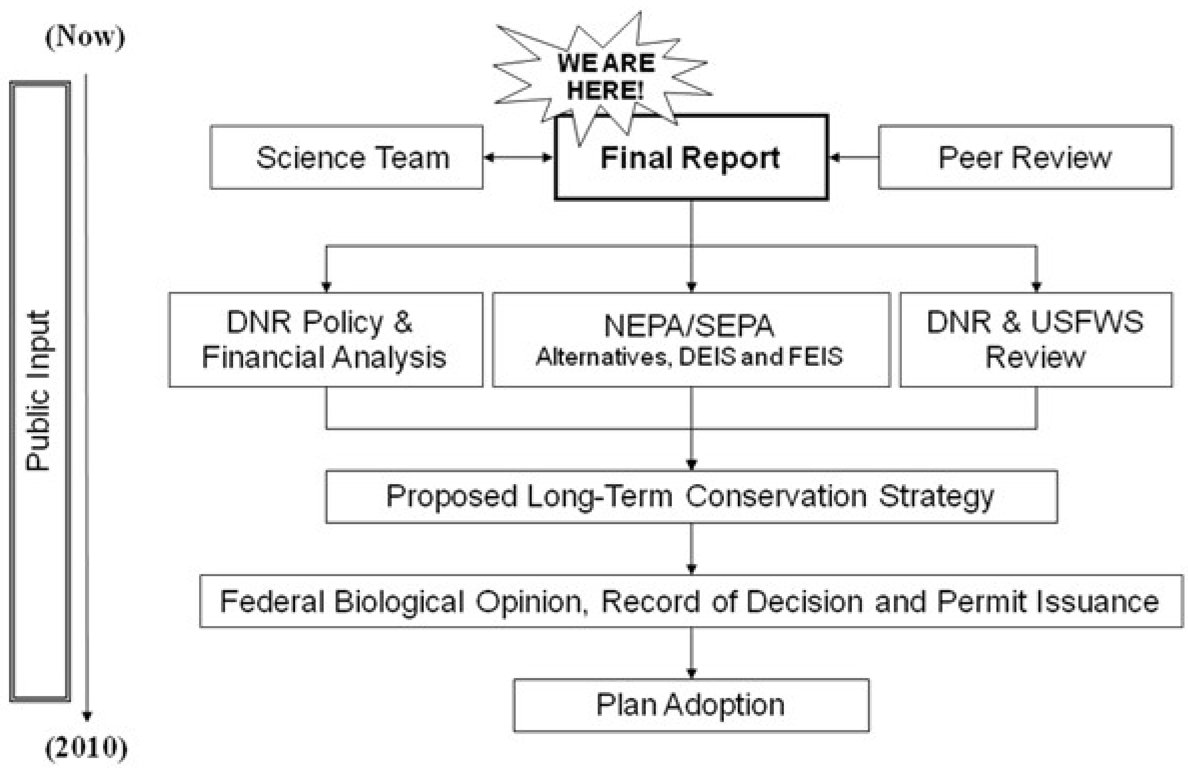


Figure 1-2. DNR Marbled Murrelet Long-Term Conservation Strategy Process Flow Chart.

The Board of Natural Resources will review the LTCS and final EIS, conduct an assessment of the impacts to the trusts, and identify an LTCS to be proposed to USFWS (Figure 1-2). Once identified, the LTCS for the marbled murrelet will be submitted to USFWS as part of the application for an amended incidental take permit. USFWS will analyze the LTCS per the requirements specified in the ESA and HCP, including writing a biological opinion to analyze impacts on the species' population. If the amended permit is granted for the LTCS, it will allow implementation of this strategy on DNR-managed lands for the term of the HCP.

1.1 Interim Conservation Strategy

1.1a Gathering Data though a Stepwise Process

The Marbled Murrelet Interim Conservation Strategy described in the HCP (DNR 1997a, pp. IV.39-45) directed DNR to complete research necessary to the development of the LTCS and involved five main steps. First, DNR identified and deferred harvest of any part of a block of suitable marbled murrelet habitat. Second, within each of the South Coast, Columbia, OESF, and Straits Planning Units, DNR conducted a two-year habitat relationship study to determine the relative occupancy of forest types used by marbled murrelets. Third, after the habitat relationship studies were completed in these planning units, DNR built predictive models to identify the marginal habitat expected to comprise a maximum of 5% of the sites occupied by marbled murrelets on DNR-managed lands within each planning unit (Prenzlow Escene 1999). Marginal habitat types were made available for harvest as described under the incidental take permit. (USFWS authorized harvest of these acres in the incidental take permit.) All acreage constituting the higher quality habitat types, as identified by predictive habitat models (comprising 95% of the occupied sites), was included in a one-time inventory survey using protocols approved by the Pacific Seabird Group (Ralph et al. 1994, 1995b, 1996, 1997, 1998, Evans Mack et al. 2003) to locate occupied sites. All known occupied sites were protected.

Fourth, outside of southwest Washington (SWWA), surveyed, unoccupied habitat was made available for timber harvest if it was not located within 0.5 miles (0.8 kilometers) of an occupied site. (For the purposes of the Interim Conservation Strategy, SWWA was defined as that portion of the Columbia Planning Unit west of Interstate 5 and that portion of the South Coast Planning Unit south of State Route 8.) After harvest, 50% of the suitable habitat on DNR-managed lands in each Watershed Administrative Unit (WAU) was designated to remain until the completion of the LTCS. Within SWWA, no surveyed, unoccupied habitat would be released until the completion of the LTCS. All known occupied sites in each planning unit were protected and any additional occupied sites found during the implementation of the Interim Conservation Strategy were protected.

Additionally, while these steps were being implemented, DNR participated in cooperative regional research efforts to further investigate the biology and ecology of the marbled murrelet. These research projects included:

- Marine surveys to document distribution and population size (Thompson 1999, Lance and Pearson 2005).
- Examination of factors affecting nest success (Marzluff et al. 1999, Marzluff et al. 2000).
- Nest predation studies (Luginbuhl et al. 2001, Bradley and Marzluff 2003).
- Analyses of temporal variability and landscape-level relationships of inland activity by marbled murrelets (Raphael et al. 2002a, 2002b, 2006).
- Development of habitat-based population models as a tool to evaluate conservation planning (Horton 2008).

The information collected during these studies and other research efforts was used to develop these recommendations for marbled murrelet habitat conservation on DNR lands managed under the HCP in SWWA and the Olympic Peninsula.

1.1b Inventory Surveys on DNR-managed Lands

Reclassified habitat is the term used in step three of the Interim Conservation Strategy to describe high-quality habitat expected to contain at least 95% of the occupied sites on DNR-managed lands within each planning unit. Reclassified habitat was determined by applying a predictive habitat model to each planning unit landscape (Prenzlow Escene 1999). The habitat models for each planning unit were developed using results of the habitat relationship studies in step two of the Interim Conservation Strategy. Per the Interim Conservation Strategy, all acres of reclassified habitat were to be surveyed using audio-visual surveys according to Pacific Seabird Group methodology to determine occupancy by marbled murrelets (DNR 1997a, Ralph et al. 1995b, 1996, 1997, 1998, Evans Mack et al. 2000, 2003). These surveys were termed “inventory surveys.”

The marbled murrelet inventory surveys were completed for the South Coast and Columbia Planning Units in 2002 and for the Straits Planning Unit in 2003 (Prenzlow Escene 1999). The OESF inventory surveys were almost 75% complete in 2002 (see description below) and were discontinued because USFWS and DNR deemed it reasonable and efficient to enter into the LTCS process with the results available at the time. The Science Team addressed the conservation potential and suggested appropriate management approaches for the unsurveyed acres. Within the OESF, approximately 39,000 acres (15,800 hectares) of reclassified habitat were surveyed, while approximately 15,000 acres (6,100 hectares) remain unsurveyed (see chapter 3.0). Marbled murrelets were detected at 92% of the survey sites in the OESF, and occupied behaviors were observed at 52% of the sites where they were detected.

1.2 Developing a Long-Term Conservation Strategy

As a first step in the development of an LTCS, the HCP called for the assembly of a Science Team, including biologists with expertise in the biology and ecology of marbled murrelets, silviculturists, Geographic Information System (GIS) specialists, and DNR planning staff familiar with components of the HCP. The Science Team would review current literature about marbled murrelets, review survey and research data collected by DNR from each planning unit, and assist DNR in the development of an LTCS. The Interim Conservation Strategy envisioned that the LTCS would take into account information on the location of occupied sites, the distribution of habitat in each planning unit, current research results, landscape-level analyses, and site-specific management plans.

In October 2003, DNR convened a Marbled Murrelet Scientific Summit in Olympia, Washington to generate input from experts in marbled murrelet biology and ecology for incorporation into DNR's LTCS. In addition, the summit discussed the most recent science on marbled murrelets and advised DNR scientists, planners, and managers on how to incorporate these insights into the development of an LTCS. The summit was also an opportunity to recruit marbled murrelet Science Team members to assist DNR in identifying conservation opportunities for the LTCS (see Appendix A for a list of summit attendees).

A Science Team was created in January 2004 (Table 1-1) to review current literature about the marbled murrelet, examine survey and research data collected by DNR and other researchers, and draft recommendations for conservation opportunities for an LTCS on DNR-managed lands

Table 1-1. Marbled Murrelet Science Team Members.

Name	**Agency**
Martin G. Raphael, Ph.D.	U.S. Forest Service, Pacific Northwest Research Station
S. Kim Nelson, M.S.	Oregon State University
Paula Swedeen, Ph.D.	Consultant
Mark Ostwald, B.S	U.S. Fish and Wildlife Service
Kim Flotlin, B.S.	U.S. Fish and Wildlife Service
Steve Desimone, M.S.	Washington Department of Fish and Wildlife
Scott Horton, Ph.D.	Washington Department of Natural Resources
Peter Harrison, B.S.	Washington Department of Natural Resources
Danielle Prenzlow Escene, M.S.	Washington Department of Natural Resources
Weikko Jaross, M.S.	Washington Department of Natural Resources

in the Columbia, South Coast, Straits, and OESF Planning Units. The Science Team consisted of biologists with marbled murrelet expertise from academic and research institutions, USFWS, Washington Department of Fish and Wildlife (WDFW), and DNR.

The Science Team held regular meetings beginning in January 2004. Data gathered during the Interim Conservation Strategy phases were reviewed and organized for further analysis. Next, the team began to develop conservation recommendations for opportunities for the LTCS.

The Science Team's recommendations for conservation opportunities for an LTCS do not include the North Puget and South Puget Planning Units. The marbled murrelet inventory surveys in the North Puget Planning Unit began in 2001 and are not yet complete. The surveys in the South Puget Planning Unit are planned for spring 2008. LTCSs for these two remaining units will be completed after surveys have been conducted or when USFWS and DNR deem it appropriate to develop an LTCS.

The following chapters of this document describe conservation opportunities for marbled murrelet habitat on DNR-managed forested lands developed by the Science Team for the South Coast, Columbia, Straits, and OESF HCP Planning Units. The document is organized as follows:

- **Chapter 2.0, "Marbled Murrelet Ecology and Life History,"** discusses marbled murrelet biology and ecology.

- **Chapter 3.0, "Recommended Landscape Conservation Approach,"** provides the Science Team's landscape recommendations for marbled murrelet conservation in the South Coast, Columbia, Straits, and OESF Planning Units.
- **Chapter 4.0, "Habitat Assessment Methods,"** provides the Science Team's methods for analyzing habitat conservation opportunities for the marbled murrelet in the South Coast, Columbia, Straits, and OESF Planning Units.
- **Chapter 5.0, "Habitat Assessment Results: Projections of Marbled Murrelet Habitat and Potential Population Response Resulting From the Science Team's Conservation Recommendations,"** details the conservation opportunities that were modeled using simplified silvicultural approaches to demonstrate two forest management scenarios. Modeling results are presented, including the likely marbled murrelet habitat development in response to each silvicultural approach.
- **Chapter 6.0, "Concepts in Adaptive Management,"** discusses how an adaptive management approach will be an integral part of the LTCS.

2.0 MARBLED MURRELET ECOLOGY AND LIFE HISTORY

The marbled murrelet is a cryptic seabird that nests in old-growth conifer forests and forages in nearby ocean environments. The range of the marbled murrelet extends from the Aleutian Islands of Alaska to the northern Baja Peninsula in Mexico, with the largest population of marbled murrelets in the three-state Northwest Forest Plan region found in Washington. Studies throughout the range of the marbled murrelet have found low rates of nest success and all populations appear to be in decline. The marbled murrelet is listed by the U.S. Fish and Wildlife Service (USFWS) as an endangered species in Washington, Oregon and California, and as a species at risk in Canada (Canadian Marbled Murrelet Recovery Team 2003). Habitat loss through forest fragmentation is thought to be the primary cause for population declines and is discussed in detail in section 2.7. This chapter briefly summarizes our knowledge to date of the marbled murrelet, its taxonomy, species characteristics, habitat requirements, population ecology and distribution. The purpose of this chapter is to inform managers of the unique ecology of the marbled murrelet, which will lead to a better understanding of which conservation efforts may be most effective in protecting populations in Washington State.

2.1 Species Description and Taxonomy

The marbled murrelet is a diving marine bird and member of the Alcidae family, which consists of 23 species divided into 11 genera within the order Charadriformes (Gaston and Jones 1998). Worldwide, three species are now recognized within the genus *Brachyramphus*: the marbled murrelet (*B. marmoratus*), the long-billed murrelet (*B. perdix*), and Kittlitz's murrelet (*B. brevirostris*) (American Ornithologists' Union 1997).

The marbled murrelet is approximately 9.5 inches (24.1 centimeters) long with a heavy compact body and a short tail and neck (Nelson 1997). The body is relatively short compared to wing length. Males and females have identical plumage that varies seasonally (Marshall 1988). In breeding plumage, the bird is dark above with rust coloring at the tips of the back feathers and heavily mottled below (National Geographic Society 1987) (Figure 2-1). This "marbled" pattern is thought to protect breeding birds in forested habitats from detection by predators (Binford et al. 1975, Nelson and Hamer 1995b). In winter, adults have a brown-gray upper body, a white lower body and are distinguished from the long-billed murrelet by white scapulars (shoulder feathers) (Figure 2-2). Juvenile (hatch-year) plumage is dusky mottled below, but by the first winter the lower body is mostly white and indistinguishable from adults (Carter and Stein 1995) (Figure 2-3).

In 1997, the American Ornithologists' Union recognized the marbled murrelet and the long-billed murrelet as separate species on the basis of molecular analysis (Friesen et al. 1996b). Long-billed murrelets are found in northeastern Asia, but occasionally occur as vagrants in North America as a result of Southern and Pacific Decadal Oscillation events (Sealy et al. 1991, Friesen et al. 1996b, Mlodinow 1997).

Marbled murrelet populations consist of three distinct genetic groups found in the western and central Aleutian Islands, eastern Aleutian Islands to northern California, and central California, respectively (Friesen et al. 1996b, Congdon et al. 2000, McShane et al. 2004, Friesen et al. 2005, Piatt et al. 2007). Piatt et al. (2007) concluded that marbled murrelet populations in the west and central Aleutian Islands and central California are peripheral populations and thus are the most vulnerable to extinction because of their small population sizes, isolation from other marbled

Figure 2-1. Marbled Murrelet Adult in Breeding Plumage. Photo by Aaron Barna Photography.

Figure 2-2. Marbled Murrelet After-Hatch-Year Bird in Winter Plumage. Photo by Rich MacIntosh.

Figure 2-3. Juvenile (Hatch-Year) Marbled Murrelet Just Before Fledging from the Nest. Photo by Tom Hamer.

murrelet populations, and marginally suitable habitat. The knowledge of genetic structure within this central population, which includes the bulk of the total current population, is limited and requires additional study (Piatt et al. 2007).

Like other alcids, marbled murrelets are adapted for both underwater (to pursue prey) and aerial flights. Marbled murrelets dive using their wings for propulsion (Burger 2002). Alcids have reduced wing areas to decrease underwater drag and well-developed flight muscles; as a result, they are relatively stocky birds with high wing loading (ratio of body mass to wing area) (Burger 2002). Birds with high wing loading require rapid flight speeds to maintain lift (Pennycuick 1987). Flight speeds of marbled murrelets range between 25 and 98 miles per hour (40 to 158 kilometers per hour). They typically fly faster when leaving the forest with a mean of 74 miles per hour (119 kilometers per hour), than when returning from the sea (46 miles per hour [74 kilometers per hour]) or circling (50 miles per hour [80 kilometers per hour]) (Burger 1997, Nelson 1997).

Molt timing varies from year to year and location to location, and is associated with prey resources, stress levels, and reproductive success (Sealy 1975, Carter and Stein 1995). Adult marbled murrelets molt into a mottled-brown breeding plumage in the spring (February–May) and replace their alternate plumage into basic (winter) plumage in late summer through early fall (July–November) (Carter and Stein 1995, Nelson 1997). The length of time required to complete an entire pre-basic molt is 2 to 3 months. It takes approximately 65 days (range of 45 to 75 days) for the molt of the primaries, secondaries, and rectrices (Pimm 1976, Carter and Stein 1995). Because of the synchronous wing-molt during the pre-basic molting period, marbled murrelets are flightless for up to two months during this time (Carter and Stein 1995). They must choose areas nearshore with predictable prey resources within swimming distance (Carter and Stein 1995, Nelson 1997).

Chicks develop plumage during the first 27 to 40 days while on the nest (Nelson and Hamer 1995a). At fledging, juveniles fly from the nest and arrive at sea in their juvenile plumage; occasionally with some down still remaining. Recently-fledged juveniles appear darker overall, older juveniles that have been at sea longer have a “speckled” appearance, and adults develop a whiter neck band and margins (Carter and Stein 1995). It is unknown whether this transition in appearance results from a partial body molt or feather wear. After a period of one to two months, the plumage changes such that by late fall all age classes resemble the adult basic plumage (Carter and Stein 1995).

2.2 Geographic Distribution

Marbled murrelets occur in North America along 6,500 miles (10,500 kilometers) of coastline between the Aleutian Islands and central California during the breeding season, and as far south as southern California and occasionally Baja California, Mexico, during the non-breeding season (McShane et al. 2004) (Figure 2-4). Populations are thought to be fairly continuous between the coastline just west of Kodiak Island and the southern edge of British Columbia, with the largest concentrations occurring between Prince William Sound and southeastern Alaska (Piatt and Naslund 1995, Ralph et al. 1995b) as well as along the west coast of Vancouver Island and Desolation Sound in British Columbia (Piatt et al. 2007). Significant gaps may occur in the distribution of marbled murrelets at sea: 1) in southeast Vancouver Island, 2) along the southern Puget Sound (near Seattle to Olympia), 3) southern Washington to northern Oregon (Columbia River to Tillamook Head), and 4) along parts of the southern Oregon and northern California coasts (Lank et al. 2003, McShane et al. 2004). The largest gap in distribution occurs in California between Humboldt and San Mateo Counties, and coincides with the lowest marbled murrelet population numbers (Huff et al. 2003, Lank et al. 2003). Within the three-state area, the largest proportion of marbled murrelets is found in Washington State, specifically in the Strait of Juan de Fuca and Puget Sound regions. However, population densities are locally higher in some locations on the coast of Oregon and northern California (Miller et al. 2006).

The *Marbled Murrelet Effectiveness Monitoring Plan for the Northwest Forest Plan* (Madsen et al. 1999) notes that the primary marbled murrelet nesting range for Washington State encompasses suitable habitat within 40 miles (64 kilometers) of the coast. The distance inland for possible nesting habitat narrows to 35 miles (56 kilometers) in Oregon, 25 miles (40 kilometers) north of Fort Bragg, California, and 10 miles (16 kilometers) south of Fort Bragg. However, the actual distance inland that marbled murrelets breed is variable from state to state and is influenced by a number of factors including nesting habitat availability, climate suitability, maximum foraging range, and possibly predation rates (Ralph et al. 1995b). Increased exposure

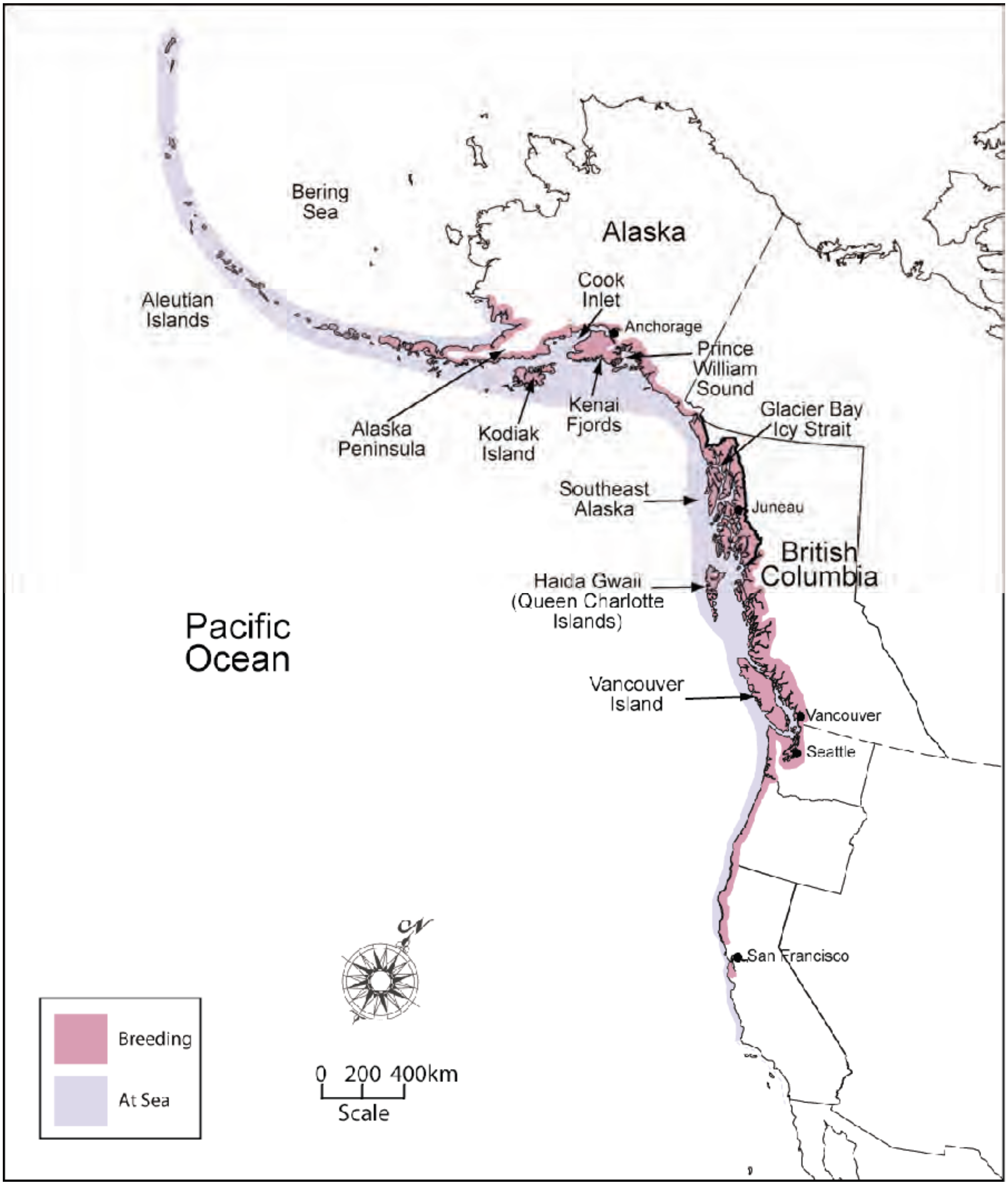


Figure 2-4. Distribution of Breeding and Non-Breeding (At-Sea) Marbled Murrelets in North America (Figure from Piatt et al. 2007).

to aerial predation may potentially raise rates of predation as marbled murrelets fly greater distances inland (Ralph et al. 1995b).

The local distribution of marbled murrelets during the breeding season (April-August) is directly related to the availability of suitable breeding resources such as old-growth and mature coniferous forests (Nelson et al. 1992, Ralph et al. 1995b, Meyer et al. 2002, Yen et al. 2004). During the breeding season, actively breeding marbled murrelets are limited to foraging within commuting distance from the nest site (Carter and Sealy 1990). In Alaska and British Columbia, marbled murrelets occur more frequently offshore; they are regularly present 25 miles (40 kilometers) offshore in the relatively shallow waters of the Gulf of Alaska (Piatt and Naslund 1995). During the non-breeding season, in some locations marbled murrelets disperse and can be found farther from shore, as is the case with some other alcids (Strachan et al. 1995). This has been observed in central California and southeast Alaska; however, in the winter months Carter and Erickson (1988) maintain that many individuals remain associated with inland nesting habitat.

2.3 Movement, Dispersal, Site Fidelity, and Philopatry

2.3a Movement and Dispersal

Evidence of movements and dispersal in alcids is typically provided by re-sightings of banded birds, documentation of the establishment of new colonies, and/or evidence of immigration to established colonies (Divoky and Horton 1995). Knowledge of inland activities and seasonal movements of marbled murrelets is limited because of difficulties in marking and recapturing marked individuals and because of their solitary nesting habitats (Divoky and Horton 1995). However, there is evidence of small- to mid-scale seasonal movements of marbled murrelets away from nesting areas (Burger 1995, Divoky and Horton 1995, Piatt and Naslund 1995, Strong et al. 1995, Beauchamp et al. 1999, Peery et al. *in press*). Throughout the marbled murrelets' range there is evidence that a portion of the population maintains residency near breeding sites outside the breeding season (Nelson 1997). In a study of common murres (*Uria aalge*) off the coast of Scotland, Harris and Wanless (1989) found breeding success to be higher in pairs that visited nest sites in the winter. Carter and Erickson (1988) believe winter visits to breeding sites may result in higher levels of breeding success by strengthening mating pair bonds, increasing familiarity of flight routes to breeding sites, and initiating breeding ahead of non-winter nest visiting pairs. The degree of year-round residency for marbled murrelets in the three state area appears to be a function of latitude. During late summer and the pre-basic molt phase, most radio-marked marbled murrelets in central California remained near nesting areas (Burkett et al. 1999, McShane et al. 2004, Peery et al. *in press*).

Breeding populations in Alaska and northern British Columbia do not regularly attend nesting habitats outside of breeding and pre-breeding seasons, although they have been detected by Alaska Department of Fish and Game personnel at inland sites during all months of the year except during pre-basic molt (Piatt et al. 2007). Agler et al. (1998) conducted at-sea surveys in southeast Alaska for four summers and four winters and documented a four- to five-fold decrease in the population from summer to winter. On the outer Washington coast and the west coast of Vancouver Island, numbers of birds drop dramatically after the breeding season, although it is unknown where they overwinter (Thompson 1997, Burger 2002). Certain areas of the Strait of Georgia and Puget Sound are used for overwintering as marbled murrelet numbers have been found to increase up to fourfold in the fall and winter (Burger 1995, 2002). Beauchamp et al. (1999) provided some of the first direct evidence of migration between breeding and non-breeding areas. A single adult female was banded in the summer of 1995 in Theodosia Inlet (Desolation Sound, southwest British Columbia), and was caught in the fall of 1996 in the San Juan Islands, Washington, approximately 137 miles (220 kilometers) south of the capture location. The same female marbled murrelet was captured a third time during the 1997 breeding season back in Desolation Sound. Seven other color-marked marbled murrelets from the Theodosia Inlet population were located in the San Juan Islands after the breeding season (Beauchamp et al. 1999).

2.3b Site Fidelity

Site fidelity is a behavior in which an animal returns repeatedly to the same area for nesting purposes, breeding season after breeding season. As a result of the low number of observed nest sites and the difficulty of observing bands on birds attending nest sites, few data are available on nest site fidelity of the marbled murrelet. From the small amount of data available, it appears that marbled murrelets display a high fidelity to nesting stands, with the same forest stands in Alaska, Oregon, and California being occupied in each survey year for 5, 10, and 20 years, respectively (Nelson 1997). There are more than 18 records of marbled murrelets using nest sites in the same or adjacent trees in successive years; however, it is unknown whether they were reused by the same birds (Nelson and Peck 1995, Singer et al. 1995, Manley 2000, Lank et al. 2003). P. Harrison (pers. comm.) observed a re-nesting attempt in 1998 at a previously successful nest site on the Olympic Peninsula. However, the re-nesting attempt was abandoned. Hebert and Golightly (2003) provided support for the hypothesis that marbled murrelets exhibit site fidelity by the confirmation of a single nest being used for two consecutive years in Redwoods National Park. Singer et al. (1995) found marbled murrelets at a site in California used the same nest tree four years in a row and used the same nest at this tree three times. There have been several other incidents of nest reuse from British Columbia: Jones (1994) found a chick in the same nest in consecutive years; Lougheed et al. (1998) stated that three of nine nests found in their study area in 1995 were either reused or revisited in 1996; and Manley (1999) reported that inter-annual reuse of nest trees in her study area on the Sunshine Coast occurred for one of eight nest trees in 1996 and at three of 27 nest trees in 1997. Though a few marbled murrelets have been documented nesting in the same trees in subsequent years, many have not, which suggests that marbled murrelets may show site fidelity only at the forest stand level, and may still move to different nest trees in subsequent years (Divoky and Horton 1995, Nelson 1997, Evans Mack et al. 2003).

2.3c Philopatry

The philopatry (proportion of chicks that return to breed at or near their nesting location) of marbled murrelets is not known (Divoky and Horton 1995); however, philopatry is common for other alcids (Harris 1983, Hudson 1985, Harris et al. 1996a, 1996b, 2007). In a study on the Isle of May in Scotland, Harris et al. (1996a) determined that 42% of common guillemots exhibited philopatry to the natal colony. The actual data on marbled murrelet juvenile dispersal and native philopatry are limited. In Desolation Sound, British Columbia, only two of 106 juvenile birds banded from 1997 through 2000 were recaptured in subsequent years; both birds were recaptured one year after the initial capture (Parker et al. 2003). None of the banded individuals were seen breeding in the study area, suggesting that juveniles may be dispersing to new areas to breed. The low numbers of juvenile recaptures could be a result of low philopatry, poor recapture methods, high juvenile mortalities, or an artifact of the study length as marbled murrelets do not breed until 2 to 3 years of age and may not return to breeding grounds until then (McShane et al. 2004). The issue of philopatry among marbled murrelets remains somewhat contentious, with some believing marbled murrelet philopatry to be similar to other alcids (Swartzman et al. 1997), and some believing it to be low due to a lack of colonial breeding and evidence of high juvenile dispersal rates (Divoky and Horton 1995).

2.4 Flight Distance and Behavior

Although breeding adults in Washington, Oregon and California typically forage less than 1.2 miles (1.9 kilometers) from shore, they have been documented traveling distances greater than 60 miles (100 kilometers) between nesting and foraging grounds (Strachan et al. 1995, Whitworth et al. 2000, Hull et al. 2001). Daily movements of breeding marbled murrelets monitored by radiotelemetry have shown that birds are consistently traveling considerable distances between potential nesting and foraging areas (McShane et al. 2004). The mean straight-line distance traveled in Prince William Sound, Alaska, was 10 miles (16 kilometers) (13 miles [21 kilometers] over sea), with a range of 0.6 to 19 miles (1 to 31 kilometers) (Kuletz 2005). In Desolation Sound, southwest British Columbia, the mean distance traveled was 24 miles (39 kilometers, with a range of 7 to 63 miles (11 to 101 kilometers) (Hull et al. 2001). Even greater nest-to-foraging distances (mean 48 miles [77 kilometers], maximum 77 miles [124 kilometers]) were documented in the inner coastal waterways of southeast Alaska (Whitworth et al. 2000). Although the radio-tagged marbled murrelets had brood patches and were associated with at least one other bird at the time of capture in this study, their breeding status was undetermined and they may not have been actively breeding when the longer movements occurred (Whitworth et al. 2000).

Marbled murrelets have distinctive flight behaviors near nest trees and in nest stands. When approaching or exiting their nest, marbled murrelets use consistent flight paths through the forest (Nelson and Peck 1995, Jones 1992). Flights below the canopy are commonly observed and are believed to be a part of predator avoidance behavior, along with minimal vocalizations and crepuscular flight patterns (Hamer and Nelson 1995, Rodway et al. 1993). Most birds appeared to use corridors such as creeks, rivers, ridges and roads whenever available as they allow the birds to approach and leave the nests directly. The direction of arrival and departure differed between birds and was highly dependant on the canopy cover and gaps around the nest tree. A study of movement around three active nests found that marbled murrelets flew under the canopy for a distance of at least 328 feet (100 meters) before reaching the nest tree (Singer et al. 1995).

In addition, Nelson and Peck (1995) found that marbled murrelets flew as low as 16 feet (five meters) above the ground, and then rapidly ascended to the level of the nest and landing pad. On some occasions, marbled murrelets were observed approaching at the nest-branch level, and after crashing through the foliage or aborting the landing, circling around for a second attempt.

Several nesting flight behaviors in nest stands and around nest trees can be categorized as follows: sub-canopy fly-throughs, landing in trees, calling from a stationary location, and flying straight or circling through or above the canopy. Another observed flight behavior is a low-pitch buzzing sound created with the wings during landings, take offs and while flying through the canopy. Landings have been observed on nest limbs but also on adjacent branches. Landing is indicative of nesting, but is also related to other behaviors such as searching for nest sites, resting or territoriality. When leaving the nest, outgoing birds were not observed to fly upward on takeoff but rather drop by several meters before ascending above the canopy (Nelson and Hamer 1995a), a behavior likely due to the high wind loading of these birds.

In their flight back to the ocean, it has been reported that nesting birds are often joined by other nesting and non-breeding birds and circle over the canopy. Non-breeders are believed to be inspecting potential nest sites and getting familiar with breeding areas (Nelson and Hamer 1995a). Singer et al. (1995) noted that fledglings flew alone and did not use the same routes used by adults.

2.5 Food Habits and Foraging Behaviors

Marbled murrelets feed in protected waters throughout the year. They can be found near shore (usually within three miles [five kilometers]) in inland saltwater bays, sounds, inlets and coves. Important differences between their winter and summer diets have been documented (Sealy 1975, Carter 1984, Ainley et al. 1995, Burkett 1995, Nelson 1997). The marbled murrelet is a generalist feeder and has a diverse diet, but primary prey include small schooling fish and large pelagic crustaceans (euphausiids, mysids, and amphipods) (Nelson 1997). The most common forage fish species are Pacific sand lance (*Ammodytes hexapterus*), northern anchovy (*Engraulis mordax*), immature Pacific herring (*Clupea pallasi*), capelin (*Mallotus villosus*), and smelt (*Hypomesus* spp.) (Burkett 1995). The fish portion of the diet is most important in the summer and corresponds to chick-rearing and the fledging period, while invertebrates (euphausiids and mysids) become more dominant during winter and spring (Burkett 1995). During the breeding season, marbled murrelets have also been found to feed on sockeye salmon (*Oncorhynchus nerka*) and Kokanee salmon (*Oncorhynchus nerka kennerlyi*), both of which are found in freshwater lakes in Russia, Alaska, British Columbia, and Washington (Carter and Sealy 1986, Nechaev 1986, Konyukhov and Kitaysky 1995, Nelson 1997). Studies suggest that marbled murrelets may use freshwater prey to facilitate more frequent chick feedings, particularly at nests located far inland (Carter and Sealy 1986, Hobson 1990, Nelson 1997).

Adult marbled murrelets commonly eat large amounts of smaller prey items (0.5 to 2.5 inches [12.7 to 63.5 millimeters] long) while larger, high-caloric and less abundant fish (2.4 to 3.9 inches [61 to 99.1 millimeters] long) are taken back to the nest to feed the young (Sealy 1975, Carter 1984, Carter and Sealy 1987a, Carter and Sealy 1990, Vermeer et al. 1987, Burkett 1995, Burger 2002). The selection of larger, heavier prey reduces the number of trips to the nest and sustains high chick growth rates (Carter and Sealy 1987a, Carter and Sealy 1990). Marbled murrelets are guided by seasonal movement and concentration of prey, and aggregate in well-defined feeding areas in relatively shallow waters (Nelson 1997). Although there is limited information on the underwater foraging behavior of most seabirds, foraging dive durations are known to vary according to water depth, and are reported to be short, averaging 16 seconds (Strachan et al. 1995). Sealy (1975) reports that marbled murrelets dive within 164 feet (50 meters) of the surface while other studies note that observations of marbled murrelet dives have been in waters less than 98 feet (30 meters) (Jodice and Collopy 1999, Kuletz 2005). In British Columbia, a study by Mathews and Burger (1998) found that an alcid the size of a marbled murrelet is expected to have a have a maximum dive depth of approximately 154 feet (47 meters). Carter and Sealy (1984) observed that marbled murrelets incidentally collected in gill nets were captured 9.8 to 16.4 feet (three to five meters) below the surface at night. Jodice and Collopy (1999) recorded that most diving occurred in water depths of less than 33 feet (10 meters). They also suggested that the birds had to increase foraging effort in rougher seas. The deepest incidental collection recorded in a gill net occurred at 89 feet (27 meters) off the coast of California (Carter and Erickson 1992). In Alaska, Sanger (1987) suggested that birds may forage in midwater depths of 59 to 148 feet (18 to 45 meters) based on prey remains found in marbled murrelets. Kuletz reports that marbled murrelets may also feed in deep waters such as fjords when prey availability is concentrated near the surface due to upwelling, tidal rips or activity patterns of preys (Kuletz 2005).

Patterns of foraging depend on prey resources, weather, season, and time of day (Speckman 1996). Marbled murrelets aggregate during nesting periods and forage individually or in pairs throughout the year (Carter 1984, Nelson 1997). Paired foraging and simultaneous diving is suggested to aid in the efficiency of foraging and prevent interference, competition and kleptoparasitism (Carter and Sealy 1990, Strachan et al. 1995, Speckman et al. 2003). Generally, marbled murrelets do not forage in mixed-species flocks, but have been reported to occasionally mix with other species in the northern part of their range (Strachan et al. 1995, Nelson 1997).

Forage fish abundance has declined indirectly through the effect of climate change on macro-zooplankton abundance and directly through fishing practices (Peery et al. 2004a, Norris et al. 2007). Therefore, it is assumed that marbled murrelets are limited by feeding conditions at sea. This hypothesis was validated by studying stable isotopes in order to understand the effects of trophic feeding levels on population dynamics of the marbled murrelet (Peery et al. 2004a,

Norris et al. 2007). The results indicate a need for more research to further investigate factors influencing the quality of the marine habitat in which marbled murrelets feed.

2.6 Population Ecology

2.6a Nesting

Most of the 22 species of alcids are colonial in their nesting habits; most exhibit breeding site, nest site, and mate fidelity; more than half lay one-egg clutches; and all share duties of incubation and chick rearing with their mates (De Santo and Nelson 1995, Gaston and Jones 1998). Although marbled murrelets are known to exhibit some of these same characteristics, the marbled murrelet is unique in the Alcidae as the only species to nest in trees.

Marbled murrelets do not build nests but use large limbs covered with a thick layer of moss or duff, mistletoe brooms, or other deformities that create a sufficiently wide and flat space (Hamer and Nelson 1995). They nest almost exclusively in coastal and inland mature and old-growth coniferous forests (Nelson 1997). Ground nesting occurs in the Aleutian Islands and in portions of southern Alaska, where trees are absent (DeGange 1996, Nelson 1997, Bradley and Cooke 2001, Marks and Kuletz 2001, McShane et al. 2004). Marbled murrelets also sometimes nest on the ground at or near the tree line (Piatt and Ford 1993). The first ground nests south of Alaska were documented by Bradley and Cooke (2001) in mainland southwestern British Columbia on mossy cliff ledges. The "structure" of these nests was similar to those of coniferous tree nests: heavy epiphyte cover, a large platform, and vegetative cover.

Courtship behavior has been observed in early spring, throughout summer, and even into the winter. During courtship, pairs join closely together, point their bills in the air, partially lift their breasts out of the water, and swim rapidly forward (Nelson and Hamer 1995b). Pairs also chase one another in flights just above the water surface throughout the spring and summer, which is thought to be courtship behavior. Year-round breeding habitat occupancy occurs more commonly in southern portions of the range; however, even in northern parts of their range where most marbled murrelets undertake seasonal migrations, small numbers remain in breeding areas during winter (Burger 1995, 2002, Agler et al. 1998, Kuletz and Kendall 1998). Migrating birds arrive at breeding areas in late winter or early spring (Nelson 1997). The regional variation in nesting chronology is provided in Table 2-1 (McShane et al. 2004), with birds in northerly latitudes initiating nesting later in the season. Additional local variation in breeding chronology may occur throughout the species' range. McFarlane Tranquilla et al. (2005) used four methods to compare the breeding chronologies of marbled murrelets at two sites in British Columbia that were only 88 miles (142 kilometers) apart. They estimated the breeding chronologies using radiotelemetry, observations of fish-holding adults, observations of juveniles on the water, and brood patch development from captured birds. They found that birds in Desolation Sound bred 30 days later than birds at Clayoquot Sound.

Table 2-1. Chronology of Breeding for the Marbled Murrelet Showing Approximate Dates of Each Phase of Breeding for Each State or Province (from McShane et al. 2004).

Region	Egg Laying & Incubation	Chicks	Fledglings
California	Late March to mid-August	Late April to mid-September	Late May through early October
Oregon	Late April to late August	Late May to late September	Late June to early October
Washington	Late April to early August	Late May to late August	Late June to early September
British Columbia	Late April to late August, peak laying end May to early June	Late May to early September	Late June to late September
Alaska	Mid-May to mid-August	Mid-June to mid-September	Mid-July to early October

Marbled murrelets have a long and asynchronous breeding season allowing ample time for replacement laying (Nelson 1997, Lougheed et al. 2002, Hamer et al. 2003, McFarlane Tranquilla et al. 2005). This behavior may be more common in this species than previously thought, particularly when failure occurs early in the breeding season (McFarlane Tranquilla et al. 2003). Marbled murrelets have been observed to lay one egg per nest attempt (Sealy 1974, Nelson 1997). Small numbers of replacement clutches have also been documented in northern California (Hebert et al. 2003). Although rare for alcids, laying replacement eggs has been documented. However, there is no direct evidence documenting marbled murrelets laying a second egg after successfully fledging the first chick.

Both the male and female share incubation duties: one broods the egg while the other forages. Incubation shifts typically last 24 hours with exchanges generally occurring before official sunrise, and often corresponding with the first auditory detections of marbled murrelets each morning (Nelson and Hamer 1995b). The timing of exchanges can be significantly affected by weather patterns and light levels; often birds arrive later during overcast or rainy conditions. During early chick rearing, nest visitation rates by males and females were found to be similar, but toward the end of chick rearing, female visitation declined while males maintained consistent visitation rates. Throughout the season, males made 1.3 more inland trips than females overall and made 1.8 times as many trips at dusk (Bradley et al. 2002). Although adult feeding visits to nest sites can occur at any time of day, about two-thirds of the meals are delivered early in the morning (often before sunrise) and about a third are delivered at dusk (Hamer and Nelson 1995). Chicks on the nest remain motionless or sleep 80 to 94% of the time (Hamer and Cummins 1991, Naslund 1993, Nelson and Peck 1995).

2.6b Breeding Success

Nest success rates have been estimated for a sample of nests in the Santa Cruz Mountains of central California with 0% success in 2000/2001 (n=7) and 16% for 19 nests found between 1989 and 2001 (Peery et al. 2004a). In northern California, nesting success varied from 13.5% to 32.4% over a 3 year period (n=37) (R. Golightly, pers. comm., cited in McShane et al. 2004). The nest success rate was 22% for a sample of 22 nests with known fates in California, Washington, and Oregon (Hamer and Nelson 1995). In western Oregon, nest success was 40% in a sample of 10 nests with known nest fates (Nelson and Wilson 2002). Higher rates of nest success up to or exceeding 46% (n=84) were found at Desolation Sound and Clayoquot Sound, British Columbia (Bradley 2002, Manley 1999, Bradley et al. 2004, Zharikov et al. 2006). In Alaska, where both ground and tree nests have been monitored, none of the nests monitored (n=9 for Nelson and Hamer 1995b, n=7 for Naslund et al. 1995) were successful. In a summary of results from several studies in Alaska from 1978-1993, 2 of 11 nests (18%) were successful (Piatt et al. 2007)

In their development of the Marbled Murrelet Conservation Zone Population Model, McShane et al. (2004) examined a high and a low value of nesting success for each conservation zone (Figure 2-5). High values were determined from telemetry studies and low values from date-adjusted juvenile:adult ratios calculated from at-sea surveys. The telemetry nest success data used in the calculations were from southern British Columbia because of limited available data in the state of Washington. Their calculations resulted in a nest success range of 38 to 54% in Conservation Zones One and Two in Washington State (Figure 2-5).

Beissinger and Peery (2007) reconstructed the historical demography of a marbled murrelet population in central California using age-ratio analysis of museum specimens collected 100 years ago, before large-scale population declines. They estimated rates of reproduction from the ratio of hatch-year (HY) to after-hatch-year (AHY) birds from specimens collected from August through October, 1892–1922. In addition, recent marbled murrelet reproduction rates were derived from age ratios collected during at-sea surveys and capture/release studies (Peery et al. 2006b, Peery et al. 2007). Contemporary estimates of reproduction were made using age ratios of birds surveyed at sea in July and August from 1996 to 2003 and from age ratios of birds captured from August through October, 2002 to 2003 for demographic studies. Productivity was estimated at the end of the breeding season both for historic specimens and for contemporary marbled murrelets captured in dip nets. Estimates were made using the total number of individuals observed in each age class (HY and AHY) during the sampling period and calculated as a ratio of productivity expressed as HY:AHY.

Results indicated that reproductive rates in contemporary marbled murrelet populations were almost an order of magnitude lower than in historical populations or the rates predicted from comparative analysis. Productivity rates derived from museum specimens were 8.5 times greater than the productivity estimated from contemporary at-sea captures, and 9.3 times greater than

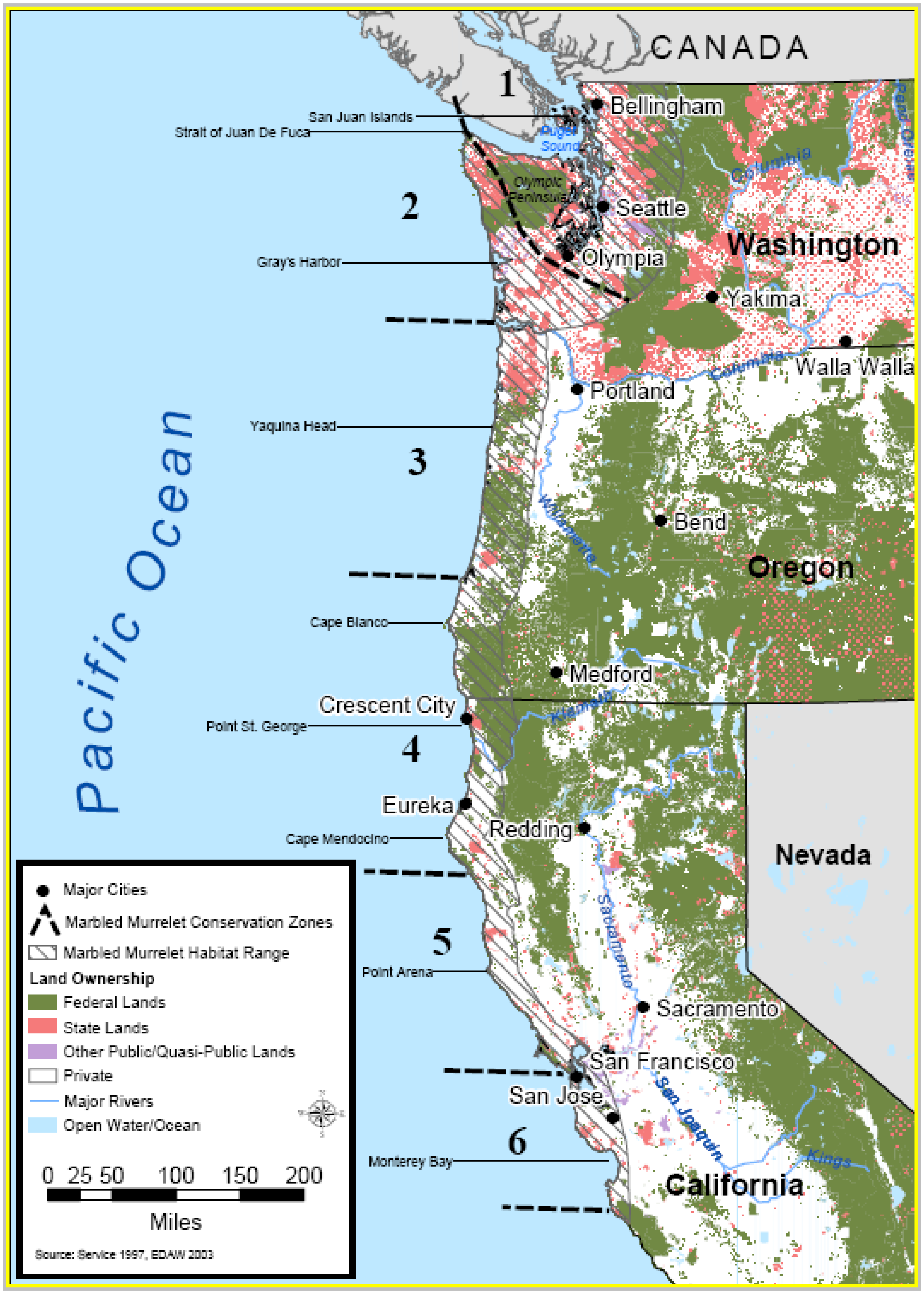


Figure 2-5. Three-State Marbled Murrelet Range, U.S. Fish and Wildlife Service Conservation Zones Boundaries, and Land Ownership (Figure from McShane et al. 2004).

estimates from at-sea surveys (Beissinger and Peery 2007). Both historical ratios and comparative analysis suggest conserving marbled murrelets will require restoring reproductive performance to yield juvenile:post-juvenile ratios of 0.2 to 0.3, a measurable benchmark for evaluating recovery (Beissinger and Peery 2007).

2.6c Fledging

Marbled murrelet chicks are very active for two evenings before fledging, with rapid pacing, frequent vigorous flapping of the wings, repeated peering over the edge of the nest platform, rapid head movements, and constant preening (Hamer and Cummins 1991, Singer et al. 1995). Fledging occurs at 27 to 40 days of age with the chicks reaching 58 to 71% of their adult mass (Nelson 1997). Chicks are thought to fly directly from the nest to the ocean. Hamer and Cummins (1991) radio tagged a juvenile on a nest in Washington, and after fledging, the bird was documented 18 hours later in the Puget Sound 1.2 miles (1.9 kilometers) north of a direct east-west line. Fledging typically occurs at dusk and it has been surmised that low light levels may be the catalyst for the juvenile leaving the nest (Nelson 1997, Jones 2001). After reaching the ocean, juveniles are independent, not attended to by either parent, and are often seen solitary on marine waters after fledging (Nelson 1997). There have been numerous documentations of fledgling birds in North America that have become grounded during flights from the nest to the Pacific (Hamer and Nelson 1995). This initial flight can be risky because many grounded fledglings may be unable to take flight again or make it to the ocean by other means.

2.6d Survivorship

Survival is strongly age dependent in seabirds, with juvenile birds and subadults showing lower survival rates compared to adults (Nur and Sydeman 1999). Without annual age-specific data on the survivorship of individual marbled murrelets, Beissinger (1995) and Beissinger and Nur (1997) extrapolated the survival rate based on an allometric relationship of survival rate compared to body mass and clutch size for 10 other alcid species. This extrapolation resulted in an estimate of annual adult (at least 3 years old) survival of 0.845 (95% CI = 0.811 to 0.880) or 84.5%. Juvenile and subadult (1 to 2 years of age) survival rates were also estimated by Boulanger et al. (1999) using data from other alcids on the proportion of adults found in these age classes. They estimated juvenile and subadult survivial to be 70.1% and 88.8%, respectively (Boulanger et al. 1999).

The direct estimate of adult survivorship in the three-state area comes from marbled murrelets captured using the "nightlighting-dipnetting" technique (Whitworth et al. 1997) in central California from 1997 to 2003 (Peery et al. 2006b). Peery et al. (2006b) estimated annual survivorship based on 331 after-hatch-year (at least one year old) individuals captured primarily in Año Nuevo Bay, where most of this small central California population congregates at night following the breeding season when adults are initiating their pre-basic molt. The estimates were 0.868 (SE=0.074) and 0.896 (SE=0.670) for males and females that were not radio tagged, respectively. For males and females that were radio tagged, estimates were 0.531 (SE=0.175) for males and 0.572 (SE=0.181) for females. Recapture rates ranged from 0.068 to 0.166. Peery et al. (2006b) modeled the effect of oceanographic conditions, sex and radio-tagging on local survival rates. They concluded that survival rates were negatively affected by radio-tagging but were positively related to the strength of the Pacific Decadal Oscillation. In warm water years, mortality was lower, likely due to fewer birds flying inland to breed and therefore less exposure to avian predators. Mortality was greatest during a domoic acid bloom in 1998. Domoic acid is a neurotoxin in the marine environment. The authors concluded that mortality of after-hatch-year marbled murrelets in central California did not appear to be of immediate concern for population viability because survival rates were not lower than expected based on comparative analyses (Beissinger and Nur 1997); however, they stated that factors affecting reproduction should be ameliorated (see section 2.6b on breeding success above).

Two annual survivorship estimates from mark-recapture data on marbled murrelets gathered in the Desolation Sound area of British Columbia are presented in Cam et al. (2003). The first estimate of 0.9289 (95% CI=0.8493 to 0.991) was based on mist net captures of 966 after-hatch-year birds at one site from 1991 to 2000. The second estimate was derived from a combination of the 966 birds mist netted and an additional 533 after-hatch-year birds captured with dip nets 3.7 miles (6.0 kilometers) from the netting area, was 0.829 (95% CI=0.7162 to 0.9029). Lank et al. (2003) suggested that despite overlapping confidence intervals, there was a real difference in point estimates, citing confounding issues related to capture biases (mist-net captures were biased toward birds caught later in the season and thus may have sampled older, more experienced birds; whereas the dip-netting sample was a more heterogeneous sample of all age groups). However, a higher proportion of dip-netted birds received radio transmitters, and in light of recent work (Peery et al. 2004b), the difference in the point estimates may be due to the physiological stress of carrying transmitters. Transmitters have been shown to negatively impact energy budgets, behavior, and reproductive success of seabirds (Ackerman et al 2004, Peery et al. 2006b).

Parker et al. (2003) reported the first direct estimates of local survival rates (0.8621 [95% CI = 0.7250 to 1.001]) of juvenile marbled murrelets by estimating the survival of 34 radio-tagged juveniles in Desolation Sound, British Columbia during the 80-day post-fledging period. From these data, an annual survival rate of 0.51 was extrapolated, based on the assumption that survival is constant over time. However, several biases within the study could confound the annual survival rates, including: 1) the assumption that transmitters did not affect individual survival; 2) the assumption of constant survival throughout the first year; 3) not accounting for birds that died during or shortly after fledgling (juveniles were captured only after they had successfully fledged from the nest to the water and survived on the water for an unknown period of time); and 4) underestimating juvenile survival in radiotelemetry and capture/recapture studies due to dispersal from the study area and the censoring of birds from the sample that cannot be located but are actually dead (Hudson 1985). The data used were only from juveniles that successfully flew from the nest to the water which eliminates a well documented period of potential mortality during the first flight to the coast (Carter and Sealy 1987b, Rodway et al. 1992).

2.6e Causes of Adult Mortality

During the breeding season (April to August in Washington State) nesting adult marbled murrelets are exposed to terrestrial predators and other hazards on their flights to and from nests and while incubating eggs and caring for young at the nest tree itself. To provide for their young, murrelets also spend time foraging at sea during this period, but spend the majority of their time at sea during the remaining seven months of the year. While at sea, adults experience a completely different host of factors that affect adult survival compared to the terrestrial environment. Therefore, the unique ecology of the marbled murrelet exposes adults to a variety of risks due to their reliance on both terrestrial and marine ecosystems.

Boulanger et al. (1999), using Leslie matrix population models, showed that population changes would be driven most strongly by variation in adult survivorship. High rates of adult survivorship are necessary to maintain population stability in species with low reproductive output and low recruitment. Marbled murrelets are particularly sensitive to adult mortality because they produce only one egg per nesting attempt (Beissinger 1995, Ralph et al. 1995b). Thus, human-caused mortality of adult marbled murrelets above natural levels can have significant negative impacts on the marbled murrelet population. The primary known and potential causes of adult mortality in both the terrestrial and marine environment are discussed below.

2.6f Inland

In the terrestrial environment, predators documented to prey upon marbled murrelet adults at the nest include the common raven (*Corvus corax*) and sharp-shinned hawk (*Accipiter striatus*) (Singer et al. 1991, Marks and Naslund 1994). In addition, peregrine falcons (*Falco peregrinus*) are known to capture marbled murrelets as they fly to and from their inland nest sites (Nelson and Hamer 1995b, Nelson 1997, Suddjian 2003). Suddjian (2003) reported five predations of marbled murrelets by peregrine falcons in central California, including finding remains of a marbled murrelet at a peregrine nest site, three aerial kills and another observation of a peregrine falcon feeding on a carcass.

Goshawks (*Accipiter gentilis*) and bald eagles (*Haliaeetus leucocephalus*) are also known to prey on marbled murrelet adults as remains of marbled murrelets have been found at nest sites of both species (Nelson 1997, Burger 2002). In some regions, goshawks may be an important predator of marbled murrelet adults. In a study in southeast Alaska, Iverson et al. (1996) documented that 20% of goshawk nests (n=15) contained remains of alcids and most of these were marbled murrelets. In a summary of data supplied by USFWS on prey remains in goshawk nests in southeast Alaska, Burger (2002) reported that 10 of 361 prey items (2.8%) recorded at goshawk nests were marbled murrelets and that 12 of 382 pellets (3.1%) contained marbled murrelet or unidentified alcid remains. In a study of goshawk food habits on Vancouver Island by Ethier (1999), 15% of pellets contained the remains of marbled murrelets.

Other sources of inland mortality include in-flight collisions by adults transiting between nest sites and the ocean. In a summary by Nelson (1997), five likely instances of marbled murrelets being killed by colliding with vehicles and three mortalities from possible collisions with powerlines were reported. In addition, at least five adult marbled murrelets were killed or stunned after nest trees were harvested during logging operations in Alaska and British Columbia (Nelson 1997).

2.6g At Sea

Large oil spills, chronic oil pollution, organochlorine pollution, and entanglement in gill nets are significant sources of mortality for marbled murrelets at sea. The levels of mortality from disease, parasites and starvation have not been studied and so effects from these factors on populations have not been assessed. However, Nelson (1997) reported that both adult and first year bird carcasses have been picked up on beaches in Oregon in the fall and winter and that some of these birds may have died of starvation. In addition, predation on marbled murrelets at sea by bald eagles, peregrine falcons, western gulls (*Larus occidentalis*), and northern fur seals (*Callorhinus ursinus*) has been documented (Vermeer and Butler 1989, Rodway et al. 1992, Campbell et al. 1977, Nelson 1997, Hooper 2001, Peery 2004). California sea lions (*Zalophus californianus*), northern sea lions (*Eumetopias jubatus*), and large fish may be occasional predators as well (Burger 2002).

The most recent review of the effects of oil spills on marbled murrelets was conducted by McShane et al. (2004). Seabird mortality from oil pollution has been a significant conservation issue in California, Oregon, and Washington (Ohlendorf et al. 1978, Burger and Fry 1993, Carter and Kuletz 1995, USFWS 1997). When birds at sea come in contact with a spill, both feathers and skin can become coated with oil. Oil destroys the ability of feathers to regulate a bird's body temperature and can be ingested by preening birds and the fumes inhaled, resulting in effects on most of a bird's physiological systems (Burger and Fry 1993). Due to their near-shore distribution (adjacent to shipping lanes), significant time spent at sea, and foraging behavior (pursuit diving), marbled murrelets have been ranked as one of the seabirds most vulnerable to oil spills (Carter and Kuletz 1995).

The 1989 *Exxon Valdez* oil spill in Prince William Sound, Alaska, killed approximately 528 marbled murrelets and 206 unidentified murrelets (marbled, Kittlitz's, and ancient murrelets [*Synthliboramphus antiquus*]) (Carter and Kuletz 1995). These data were from counts of carcasses actually recovered from the spill zone. Using models of estimated carcass recovery rates by location, the total estimated mortality of marbled murrelets and unidentified murrelets was 8,127 birds. This was the largest recorded single mortality event for marbled murrelets in

North America. Indirect effects on marbled murrelets from the spill likely included sublethal levels of oil that reduced prey populations, disturbance from increased human activity during cleanup and monitoring after the spill, and reduced productivity of the local population in the vicinity of the spill (Irons 1992, Oakley and Kuletz 1994, Oakley et al. 1994, Carter and Kuletz 1995, Kuletz 1996).

On the west coast, most oil spills and chronic oil pollution occur in areas of high shipping traffic. In Washington State, these high traffic areas would include the Strait of Juan de Fuca and Puget Sound. Lower levels also occur near smaller ports such as Grays Harbor, Washington and other small ports along the western coast of the U.S. such as Humboldt Bay, California, and the Columbia River in Oregon (Neel et al. 1997, USFWS 1997, Carter 2003). Most oil spills were likely not reported before 1977 with many of the data on seabird mortalities coming from spills reported after 1976 (Carter 2003). In Washington State, eight major spills have been reported since 1971. These include the 1985 *Arco Anchorage* spill near Port Angeles, the 1988 *Nestuca* spill off Grays Harbor, and the 1991 *Tenyo Maru* spill off Willapa Bay. Oiled carcasses of marbled murrelets were recovered at each of these spills. In the *Tenyo Maru* spill, approximately 45 marbled murrelet carcasses were recovered. Estimates of total mortality ranged from 200 to 400 marbled murrelets which may have represented a large portion of the local breeding population (Carter and Kuletz 1995). The authors state that this was likely the largest recorded loss of marbled murrelets to an oil spill on the U.S. Pacific coast south of Alaska (Carter and Kuletz 1995).

McShane et al. (2004) estimated oiling mortality of marbled murrelets in each conservation zone for all spills and chronic oiling. Where estimates comparable to recent studies were not available, they used correction factors developed by Ford et al. (2002) to determine approximate mortality. An effort was made to account for additional mortality expected from chronic oiling of marbled murrelets for each conservation zone by assuming conservative annual levels of mortality per zone (Carter and Kuletz 1995). McShane et al. (2004) found that the annual mortality in Zone One (Puget Sound, San Juan Islands and Strait of Juan de Fuca) (Figure 2-5) for the periods 1977 to 1992 and 1993 to 2003 ranged from 1.8 to 4.8 and 1.0 to 2.0 birds per year, respectively. Based on estimates of the winter population for the San Juan Islands/northern Puget Sound area, they concluded that annual oiling rates were well below one percent of the population. One percent was considered a threshold, since marbled murrelet population models developed by

Beissinger (1995) showed that declining population projections begin to differ greatly when human-caused mortality exceeded one percent of the population. The annual mortality for Zone Two (outer coast of Washington) (Figure 2-5) was estimated to be one marbled murrelet per year from 1993-2003 but may have ranged from 13.8 to 40.4 birds per year in previous years. Although the recent low mortality estimate of one marbled murrelet per year in Zone Two is less than one percent of the estimated subpopulation (Huff et al. 2003), previous mortality from oil spills may have reached one to five percent of the Zone Two population leading to steeper population declines. Overall, McShane et al. (2004) concluded that, although still a major concern, threats from oil spills have been reduced in most areas since the 1990s through increased regulation.

Fry (1995) identified organochlorine compounds as a prevalent non-oil pollution threat within the range of the marbled murrelet. Specifically, polychlorinated dibenzo-dioxins (PCDD) and polychlorinated dibenzo-furans (PCDF), which are contained in pulp-mill discharges, cause significant injury to fish, birds, and estuarine environments (Elliot et al. 1989, Whitehead 1989, Colodey and Wells 1992, Fry 1995). PCDDs and PCDFs bioaccumulate in marine sediments, fish, and fish-eating birds and can impair bird reproduction (Elliot et al. 1989, Bellward et al. 1990). There has been no record of bioaccumulated residues or breeding impairment in marbled murrelets to date, although marbled murrelets that breed in areas of historical or current discharge from bleached paper mills could be at risk from eating fish with bioaccumulated organochlorine compounds (Fry 1995). In the 1990s, paper mill effluents that could affect marbled murrelets in Washington would likely have been in areas such as Port Angeles, Bellingham, Everett and Grays Harbor (Fry 1995). However, the author points out the impact on marbled murrelets was likely lessened since the highest densities of marbled murrelets in Washington are found in the Strait of Juan de Fuca and San Juan Islands with lower densities and smaller populations in the more polluted areas of southern Puget Sound.

A detailed assessment of the potential impacts to marbled murrelets in Washington State from gill-net and purse seine fisheries was conducted by McShane et al (2004). Although mortality from entanglement and drowning in monofilament nests was suspected to occur from net fisheries, little information was available before the 1990s (Carter et al. 1995). Currently however, there is sufficient information to indicate that the number of marbled murrelets killed in gill nets for tribal and non-treaty fisheries has declined since the 1980s as a result of increased restrictions and less fishing. In general, fishing efforts in northern and western Washington decreased five- to tenfold between the 1980s and the late 1990s because of lower catches, fewer fishing vessels, and greater restrictions (McShane et al. 2004). Beattie and Seiders (2003) also noted that total gill-net effort for tribal fisheries in northern Washington waters declined by 57% between 1993–1997 and 1998–2000. Little solid evidence is available to estimate levels of mortality in any one year because of the complicated nature of fisheries, difficulty of obtaining suitable observer data, clumped and variable distribution of available data and abundance of marbled murrelets in northern Washington waters during the fall and winter. However, to provide a general assessment of the potential significance of gill-net mortality on marbled murrelet populations in Conservation Zone One, McShane et al. (2004) produced estimates using a series of assumptions including: 1) residency of marbled murrelets in Zone One; 2) ratios of populations sizes in winter versus summer and regionally; 3) marbled murrelet occurrence in fishing areas in the fall and; 4) total estimated population size.

Using these parameters, McShane et al. (2004) estimated current gill-net mortality of about 30 birds per year from 1993-2003, although some of these birds would likely have originated from British Columbia or Conservation Zone Two (the outer coast of Washington). By accounting for the presence of these birds, they estimated that current gill-net mortality may remove about 19 to 25 marbled murrelets per year from the Zone One subpopulation. Although this mortality level corresponds to less than one percent of the current estimated size of the subpopulation, the authors considered their mortality estimates to be conservative. However, Washington Department of Fish and Wildlife implemented a series of recommendations after 1995 to reduce mortality from non-tribal gill-net fisheries. These efforts, along with a decreased fishing effort due to declining salmon stocks, have likely reduced mortality levels. Marbled murrelets can also be killed by sport fisheries (entangled in fishing lines and hooked by fishing lures) (Carter et al. 1995), but these incidences are not considered to be common and may only be an issue in localized areas (McShane et al. 2004).

2.6h Population Size, Trend and Densities of At-Sea Populations

The size of the entire marbled murrelet population in North America is not known with certainty because of the secretive nesting habits of the species, which make marbled murrelets difficult to census on land. As a result, most population estimates are based on at-sea and radar surveys. In an assessment of marbled murrelets completed in 1995, Ralph et al. (1995a) estimated the North American population to be 300,000 birds. However, Degange (1996) estimated the North American population to be much higher (600,000 birds) and McShane et al. (2004) estimated the population closer to 1 million. McShane et al. (2004) provided estimates of 947,500 birds in North America, of which 90.7% (859,100) were in Alaska, 7% (66,500) in British Columbia, 1% (9,800) in Washington, 0.8% (7,502) in Oregon, and 0.5% (4,598) in California.

However, because the majority of birds were estimated to exist in Alaska and British Columbia (97.7%), the accuracy of population estimates from these two regions greatly influences the overall North American population estimate. Piatt et al. (2007) conducted the most recent comprehensive status review of marbled murrelets in Alaska and British Columbia. After examining the abundance of available information from multiple studies, they estimated that in the recent past, marbled murrelets in Alaska may have numbered on the order of 1 million birds. However, using trend information from at-sea surveys that covered a wide geographic range in Alaska, they found that marbled murrelet numbers had declined significantly at five of the eight study sites. Annual rates of decline were estimated to range from -5.4 to -12.7% since the early 1990s. By applying these rates of decline to historical population estimates, they then estimated the current population size of marbled murrelets in Alaska to be approximately 270,000 birds. They stated that this represented an overall population decline of about 70% over the past 25 years (Piatt et al. 2007). In British Columbia, the trend data they reviewed indicated that marbled murrelet populations have experienced similar declines to those reported for Alaska. Their most recent estimate of the number of marbled murrelets in British Columbia was between 54,000 and 92,000 birds. These new estimates would put the size of the North American population between 345,900 and 383,900 birds, approximately one-third of previous assessments. Assuming previous population assessments for the three-state area are correct, the new estimates from Alaska and British Columbia would also more than double the estimated proportion of the North American population inhabiting the listed range (California, Oregon, and Washington) from 2.3% to 5.7 to 6.3%.

More recent population estimates for Washington are also available from the latest 10-year report from the Northwest Forest Plan Effectiveness Monitoring Program (Miller et al. 2006), where at-sea surveys were carried out from 2000 to 2003. Two survey zones (Puget Sound and Outer Coast), corresponding to established U.S. Fish and Wildlife Service recovery zones

(Figure 2-5), were surveyed in Washington with two to three survey strata delineated within each zone (Figures 2-6 and 2-7). Zone One included three strata: Puget Sound, the Strait of Juan de Fuca, and the San Juan Islands. Zone Two included two strata along the outer coast of Washington. Population estimates in 2003 in Zone One (Figure 2-6) for Strata One, Two, and Three were 5,600 (95% CI=3500 to 8200), 1,700 (95% CI=900 to 2800) and 1,200 (95% CI = 200 to 1900) birds, respectively. Population estimates in 2003 in Zone Two (Figure 2-7) for Strata One and Two were 1,900 (95% CI=1100 to 3200) and 1,500 (95% CI=500 to 2400), birds, respectively. Therefore, the total population estimate in 2003 for Washington State was 11,900 (95% CI=7,700 to 16,700) (Miller et al. 2006). An analysis of the population trend over the four years did not show any population declines. However, the authors completed a power analysis showing that to detect an annual population decline of 2% (α=0.05), with the reported level of annual survey effort, would require 15 years of data collection. Nine years would be required to detect a five percent annual decline (Miller et al. 2006).

Bigger et al. (2006a) compared the use of radar and audio-visual surveys for determining the trend of a marbled murrelet population in northwestern California using data collected from 2001 to 2004. Counts of marbled murrelets at inland sites using audio-visual surveys showed much higher variation within a given survey site and overall when compared to radar data. Additionally, twice the audiovisual survey effort would be needed to detect trends in population size with reasonable power (80%). The advantage of using radar instead of audiovisual surveys to detect marbled murrelet population trends include far more accurate estimates of the number of breeding individuals from year to year (in certain situations), the ability to collect data under poor visibility conditions, and being able to sample larger areas and detect larger proportions of birds flying inland (Bigger et al. 2006a).

Trends in marbled murrelet populations in the three-state area and in Washington State have been estimated using demographic models and radar count data. Using demographic analysis, Beissinger and Nur (1997) estimated the decline in marbled murrelet populations in the Pacific Northwest ranged from 1 to 14% per year with the most likely rate of decline around four to eight percent per year. They estimated a four percent decline per year for Puget Sound and northern Oregon populations. McShane et al. (2004) also developed a demographic model of marbled murrelet populations for each conservation zone in the three-state area in an effort to

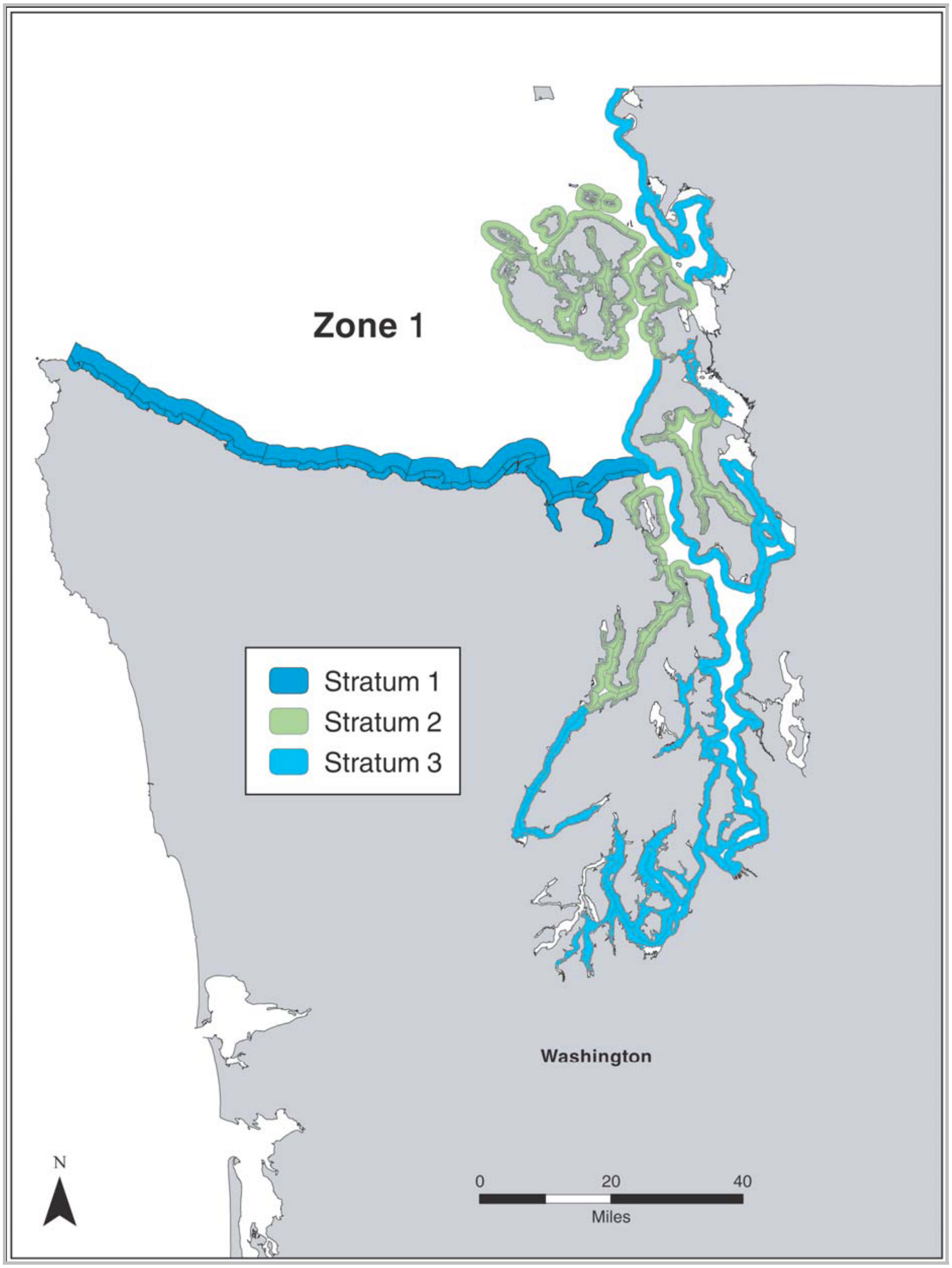


Figure 2-6. Marbled Murrelet Conservation Zone One and the Three Primary Sampling Units Used to Estimate Population Size for the Northwest Forest Plan Effectiveness Monitoring Program (Figure from Miller et al. 2006).

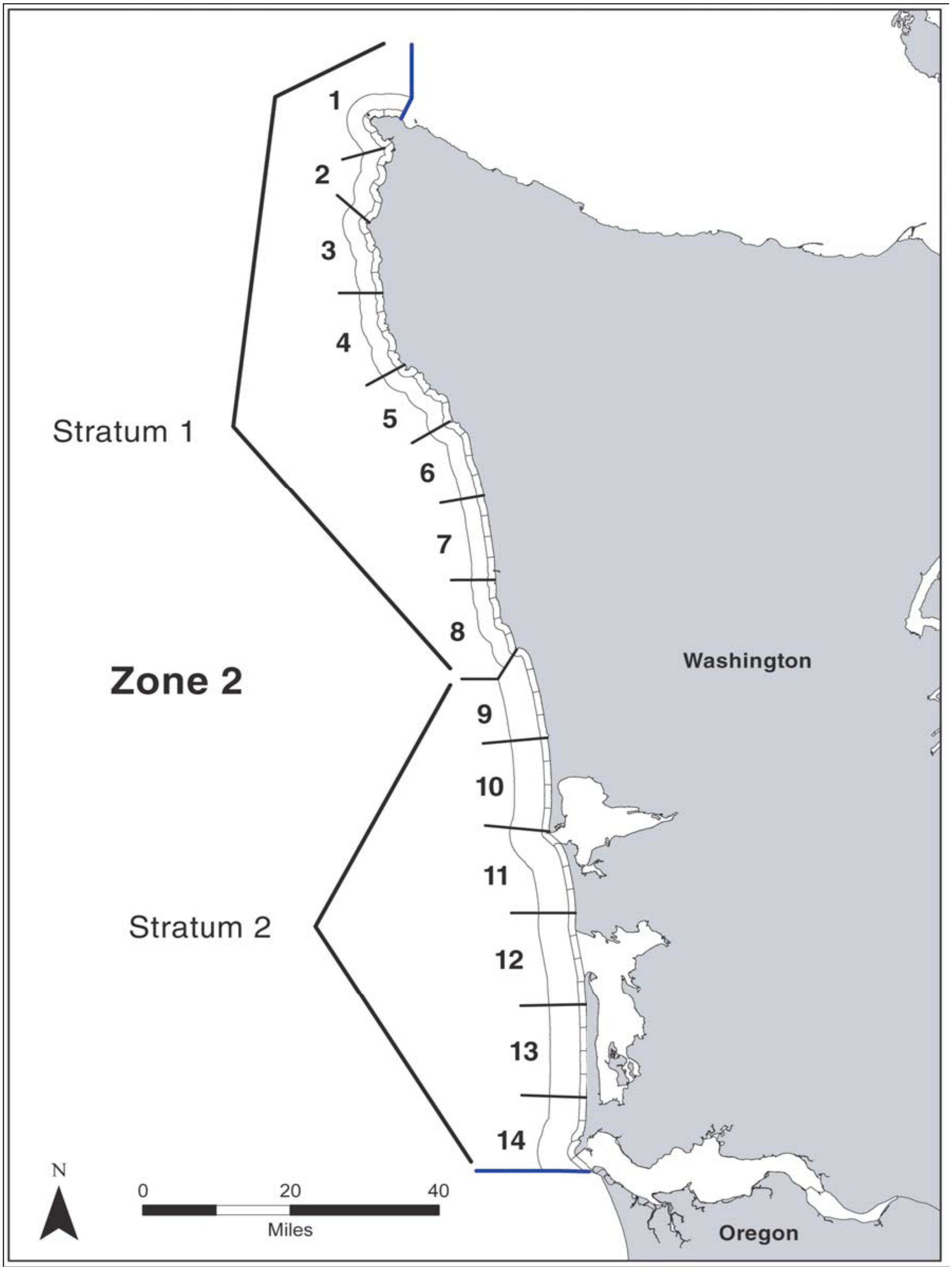


Figure 2-7. Marbled Murrelet Conservation Zone Two and the Two Primary Sampling Units Used to Estimate Population Size for the Northwest Forest Plan Effectiveness Monitoring Program (Figure from Miller et al. 2006).

predict population changes. The modeling effort used a combination of adult survival data derived from mark-recapture studies in British Columbia, estimates of productivity (nest success) from telemetry studies, and date-adjusted ratios of juveniles to after-hatch-year birds from at-sea surveys. Populations in all conservation zones were estimated to be in decline with annual rates of decline per decade (40 year period) ranging from 2.1 to 6.2% (McShane et. al. 2004). Annual percent rate of population decline (assuming a 2% annual immigration rate) for conservation Zones One and Two in the first decade were 3.4% and 3.0% respectively. In a study on the Olympic Peninsula using radar counts of marbled murrelets flying inland during the breeding seasons from 1996-2004, no significant differences were detected in counts between years (Cooper et al. 2006). However, the authors concluded that their power to detect a two to four percent decline in the population was low and the study would have to be extended 15 and 11 years, respectively, to detect these smaller declines.

Peery et al. (2006a) found that the marbled murrelet population in central California was likely a sink population stabilized only through immigration from northern populations. This finding was based on a model that took into account immigration, birth rates and mortality rates within the population. Sources and sinks must be considered in the broader landscape context. Pulliam (1988) defines a source habitat as a location within a larger metapopulation where births are greater than deaths and emigration is greater than immigration and a sink habitat or location as a location where births are fewer than deaths and emigration is less than immigration. These results reveal the need to view all demographic components of a larger metapopulation when assessing local population parameters or habitat carrying capacity.

A number of past surveys indicate that marbled murrelets are widely distributed in Washington. Speich and Wahl (1995) conducted surveys by small boat during the 1978 and 1979 breeding season in northern Puget Sound (including the San Juan Islands and southern Georgia Strait) and reported densities not greater than 1.1 birds/mile^2 (0.43 birds/kilometer^2) in any section. Varoujean and Williams (1995), using aerial surveys, estimated the densities of marbled murrelets along the Washington coast in September 1993. They found densities of marbled murrelets to be substantially lower (0.8 to 2.3 birds/mile^2 [0.3 to 0.9 birds/kilometer^2]) from the Columbia River to Destruction Island when compared to the Destruction Island to Cape Flattery region (13.1 to 23.6 birds/mile^2 [5.1 to 9.2 birds/kilometer^2]). Densities along the southern border of the Strait of Juan de Fuca ranged from 2.3 to 20.8 birds/mile^2 (0.9 to 8.1 birds/kilometer^2) (Varoujean and Williams 1995).

2.7 Habitat Loss and Fragmentation

USFWS recognized habitat loss as the major factor causing the decline of marbled murrelet populations in its listing decision (Volume 57, page 45328 of the *Federal Register*, October 1, 1992). Threats associated with loss of nesting habitat include the following (Divoky and Horton 1995):

- A decrease in the proportion of the population that is able to reproduce due to reduced nest site availability.
- A decrease in the population's reproductive rate because of the inability of displaced adult breeders to locate new nest sites after their previous sites have been destroyed.
- Fragmentation of existing habitat, which increases nest site predation, deleteriously alters nest site microclimates and isolates portions of the population, leading to increased vulnerability to genetic and environmental changes.

Raphael et al. (2002b) suggested that the reduced amount of nesting habitat would likely have long-term negative impacts on nest success and short-term impacts on nest location (displaced birds might move elsewhere, nest in marginal habitat or all move to remaining patches), both of which would ultimately reduce population size. Marbled murrelets are thought to exhibit fidelity to forest stands. However, the short-term consequences of habitat loss are not well known (Nelson 1997). As a result, birds returning to newly logged areas might not breed for several years or until they have found suitable nesting habitat elsewhere (Burger 2002). Meyer et al. (2002) noted a time lag of a few years before marbled murrelets abandoned fragmented forests, providing evidence for the negative response to fragmentation.

Five independent radar studies from British Columbia and one from the Olympic Peninsula, Washington, reported significant correlations between the numbers of marbled murrelets entering watersheds and existing areas of suitable habitat (Schroeder et al. 1999, Burger 2001, 2002, Raphael et al. 2002a, Raphael et al. 2002b, Steventon and Holmes 2002, Burger et al. 2004). Radar counts from these studies show strong positive correlations with the amount of nesting habitat available at the drainage scale (Raphael 2006). Burger (2001) showed reduced populations in watersheds subjected to intensive logging and concluded that marbled murrelets did not nest in higher densities within remaining old forest stands. In addition to amounts of available nesting habitat, Burger et al. (2004) found distance to foraging grounds to be a significant covariate for all mainland British Columbia marbled murrelet populations, but not for west Vancouver Island marbled murrelets. These data suggest that watershed populations of marbled murrelets are directly proportional to the areas of nesting habitat available. The strong correlation between the total amount of habitat and the size of adjacent marbled murrelet populations for large segments of the marbled murrelet range is shown in Figure 2-8 (Raphael 2006).

Over the three-state marbled murrelet range (Washington, Oregon and California), estimated losses from 1994 to 2003 total 29,700 acres (12,000 hectares) of high-quality nesting habitat on federal lands (Raphael 2006, Raphael et al. 2006). As noted by Raphael (2006), marbled murrelet habitat losses from timber harvest totaled 2,700 acres (1,100 hectares), 74% outside of reserves,

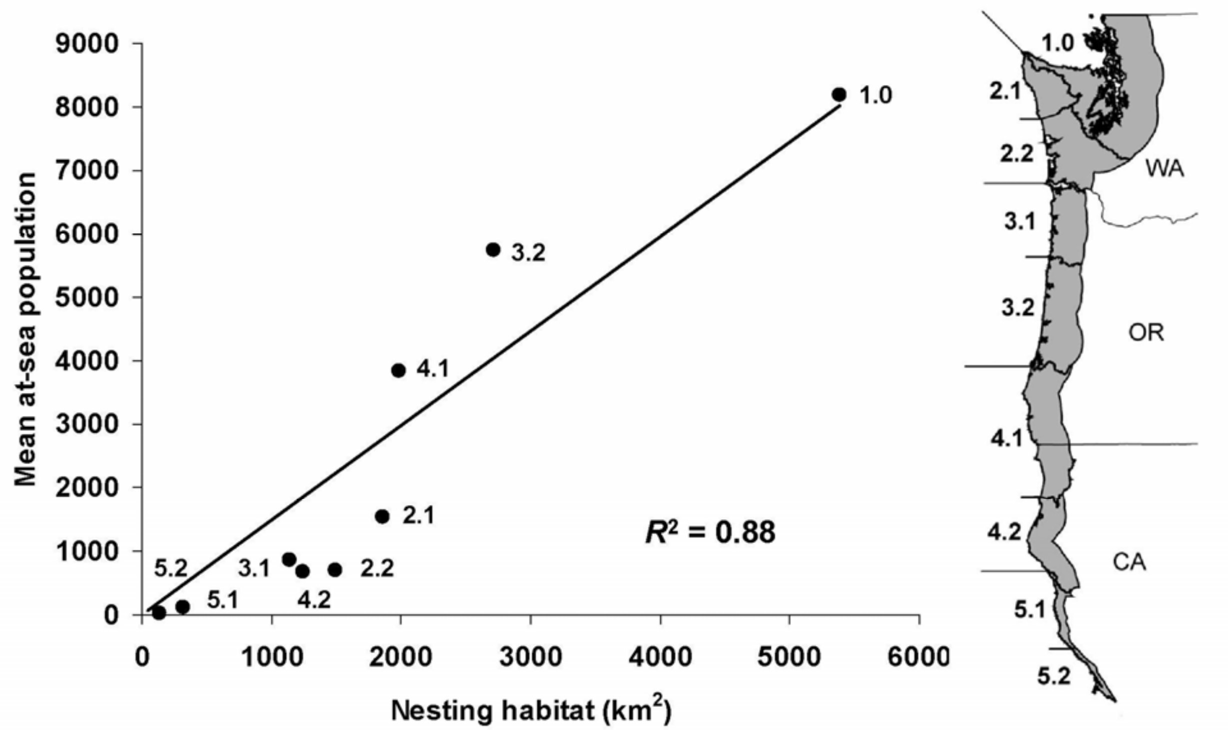


Figure 2-8. Relationship of Estimated Mean At-Sea Marbled Murrelet Population Size with Adjacent Potential Marbled Murrelet Nesting Habitat within the Conservation Zones, with Segment Numbers Denoting Conservation Zones and Segments within Zones (Figure from Raphael 2006).

while losses from fire and other stand-replacing events totaled 26,900 acres (10,900 hectares), with 93% in reserves (most of the fire losses were from the Biscuit Fire). Total marbled murrelet habitat losses represented 1.5% of nesting habitat on federal land over 10 years (Raphael 2006). Raphael et al. (2006) estimated that more than 248,800 acres (100,700 hectares), about 12%, of higher-suitability nesting habitat on non-federal lands have been lost because of timber harvest on these lands from 1994 to 2003 in these three states.

A dramatic decline in logging of older forests in the three-state area has occurred at the federal level since the adoption of the Northwest Forest Plan and the signing of the *Record of Decision for Amendments to Forest Service and Bureau of Land Management Planning Documents within the Range of the Northern Spotted Owl* (USDA and USDI 1994). From the peak annual extraction rate of 1.8 billion board feet of federal timber harvested in 1968, harvest on U.S. Forest Service lands dropped 96% to only 72 million board feet in 2002 (DNR 2004a) (Figure 2-9). The most drastic decline in the harvest of federal timber occurred between 1988 and 1994 (Figure 2-10).

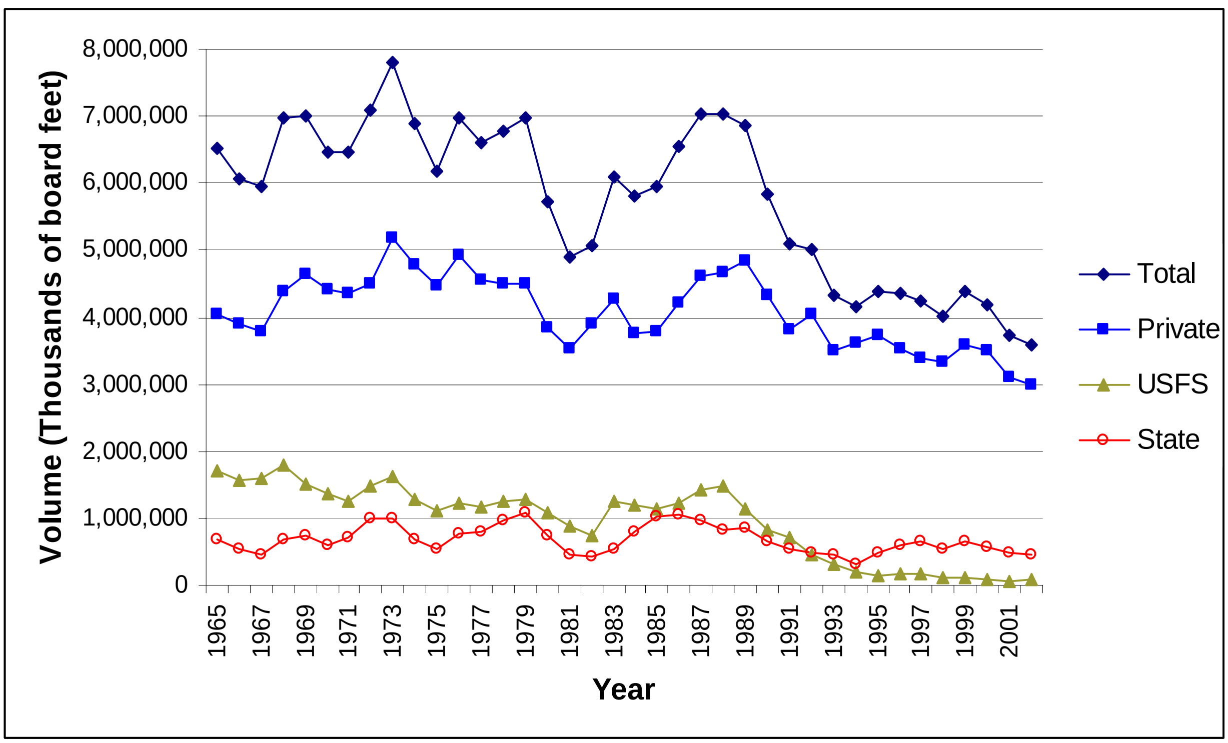


Figure 2-9. Recent Trends in Washington Timber Harvests on Public and Private Lands (DNR 2004a).

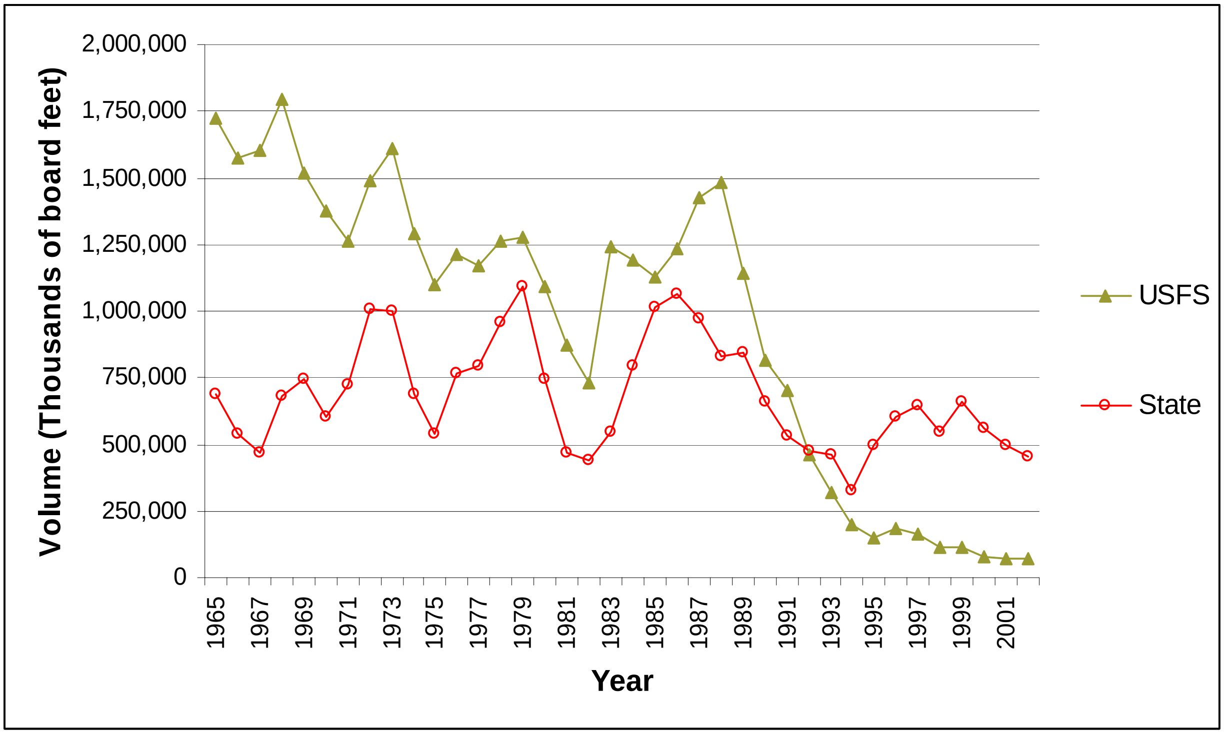


Figure 2-10. Recent Trends in Washington Timber Harvests on Public Lands (DNR 2004a).

Old-growth forests in Washington, Oregon, California, and some areas of British Columbia have been reduced by over 80% from historic levels (USFWS 1997, Burger 2002), leaving small, isolated stands of older trees for nesting marbled murrelets (McShane et al. 2004). The magnitude of habitat fragmentation and effects of creation of forest edges by clearcut logging on marbled murrelets are unclear, and field data are somewhat contradictory (Burger 2002).

2.7a Microclimate Edge Effects

Forest fragmentation results in abiotic changes to forest structure which affects nest site suitability (Malt and Lank 2007). Chen et al. (1993, 1995) found fragmented stands and forest edge areas to have higher winds, increased solar radiation, and lower humidity than contiguous mature and old-growth forests. Malt and Lank (2007) found that sites at timber harvest edge (both clearcuts and regenerating forests) had lower moss abundance than interior sites and natural edge sites (stream corridors and avalanche chutes) due to stronger winds, higher temperature variability and lower moisture retention when compared with interior sites. Burger (2002) found that marbled murrelets are more likely to select suitable nest trees and stands with high rates of lichen and bryophyte growth. These findings show that effects of forest fragmentation may be more complicated and lasting than previously thought.

2.7b Nest Success

Nelson and Hamer (1995b) studied the success of nests with respect to forest edge and found that successful nests were appreciably farther from forest edges than failed nests. Manley and Nelson (1999) came to similar findings for 58 nests from British Columbia, Washington, Oregon, and California. The success of nests within 164 feet (50 meters) of a forest edge was 38% (n=29) and for those greater than 164 feet (50 meters) from an edge success was 55% (n=29), but the difference was not statistically significant. Predation rates were higher within 164 feet (50 meters) of the forest edge and predation was responsible for the failure of 60% of all active nests. Although not statistically significant, there was evidence to suggest that successful nests occurred in larger stands (Manley and Nelson 1999).

Bradley (2002) conducted two analyses on the success of nests found by telemetry in Desolation Sound, southwest British Columbia, relative to forest edges. The first analysis related nest success at 37 nests to distances from forest edge (164 feet [50 meters] and 328 feet [100 meters]) and found no significant differences in nest success relative to forest edge. The second analysis was conducted using 98 nests and compared nest success to nests located near natural versus artificial edges, and interior sites. Bradley (2002) found that nests near natural edges had significantly higher rates of nest success than interior nests, however no significant differences between nest success at artificial edge and interior sites or artificial and natural edge sites were determined.

Zharikov et al. (2006) analyzed landscape-level habitat associations and breeding success for two sets of marbled murrelet nests at two climatologically similar sites in southwest British Columbia, which differed substantially in historic levels of logging activity and forest fragmentation. Their controversial results show that nesting marbled murrelets did not select disproportionately large fragments of old-growth forest in a landscape, but either showed no selection at all or preferred smaller stands of forest relative to what was available. However, as suggested by the multivariate analyses, it is not the size of a forest fragment that is important to a nesting marbled murrelet, but the proximity of a nesting site (tree) to an abrupt natural or artificial edge. Edges created by streams appear to be particularly important, as they are associated with preferred nesting substrate conditions and provide flight access routes to nests (Burger 2002). Burger and Page (2007) note many discrepancies in this research, specifically regarding the conclusion made by Zharikov et al. (2006) that marbled murrelets prefer smaller patch sizes 25 acres (10 hectares) versus larger habitat patches up to 494 acres (200 hectares). Burger and Page (2007) caution that this is a misleading conclusion, and should not draw forest managers to change their management plans in mitigating for marbled murrelet nesting habitat.

2.7c Predation Threats

Malt and Lank (2007) analyzed edge effects of forest fragmentation on predation rates at Nimkish Valley and Desolation Sound in southwest British Columbia. Malt and Lank's (2007) study compared predation at interior forest stands and three types of forest edge: lands adjacent to clearcuts, lands adjacent to regenerating forests, and lands adjacent to natural edges such as stream corridors or avalanche chutes. Using artificial marbled murrelet nest eggs and fledglings, Malt and Lank (2007) found that predation rates were the highest at edge sites adjacent to clearcuts and low at all other remaining sites, suggesting that predation rates may decline at forest edges as adjacent clearcuts regenerate over time. They found no difference in predation rates between natural forest edges, and interior sites.

McShane et al. (2004) summarized general patterns that have emerged from research results on predation risk relative to fragmentation and forest edges:

- Higher nest predation in areas with high predator densities.
- Increased abundance or diversity of predators with increasing habitat variety and complexity.
- Increased abundance of some corvid species (jays, crows, ravens, etc.) along edges or in forest fragments near human activities.
- High nest predation by corvids along edges near human activities or in areas of low forest cover.
- High predation risk by small mammals in a variety of habitats, including interior forests and along human-created edges.

Marbled murrelets are highly vulnerable to nest site predation. By far, the greatest threat to marbled murrelets from forest fragmentation is increased levels of nest site predation associated with forest edges (USFWS 1997). Based on a compilation of surveys by Nelson and Hamer (1995b), 72% of nests (n=32) with known outcomes failed. Fifty-six percent of these failures resulted from predation. In a study of marbled murrelets in central California, Peery (2004) determined a failure rate of 84% (n=19) with predation causing nest failure at 67 to 84% of failed nests. Most active marbled murrelet nests that have been detected and monitored have failed; most failures appear to be the result of predation (Nelson and Hamer 1995b, Hamer and Meekins 1999, Manley and Nelson 1999, Bradley 2002, Nelson and Wilson 2002, Hebert and Golightly 2003, Manley 2003, Peery 2004). Predation has consistently been the most significant cause of nest failure, with corvids being the primary predator (Nelson and Hamer 1995b, Raphael et al. 2002b).

Corvids were the primary predator of active marbled murrelet nests (Raphael et al. 2002b) and corvids and squirrels were the key predators at artificial nests (Nelson and Hamer 1995b, reviewed in Raphael et al. 2002b, Malt and Lank 2007). Forest fragmentation, as well as urbanization and agriculture have resulted in dramatic population growth of several corvid species in the west (Marzluff et al. 1994). Corvid populations will likely continue to increase with increased urbanization and the creation of new clearcuts that support berry-producing plants (Marzluff and Restani 1999).

Common ravens and Steller's jays (*Cyanocitta stelleri*) are known egg and chick predators, while sharp-shinned hawks have also been found to take chicks. Suspected predators at nest sites include great horned owls (*Bubo virginianus*), barred owls (*Strix varia*), Cooper's hawks (*Accipiter cooperii*), northwestern crows (*Corvus caurinus*), American crows (*Corvus brachyrhynchos*), gray jays (*Perisoreus canadensis*), peregrine falcons, northern goshawks, sharp-shinned hawks and red-shouldered hawks (*Buteo lineatus*) (Nelson and Hamer 1995b, Nelson 1997, Manley 1999, Raphael et al. 2002b, Vigallon and Marzluff 2005).

Multiple artificial nest studies in Oregon and Washington documented that the risk of predation by jays increased with jay abundance (Luginbuhl et al. 2001, Vigallon and Marzluff 2005). Luginbuhl et al. (2001) found that the rate of artificial nest predation in contiguous and complex mature and old-growth forest landscapes was directly correlated to corvid abundance. Although corvids in general are successful at preying on marbled murrelet chicks and eggs, only common ravens are known to be capable of flushing brooding or incubating adults from nests (Nelson and Hamer 1995b, Singer et al. 1991, Suddjian 2003).

Predation by mammals at marbled murrelet nests has only recently been documented, and is thought to be a significant cause of nest failure (Nelson and Hamer 1995b, Nelson 1997, Manley and Nelson 1999, Burger 2002, Malt and Lank 2007). The first documented case of predation on a marbled murrelet nest egg by a Douglas squirrel (*Tamiasciurus douglasii*) was made by Bloxton and Raphael (2006). In Pacific Northwest conifer forests, several small mammal species are known to visit tree canopies (Bradley and Marzluff 2003). Experimental studies in Washington and Oregon provide strong evidence for mammalian predation of marbled murrelet eggs and nestlings (Marzluff et al. 1999, Marzluff et al. 2000, Luginbuhl et al. 2001, Raphael et al. 2002b, Bradley and Marzluff 2003). In experimental studies involving artificial nest eggs and pigeon nestlings, the following mammals have all made documented attacks: northern flying squirrel (*Glaucomys sabrinus*), Douglas squirrel, red squirrel (*Tamiasciurus hudsonicus*), deer mice (*Peromyscus maniculatus* and *P. keeni*), bushy-tailed woodrat (*Neotoma cinerea*), and an unidentified mustellid (Marzluff et al. 1999, Flaherty et al. 2000, Luginbuhl et al. 2001, Bradley and Marzluff 2003, Malt and Lank 2007).

A study by Flaherty et al. (2000) concluded that northern flying squirrels are unlikely to be able to break into marbled murrelet eggs, suggesting that both mouth gape and egg shell thickness could limit egg predation. In a southwestern British Columbia study using artificial eggs and nestlings and real marbled murrelet nests, Malt and Lank (2007) found Douglas squirrel (native to Washington State) and red squirrel (not found in the marbled murrelet's habitat range in Washington) predation rates to be higher at all types of forest edge (including natural edges) than interior sites. Malt and Lank's study (2007) found squirrels more likely to attack nest eggs than nestlings.

With the exception of Malt and Lank's study (2007), artificial nest studies showed corvids to be the primary predators on eggs, whereas mammals, given their olfaction, were more adept than corvids at depredating simulated nestlings.

2.8 Conclusion

Habitat loss is the primary cause for decline in marbled murrelets, with habitat fragmentation causing increased rates of predation and changes in microhabitat quality in remaining habitat. Marbled murrelets also face predation while at sea, and have been adversely affected by oil spills and entanglement in gill nets. Demographic analyses indicate that marbled murrelet populations in Washington State are likely in decline. . The unique aspects of marbled murrelet biology and threats to population viability outlined in this chapter will be taken into consideration in the design of the Long-Term Conservation Strategy (LTCS). Modeling exercises and population monitoring results will be used to test the effectiveness of the LTCS in preserving habitat and stabilizing marbled murrelet populations in Washington State.

This page intentionally left blank.

3.0 RECOMMENDED LANDSCAPE CONSERVATION APPROACH

I. INTRODUCTION

This chapter provides the Science Team's conservation recommendations which the Washington State Department of Natural Resources (DNR) will use to inform the development of a Long-Term Conservation Strategy (LTCS) for the marbled murrelet in the South Coast, Columbia, Straits, and Olympic Experimental State Forest (OESF) Habitat Conservation Plan (HCP) Planning Units.

II. DNR MANAGEMENT GUIDANCE

DNR management tasked the Science Team with developing recommendations that would provide the foundation for a credible, science-based LTCS that would meet DNR's obligations under the HCP. This task does not address DNR's fiduciary responsibility to the trusts. The Science Team developed the conservation recommendations without consideration for DNR's fiduciary responsibility to the trusts, with the exception of special considerations for Wahkiakum and Pacific Counties. The Science Team received special guidance from DNR management for Wahkiakum and Pacific Counties, as they rely primarily on revenue generated from DNR-managed trust lands for their operations budget (Daniels 2004). A special effort was made to recommend marbled murrelet conservation measures that reflect DNR's responsibility to consider potential revenue impacts to those two smaller trust beneficiaries. The financial analyses and impacts will be addressed for all DNR-managed lands in part through DNR's analysis of alternatives in the environmental impact statement (EIS) process.

The Science Team was not asked to review DNR's policies and procedures in the development of their recommendations. They were provided existing HCP conservation commitments (e.g., OESF HCP conservation objectives, northern spotted owl conservation strategy, riparian conservation strategy, and the conservation strategy for unstable slopes) to understand and evaluate existing conservation as described in the HCP, as it might contribute to marbled murrelet conservation.

III. CONSERVATION OBJECTIVES

The U.S. Fish and Wildlife Service's (USFWS) *Recovery Plan for the Threatened Marbled Murrelet* (*Brachyramphus marmoratus*) *in Washington, Oregon, and California* (USFWS 1997) described two principal strategic goals for marbled murrelet recovery:

1. "to stabilize and then increase population size, changing the current downward trend to an upward (improving) trend throughout the listing range" and
2. "to provide conditions in the future that allow for a reasonable likelihood of continued existence of viable populations" (p. 112).

These goals are consistent with widely recognized principles of conservation biology and were intended to provide conditions that enable the species to persist through chronic and catastrophic events. DNR defined its goal in the HCP to contribute to the USFWS recovery objectives and "*…make a significant contribution to maintaining and protecting marbled murrelet populations in western Washington over the life of the HCP"* (DNR 1997a. p. IV.44). The Science Team used USFWS's (1997) two recovery principles and adopted biological goals that reflect those principles at a scale appropriate to the abundance and distribution of DNR-managed forestlands in Washington. The Science Team recommends that DNR manage forest habitat to contribute to the following three biological goals: a stable or increasing population, an increasing geographic distribution, and thus a population that is resilient to disturbances. Because DNR manages forestland and not wildlife, DNR is able to contribute to the USFWS recovery plan and population goals for the marbled murrelet through the maintenance and creation of nesting habitat.

The marbled murrelet was listed because its numbers in Washington, Oregon, and California were declining, primarily due to the loss of older forest habitat (USFWS 1997). USFWS hypothesized the following mechanisms, which are not mutually exclusive, by which the condition of nesting habitat threatened this population:

1. Timber harvest has reduced the amount of nesting habitat in older forests, thus decreasing the proportion of the population that is able to find nest sites.
2. Nests in old forests fragmented by logging are subject to deleterious edge effects, especially predation, that reduce their success rate.

3. The diminished availability of prime nesting habitat forces marbled murrelets to nest in lower-quality habitat, which diminishes nest success.

4. Nesting marbled murrelets pack into the diminished amounts of habitat at higher densities, thus encouraging area-restricted searching by predators, which further reduces nest success.

Subsequent research on predator behavior (e.g., Vigallon and Marzluff 2005) and marbled murrelet nesting density (e.g., Burger 2002, Raphael et al. 2002a) suggests that packing and consequent increased predation are less likely to be major factors contributing to diminished fecundity. However, the first three hypotheses remain to provide significant guidance to efforts for conservation of the marbled murrelet throughout its range.

The Science Team's conservation objectives set the foundation for the following recommendations and analyses developed by the Science Team. The objectives of the analyses applied to the Science Team's recommendations are to:

1. Present objective, repeatable, quantitative comparisons of current and projected forest habitat for marbled murrelets on DNR-managed and other lands.

2. Illustrate potential marbled murrelet population responses to current and projected habitat using an index of carrying capacity.

This information will prove valuable for DNR and USFWS managers as they evaluate the overall effects of different management alternatives and their contributions to HCP conservation objectives for the marbled murrelet.

IV. POPULATION-BASED CONSERVATION APPROACH FOR DNR-MANAGED FORESTLANDS

The abundance and distribution of marbled murrelets and their potential inland habitat vary regionally within Washington, as do the distribution and relative abundance of DNR-managed lands. To determine the association between marbled murrelets and their habitat distribution on state forestland, DNR agreed to consider and develop marbled murrelet conservation plans unique to each of six ecologically-based HCP planning units (DNR 1997a), four of which are considered in this document (Figure 3-1):

1. Columbia

2. South Coast

3. Olympic Experimental State Forest (OESF)

4. Straits

Based on similar distribution and quantity of DNR-managed lands and the abundance of inland habitat and marbled murrelets, the Columbia and South Coast Planning Units (west of Interstate 5, south of the Olympic National Forest, and south of the Quinault Indian Reservation) were combined, and are referred to as the Southwest Washington (SWWA) Analysis Unit (see Figure 3-1). SWWA is the term used in the following conservation approach and model analyses sections of this report. Within SWWA, the Science Team focused conservation efforts on DNR-managed lands within approximately 40 miles of the Pacific Coast (see Figure 3-1). The OESF and Straits Planning Units (hereafter referred to as analysis units, see Table 3-3) have distinctive characteristics and retain separate identities. The geographic area north of SWWA and south of OESF is referred to as "Other Olympic Peninsula." It is approximately 450,000 acres (182,000 hectares), but contains less than 750 acres (304 hectares) of DNR-managed lands and only one occupied site (which the Science Team recommends be deferred from harvest consistent with its recommendations for all other known occupied sites). For this reason, it is not discussed further in this document.

The Science Team first considered regional context in their landscape-level approach to conservation planning for each of the HCP planning units (Figure 3-2, Table 3-1). The land and habitat base in the Straits Analysis Unit is dominated by the federally managed Olympic National Forest and Olympic National Park, with DNR-managed lands comprising only 10% of the entire analysis unit. The OESF Analysis Unit is similar but with somewhat fewer federal acres and more DNR-managed lands. In the Straits Analysis Unit, DNR-managed lands occur in a narrow, mid-elevation band between the ocean and the federal uplands, while they are distributed more broadly in the OESF, including the low-elevation coastal plain where federal lands are scarce. In the OESF and Straits Analysis Units, the fairly abundant existing marbled murrelet habitat is concentrated largely on federal lands, with habitat on DNR-managed lands occurring approximately in proportion to its abundance (Table 3-1). This contrasts sharply with the SWWA Analysis Unit, where there is little federal land or federally managed habitat. Although DNR-managed lands are relatively scarce, making up only 13% of the total area, they contain 28% of the currently existing habitat in the analysis unit (Table 3-1).

The Science Team reconciled issues regarding the implementation of the marbled murrelet Interim Conservation Strategy. The primary issues are outlined below.

1. The habitat relationship study predictive model (Prenzlow Escene 1999) did not identify all high-quality habitat (termed reclassified habitat) that was to be surveyed in the inventory surveys.
2. Pacific Seabird Group's (PSG) protocol for conducting inland surveys was revised by PSG annually. Because these revisions added to the number of visits required to correctly classify a site, earlier survey analyses were not as complete (see Appendix F).

The first issue was addressed by an inspection of color orthophotos (dated 2005 for OESF and 2003 for SWWA), and supplemented by limited field verification. During the orthophoto inspection, the delineation of occupied sites was evaluated, and the condition of marbled murrelet non-habitat, marginal habitat, and reclassified habitat was evaluated for all analysis units. Throughout the sections of this chapter pertaining to the OESF, the term "habitat" refers to reclassified habitat that has been adjusted with subtractions and additions based on the orthophoto inspection. The second issue was also addressed by the Science Team and is explained in Appendix F.

It is important to note that this report focuses solely on inland habitat and does not address climate change issues or ocean conditions. While it is recognized that the latter two factors exert a large influence on the life history of the marbled murrelet, DNR can only affect the terrestrial portion of the conservation objectives.

The breeding-season marine distribution and abundance of marbled murrelets on the Olympic Peninsula and in SWWA generally corresponds with the inland distribution of habitat. The majority of the marbled murrelet numbers from survey counts (Hull et al. 2001 [at-sea and inland surveys], Miller et al. 2006 [at-sea surveys]: approximately 90%) occur within 40 miles (64 kilometers, a reasonable commuting distance for nesting birds) of the Olympic Peninsula, while less than 10% of the offshore birds counted occur adjacent to SWWA (Miller et al. 2006). Additionally, more general range-wide assessments (USFWS 1997, McShane et al. 2004) identified SWWA as an area of low-density in the distribution of marbled murrelets and their inland habitat. Thus, SWWA is an important area for which to address the conservation goal of increasing the geographic distribution by increasing their inland nesting habitat (DNR 1997a).

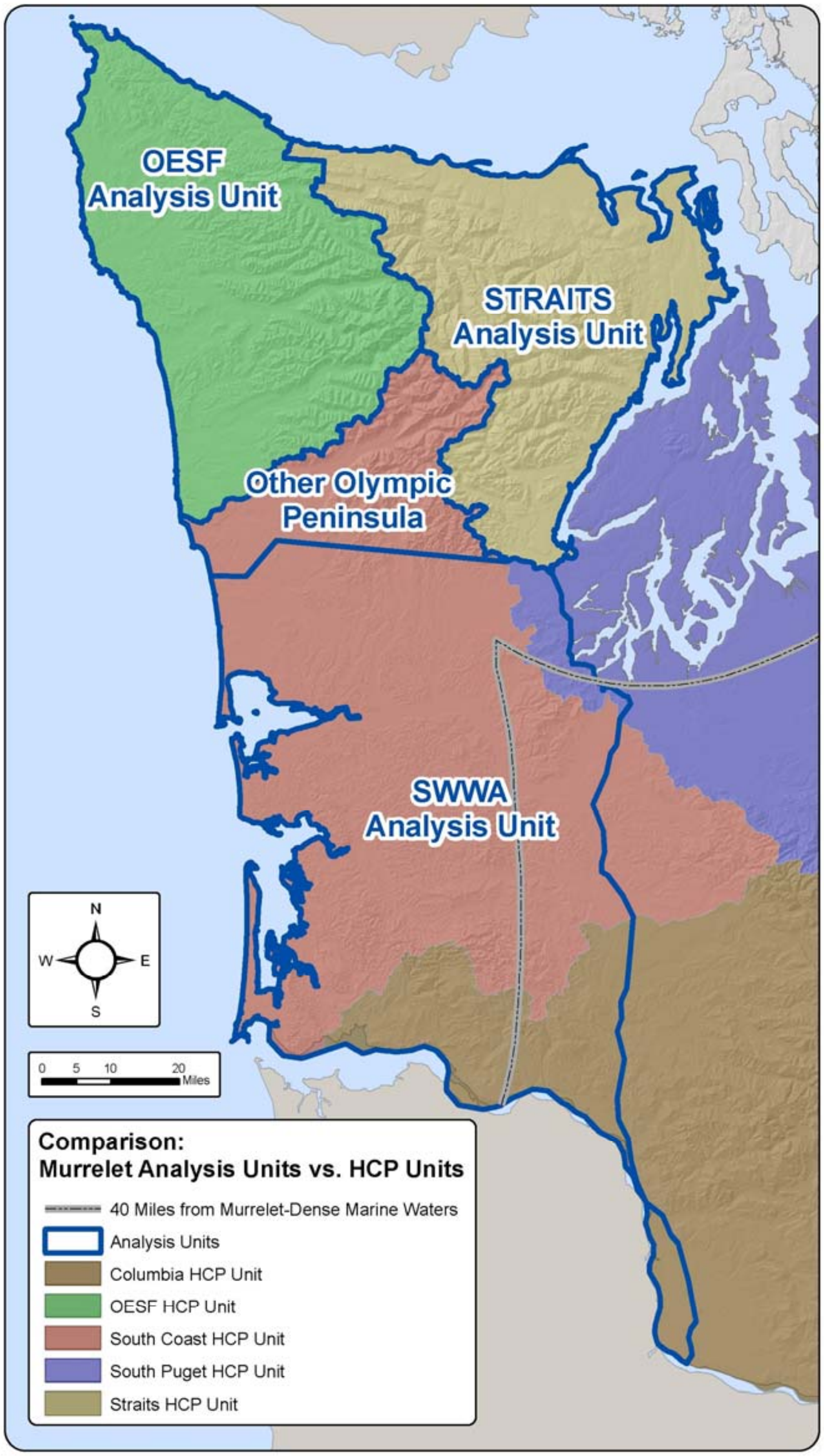


Figure 3-1. Planning Area Considered by the Science Team, Including Marbled Murrelet Analysis Units and DNR HCP Planning Units. Murrelet-Dense Marine Waters are Defined in Section 3.2b.

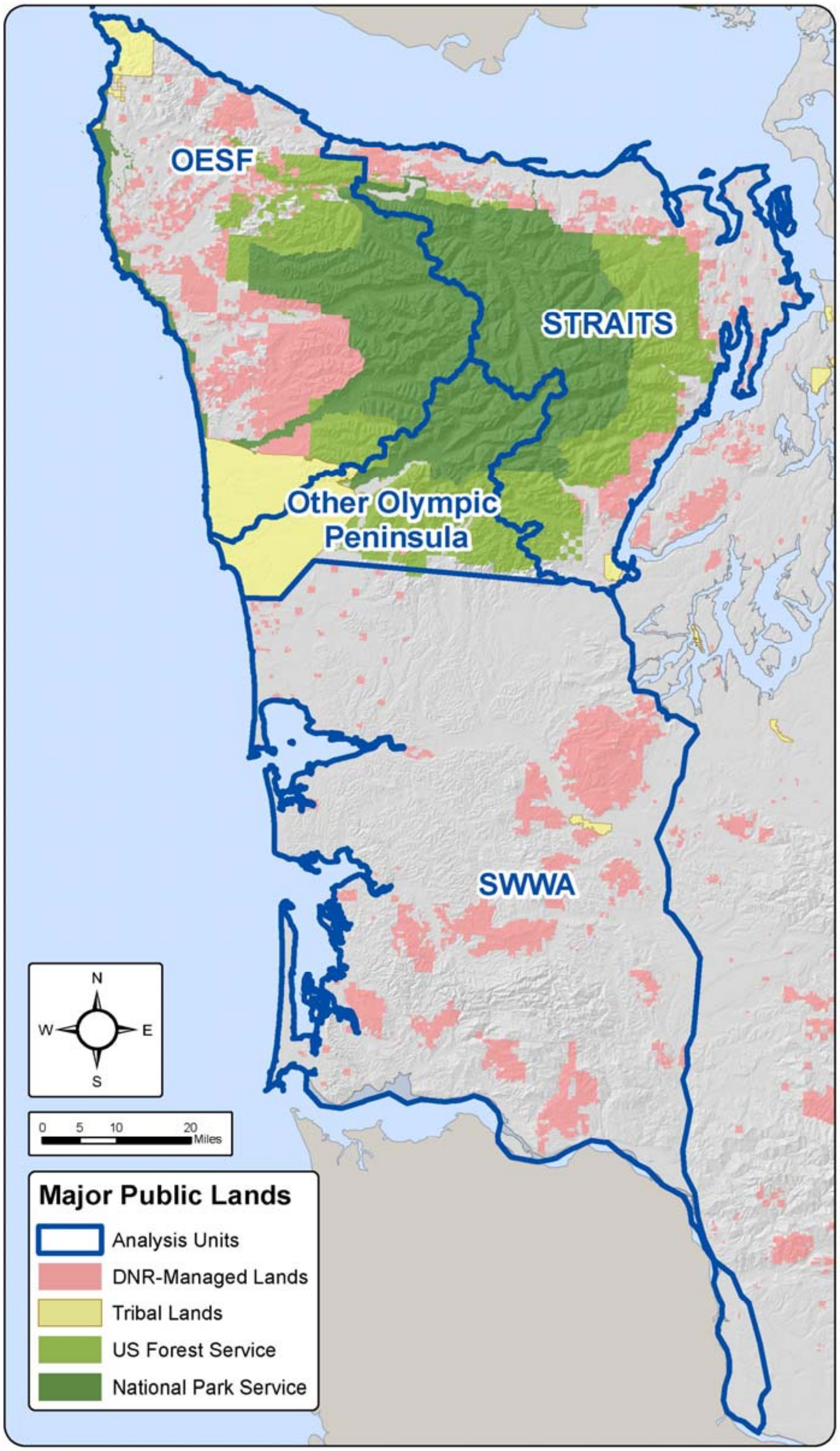


Figure 3-2. Major Public Lands in Each Analysis Unit within the Planning Area Considered by the Science Team.

Table 3-1. Abundance of Federally Managed and DNR-Managed Lands and Marbled Murrelet Forest Habitat in the Marbled Murrelet Analysis Units.

Geographic Area	Total			Federally Managed[1]				DNR-Managed			
	Area[2]	Habitat[2,3]	% of Total	Area[2]	% of Total	Habitat[2,3]	% of Total Habitat	Area[2]	% of Total	Habitat[2,3]	% of Total Habitat
SWWA	2,530	268	11	1.5	0	0.7	0	324	13	74	28
OESF	1,299	421	32	523	40	266	63	271	21	83	20
Straits	1,178	377	32	704	60	284	75	118	10	46	12
Olympic Peninsula[4]	2,932	948	32	1,530	52	675	71	389	13	129	14

[1] Includes lands managed by National Park Service and U.S. Forest Service. Lands managed by other federal agencies are not included.
[2] Thousands of acres.
[3] Habitat estimates are Biomapper estimates from Raphael et al. (2006) who used this program to build an Ecological Niche Factor Analysis Model (ENFA) of marbled murrelet habitat suitability. Model inputs were GIS-based rasters of ecogeographical variables (forest cover derived from satellite imagery, as well as topography, solar radiation, and distance to coastline) and species presence data. Habitat estimates are based on an ENFA habitat suitability index greater than 60.
[4] Entire Olympic Peninsula: OESF, Straits, plus Other Olympic Peninsula (see Figure 3-2).
Note: analysis unit and ownership areas are from DNR's GIS data (July 20, 2005). Percentages do not sum to 100 because tribal lands, privately managed lands, and some federally managed lands are not included.

The differences in current habitat and federal land distribution led to three specific strategic approaches to marbled murrelet conservation that acknowledged how conservation efforts in each analysis unit could help achieve objectives for population stability or increasing size, distribution, and resilience.

- In SWWA, DNR-managed lands contain 28% of the existing inland habitat base for a depressed marbled murrelet population (Table 3-1). Substantial habitat restoration across much of the DNR-managed land base is central to achieving conservation objectives (chapter 4.0, USFWS 1997, McShane et al. 2004).
- In the OESF, where DNR-managed lands in the low-elevation Sitka spruce zone have the potential to increase the number of forest types occupied by marbled murrelets, explicit efforts at habitat restoration through active silviculture in distinct DNR-managed areas are a key component of the recommended conservation approach.
- In the Straits, where DNR-managed lands contribute less to the land and habitat base, a relatively minimal approach is appropriate—occupied sites identified during comprehensive inland surveys were mapped and designated for conservation management.

The landscape-level conservation approach, methodology, and rationale are presented in the above sequence in sections 3.2, 3.3 and 3.4, respectively.

3.1 Land Designations for Habitat Conservation

The Science Team recommends the employment of three basic management approaches to creating and maintaining habitat in the three analysis units (SWWA, OESF and Straits).

In areas where potential and known marbled murrelet nesting habitat is well developed and needs to simply be retained on the landscape in support of the stated biological goals, the Science Team proposes deferral of those lands from harvest for the life of the conservation strategy. These include all currently known occupied sites and old forest stands in the OESF (Table 3-2). The Science Team is not recommending a survey and manage approach to identify additional occupied sites once the LTCS is completed.

Areas of the landscape that have the ability to provide future potential nesting habitat have been identified and proposed to be actively managed as marbled murrelet management areas (MMMAs). Some proportion or all of DNR-managed lands within their boundaries (depending on the analysis unit) would have as their management goal high-quality nesting habitat (Table 3-2).

Marbled murrelet nesting habitat is defined as large trees with sizeable nesting platforms supporting high levels of moss, and generally occurring in old-growth forests with low amounts of edge (Nelson et al. 2006). Based on current data and knowledge, there is no explicit way to identify these features on DNR-managed lands. For the purposes of this report, forest stand development stages (Brodie et al. 2004, see also Appendix B) are used as a surrogate measure for nesting habitat. Under this classification system, the more complex, older stages—Large Tree Exclusion, Understory Development, Botanically Diverse, Niche Diversification, and Fully Functional—are classified as "potential marbled murrelet habitat."

It is envisioned that active management techniques will be applied to accelerate the development of non-habitat to stimulate the development of suitable marbled murrelet habitat where silviculturally appropriate. This aspect of the Science Team's conservation approach was developed to emphasize marbled murrelet conservation in a geographic area where it could be most effective in meeting the biological goals and gaining the largest benefit for marbled murrelet habitat conservation. The Science Team recommends deferral of all known occupied marbled murrelet sites located inside proposed MMMAs.

In some cases, the Science Team has recommended moderated forest management to complement deferred areas and habitat areas within MMMAs. In these areas, retention of forest structure around areas being recommended specifically for habitat creation and maintenance is proposed. These include areas not required for meeting habitat thresholds in MMMAs, and buffers around occupied sites and old forest.

Finally, the Science Team anticipates that other conservation strategies being implemented in fulfillment of the HCP on DNR-managed lands will complement the recommended marbled murrelet conservation measures. Conservation measures including the northern spotted owl strategy, riparian forest restoration strategy, and efforts to protect unstable landforms, to name a few, are expected to develop a matrix of complex forest structure on the landscape and support marbled murrelet biological goals. An assessment of these conservation strategies as to their expected contribution to marbled murrelet habitat is recommended.

Table 3-2. Definitions for Habitat Terms Used in this Document. Please Note that the Terms Defined in this Table Have a Very Specific Meaning Related to this Document and the Processes it Describes, and May Not Apply Beyond this Specific Context.

Habitat Term	**Definition**
Suitable Habitat	Identified by Step One of the Marbled Murrelet Interim Conservation Strategy (DNR 1997a, p. IV.39). Suitable habitat is defined as a contiguous forested area meeting all of the following three criteria: 1. At least five acres in size 2. Containing an average of at least two potential "nesting platforms" per acre. <u>Nesting platforms</u> are defined as any large limb or other structure, such as a mistletoe broom, at least 50 feet above ground and at least 7 inches in diameter. 3. Within 50 miles of marine waters. Distance is determined from the Pacific coast, from Puget Sound, or from Rice Island (located in the Columbia River upstream from the Astoria Bridge), whichever is closest to the site.
Reclassified Habitat	Identified by Step Two of the Marbled Murrelet Interim Conservation Strategy (DNR 1997a) through the use of a habitat relationship study predictive model (Prenzlow Escene 1999). Two classes of habitat were identified based on this model: 1. **Marginal habitat**: defined as those lands expected to contain a maximum of five percent of the occupied sites on DNR-managed lands within each planning unit. These areas were made available for harvest. All known occupied sites were deferred from harvest, and were not included in this habitat designation. 2. **High-quality habitat:** in contrast to marginal habitat, this is defined as those lands expected to contain at least 95% of the occupied sites on DNR-managed lands within each planning unit. This habitat is frequently referred to simply as "reclassified habitat."
Old Forest	The term "old forest habitat" is used in the HCP to help define northern spotted owl habitat in the conservation strategy for the OESF (DNR 1997a, p. IV.88). Old forest

Habitat Term	**Definition**
	habitat was identified in the OESF in fulfillment of that strategy, and was then used by the Science Team to help identify areas likely to provide nesting habitat and therefore make a contribution to marbled murrelet conservation.
Desired Future Forest Condition (DFFC)	A Desired Future Forest Condition (DFFC) is a visionary but incompletely defined end state (Holmberg et al. 2005). The Science Team described an initial DFFC for stand-level marbled murrelet habitat on DNR-managed lands as having very large, tall trees with broad, deep crowns that support potential nest platforms, in a stand with multiple canopy layers and canopy gaps. A DFFC is not a rigorously defined forest development stage, but rather a benchmark against which managers can measure progress toward a structurally complex forest that will have many of the minimal habitat elements to support successful marbled murrelet nesting. The DFFC was used to describe tree and stand-level characteristics employed by the Science Team to project the development of habitat through forest modeling.
Nesting Habitat	The Science Team means "nesting habitat" to reflect the best available information based on current scientific literature. The Science Team recognizes that as our understanding of nesting requirements of the marbled murrelet improves so will the best available definition of nesting habitat. The best available definition is detailed below. Nelson et al. (2006) define marbled murrelet nesting habitat at three spatial scales: 1. Tree-level: large trees (>19 inches dbh and >98 feet tall) with sizeable platforms (≥4 inches diameter and ≥33 feet above the ground) supporting extensive amounts of substrate (e.g., moss), >70% canopy closure, and some horizontal cover. 2. Stand-level: sections of forest with extensive amounts of large trees, platforms with epiphytes, old forest, structural complexity, and gaps in the canopy for nest site access. 3. Landscape-level: old growth with low amounts of edge.
High-Quality Nesting Habitat	The Science Team uses the term "high-quality nesting habitat" to denote nesting habitat that has the highest likelihood of supporting successfully reproductive marbled murrelets in a landscape. Such habitat is characterized by the Science Team as forest stands that 1) have very large, tall trees with broad, deep crowns that support potential nest platforms; 2) have multiple canopy layers and canopy gaps; and 3) are situated within a secure landscape that minimizes predation and allows for the successful fledging of young. The extent to which high-quality nesting habitat can be achieved in a given landscape over time will depend to a great extent on the potential of those forests and that land ownership pattern to achieve the above characteristics. The capability of landscapes with DNR-managed lands to create and maintain high-quality nesting habitat is not uniform. It is expected by the Science Team that high-quality nesting habitat will meet or exceed the characteristics of nesting habitat identified in Nelson et al. (2006).
Occupied Site	A "contiguous area of habitat" where at least one of the following marbled murrelet behaviors occur (Evans Mack et al. 2003): 1. A nest is located; 2. Downy chicks or eggs or egg shells are found; 3. Marbled murrelets are detected flying below, through, into or out of the forest canopy; 4. Birds are calling from a stationary location within the area; or 5. Birds are circling above a stand within one tree height of the top of the canopy. A contiguous area of habitat is a minimum 5 acre block of habitat, to a maximum of 1.5 miles from the "point-of-occupancy," but confined to contiguous habitat. Once a 5 acre area whose characteristics meet the criteria of habitat is identified, all adjoining acres that also contain such criteria would be included in the suitable habitat block until there is a 300-foot or wider "break" (an area that does not meet the criteria) that completely encircles the block (DNR 1997a, p. IV.41). A point of occupancy is the point location where behavior or conditions indicating occupancy occurred.

3.2 Conservation Approach for a Marbled Murrelet Long-Term Conservation Strategy in Southwest Washington

SWWA serves an important distributional role in the listed range of the marbled murrelet (USFWS 1997, McShane et al. 2004). This area, close to coastal waters, has very little forested federal ownership (Table 3-1); thus, non-federal forests are critical to marbled murrelet conservation. Among non-federal owners, habitat is disproportionately abundant on DNR-managed lands, which contain 28% of current habitat (Table 3-1). DNR-managed lands also account for most of the known occupied sites in SWWA (McShane et al. 2004, WDFW Wildlife Survey Observation Database). DNR-managed forestlands in this landscape provide a significant and vital opportunity for maintenance of local breeding populations and are crucial to meeting the above stated biological goals (see page 3-2).

Resilience is a property of populations that enables them to recover following disturbance (Holling 1973). Resilience results from characteristics of individuals and populations, such as abundance, stability, and distribution (Weaver et al. 1996). Marbled murrelet conservation on DNR-managed lands can contribute to a resilient population by increasing its size, stability, and geographic and ecological distribution such that it is more likely to persist in the face of disturbances such as changes in ocean conditions, oil spills, or catastrophic windthrow.

Within SWWA, ownership blocks were examined for their potential to contribute to the biological objectives (population stability, distribution, and resilience). A scorecard ranking exercise was used to achieve an objective, replicable means of identifying high-priority areas in which to invest DNR's efforts at marbled murrelet conservation.

3.2a The Scorecard

The Science Team used a scorecard to rank the potential conservation value of geographic land blocks (planning blocks, defined in Table 3-3) and to inform their proposals regarding the size and locations of MMMAs. The Science Team defined 20 metrics, including marbled murrelet detections, habitat data, and other ecological and topographic data deemed important to marbled murrelet conservation (see below). Values for the metrics were calculated relative to the maximum value for all blocks and rescaled to range from 0 to 10. Each metric was assigned a weight by the Science Team to reflect its overall importance in estimating potential conservation value. The sum of the 20 weighted category scores resulted in an overall score for each block.

Table 3-3. Definitions for Terms Used Throughout This Document to Delineate the Landscape.

Size	Term	Description	Valid for these Analysis Units
Larger	Planning Unit	"DNR-managed land units, grouped into three blocks for the purpose of implementing the HCP: the Olympic Experimental State Forest, five west-side planning units, and three east-side planning units. The nine planning units in the HCP area are: Olympic Experimental State Forest, South Coast, Columbia, Straits, North Puget, South Puget, Chelan, Yakima and Klickitat" (DNR 1997a, Glossary p. 11).	SWWA, OESF, Straits, and Other Olympic Peninsula
⋮	Analysis Unit	The term was created by the Science Team for the purpose of this report. The OESF and Straits Analysis Units match their planning unit boundaries, while SWWA is a combination of South Coast and Columbia Planning Units, truncated to the area west of Interstate 5, south of Olympic National Forest, and south of the Quinault Indian Reservation.	SWWA, OESF, Straits, and Other Olympic Peninsula
⋮	Landscape Planning Unit (LPU)	"Landscape-level planning units used by DNR's Olympic Region to identify 11 watershed-based units within the Olympic Experimental State Forest." (DNR 1997a, Glossary p. 7).	OESF
⋮	Planning Block	The term was created by the Science Team to group the SWWA Analysis Unit into smaller pieces based on existing blocks of DNR-managed lands.	SWWA
Smaller	Marbled Murrelet Management Area (MMMA)	The term was created by the Science Team for this report. MMMAs exist as subdivisions within LPUs and planning blocks to protect occupied sites and direct habitat development in areas that are not occupied.	SWWA, OESF

The Science Team used these overall scores to rank the potential conservation value of geographic blocks and to assist their decisions regarding the size and locations of MMMAs within these blocks.

3.2b Scorecard Metrics

The first four metrics (also referred to as Categories in Table 3-4) were derived from audio-visual, ground-based, inland surveys of marbled murrelets. These metrics are:

1. The number of marbled murrelet detections within a block divided by the number of survey visits within that block;
2. The total number of occupied detections, defined as one or more marbled murrelets observed exhibiting sub-canopy behavior (Evans Mack et al. 2003), within a block plus a 1-mile (1.6-kilometer) buffer around that block. Occupied detections were obtained from the WDFW Wildlife Survey Observation Database;

3. The percentage of all DNR survey sites in a block that were occupied (Evans Mack et al. 2003) during the years the DNR-led surveys were conducted; and

4. The percentage of all DNR survey sites in a block that had a status of occupancy or presence during the years the DNR-led surveys were conducted.

The next four metrics were derived from DNR's GIS cover of stand development stages (Brodie et al. 2004, Appendix B). The Science Team combined the eight stand development stages into four seral classes (Appendix B). Ecosystem Initiation and Sapling Exclusion stages were combined into an "early-seral" stage. Pole Exclusion was labeled "pole." Large Tree Exclusion, Understory Development, and Botanically Diverse were combined into a "mid-seral" stage. Niche Diversification, Fully Functional, and Old Growth Natural were combined into a "late-seral" stage. Stands labeled mid-seral were further characterized by their relative amount of western hemlock. These metrics are:

5. Acres of late-seral stands plus the acres of mid-seral stands in which western hemlock composes at least 30% of the total basal area;

6. The acres of core area of the stands defined by category five (Table 3-4) (core area was delineated by producing a 328-foot (100-meter) interior buffer of the area of stands of interest.);

7. Acres of late-seral stands plus the acres of mid-seral and pole stands in which western hemlock composes at least 30% of the total basal area; and

8. The acres of core area of the stands defined by category seven (Table 3-4).

The remaining 12 metrics represent:

9. The area-weighted average site index for a block (The site index was retrieved from DNR's Forest Resource Inventory System (FRIS) and is defined as an index of productivity for the stand determined using a sample of tree height and age.);

10. The percentage of the block biologically suited to the coastal western hemlock zone (differentiation between western hemlock and Douglas-fir zones is based on DNR District Management Unit and Local Management Unit boundaries [Bergvall and Sharma 1978]);

11. The acres of forest in a block that are currently deferred by DNR for marbled murrelets (The

current deferral includes reclassified habitat (see section 3.5), occupied survey sites, and additional areas in close proximity to occupied sites.);

12. The acres of core area of the stands defined by category 11 (Table 3-4) (The core area was delineated by producing a 328-foot (100-meter) interior buffer of the area of stands of interest.);
13. The acres in a block of high-quality marbled murrelet habitat defined by the U.S. Forest Service for marbled murrelet effectiveness monitoring from a model built using Interagency Vegetation Mapping Project (IVMP) data (http://www.blm.gov/or/gis/index.php);
14. The acres of forest core area defined by category 13 (Table 3-4) (The core area was delineated by producing a 328-foot (100-meter) interior buffer surrounding the stands of interest.);
15. The average distance in miles from any part of a block to marbled murrelet-dense marine waters (Miller et al. 2006) (Murrelet-dense marine waters were defined as marine waters with the following omissions: any part of the mouth of the Columbia River, all of Willapa Bay, all of Grays Harbor, Hood Canal south of the Duckabush River, and the rest of Puget Sound south of the southern tip of Whidbey Island.);
16. The acres of reserved lands in a block plus a 1.5-mile (2.4-kilometer) buffer around that block (Reserved lands managed by DNR were primarily Natural Area Preserves and Natural Resources Conservation Areas, but also included substantial acres of forests designated as inoperable. Many other designations, such as research plots and gene pool reserves also contributed to the reserved lands managed by DNR. Federal, state, county, and city lands were all designated as reserve lands unless the management type was listed as Unknown, Other, or Non Designated Forest (DNR 2004b).);
17. The percentage of a block that is within 0.93 miles (1.5 kilometers) of a paved road (This metric was chosen as an index to human influence and, thus, an indirect index to corvid abundance and predation of marbled murrelet nests.);

18 & 19. The percentage of a block and acres in a block, respectively, that are riparian buffer; areas with high-modeled probability of shallow, rapid landslides; or known landslide locations, including shallow-rapid, debris-flow, and deep-seated categories; and

20. The local biologists' average ranking of the blocks for their overall value to marbled murrelet conservation, with small numbers ranking higher than larger numbers.

Formulas for scoring the blocks are listed in Table 3-4. The overall scores, by geographic block (Figure 3-3), were sorted from highest to lowest, charted (Figure 3-4), and referred to by the Science Team throughout the development of the conservation recommendations.

Table 3-4. Scorecard Category Definitions, Formulas, and Weights.

Category	Definition	Formula[1]	Weight
1	Total Detections / Total Visits, DNR-led surveys only	10(value/max)	0.11
2	Total Occupied Detections, from WDFW, in block plus 1 mile buffer	10(value/max)	0.12
3	% Sites Occupied, DNR-led surveys only	percentage/10	0.03
4	% Sites with Occupancy or Presence, DNR-led surveys only	percentage/10	0.05
5	Current Habitat: Mid-Seral with >30% basal area Hemlock, or Late-Seral (acres)	10(value/max)	0.08
6	Core Area of Category Five; 328-foot interior buffer (acres)	10(value/max)	0.07
7	Future Habitat: Mid-Seral or Pole with >30% basal area Hemlock, or Late-Seral (acres)	10(value/max)	0.05
8	Core Area of Category Seven; 328-foot interior buffer (acres)	10(value/max)	0.05
9	Site Index, area-weighted average	10(value/max)	0.01
10	Western Hemlock Zone, % of block	percentage/10	0.05
11	Current Deferral by DNR for marbled murrelets (acres)	10(value/max)	0.03
12	Core Area of Category 11; 328-foot interior buffer (acres)	10(value/max)	0.02
13	IVMP High-Quality Habitat for marbled murrelets (acres)	10(value/max)	0.05
14	Core Area of Category 13; 328-foot interior buffer (acres)	10(value/max)	0.00
15	Distance to marbled murrelet-dense marine waters (miles)	10(1-(value/max))	0.08
16	Reserved Lands, all ownerships, in block plus 1.5 mile buffer (acres)	10(value/max)	0.04
17	Index to Corvid Abundance, 0.93 mile buffer of paved roads, % of block	(100-percentage)/10	0.07
18	Riparian Buffers + Unstable Slopes, % of block	percentage/10	0.05
19	Riparian Buffers + Unstable Slopes (acres)	10(value/max)	0.02
20	Local Biologists Ranking of Overall Value to Marbled Murrelet Conservation	10(1-(value/max))	0.03

[1] "Max" is the maximum value of the metric for all blocks.

3.2c Marbled Murrelet Management Areas in SWWA

Seventeen ownership blocks of DNR-managed lands were delineated by the Science Team and subsequently reviewed and edited by the local biologists (Figure 3-3). These ownership blocks (planning blocks) were delineated as logical groupings of DNR-managed lands.

Figure 3-4 is the chart of overall scores for SWWA. The overall scores ranged from 0.88 for the Lake Creek block to 8.41 for the Nemah block. The top five blocks down to Skamokawa were considered the highest priority. The second six blocks, including Humptulips through Pe Ell, were considered a secondary priority, except Capitol which contained no occupied sites and is not discussed in this report. The bottom six blocks from Lincoln to Lake Creek were considered the lowest priority, do not contain occupied sites, and therefore are not discussed in this report.

3.2d Delineation of Marbled Murrelet Management Areas

MMMAs in SWWA were delineated to retain all occupied sites; retain mature forest; block up, connect, and buffer mature forest; and reduce the negative effect of forest edge on nest success by considering the ratio of DNR-managed lands to privately managed, commercial forests. The purpose of retaining mature forest around occupied sites is to create core areas[1] of high-quality habitat. In addition to the large MMMAs, 13 isolated occupied sites were delineated for protection as MMMAs. The isolated occupied sites are areas where DNR-managed lands are small "islands" surrounded by non-DNR land (Salmon Creek, Browning, and Nemah) or are in areas of medium priority according to the scorecard (Humptulips and Lebam). The large MMMAs in SWWA, totaling 63,471 acres (25,686 hectares), along with 2,552 additional acres (1,033 hectares) of MMMAs from isolated occupied sites, are recommended to be managed to become 100% marbled murrelet high-quality nesting habitat. The Science Team delineated MMMAs in SWWA in an iterative process that:

- Used the scorecard exercise to help consider the relative importance of each planning block to the stated biological goals.
- Examined amounts and locations of past and current marbled murrelet activity.
- Reviewed amounts and locations of mature forest conditions.

[1] Core areas are defined as high-quality nesting habitat 170 acres (69 hectares) or larger and greater than 328 feet (100 meters) from an edge.

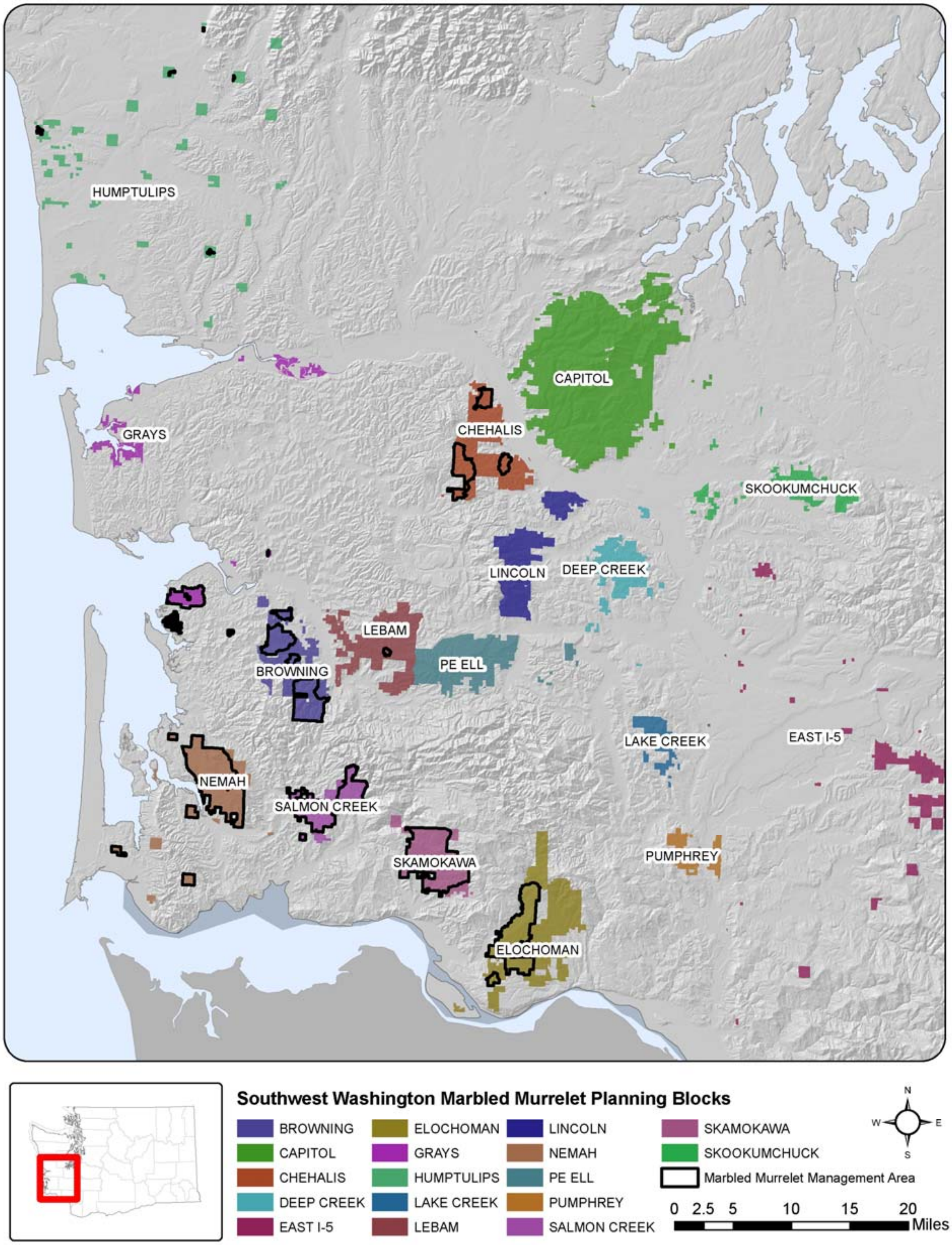


Figure 3-3. Geographic Planning Blocks for the Southwest Washington Analysis Unit.

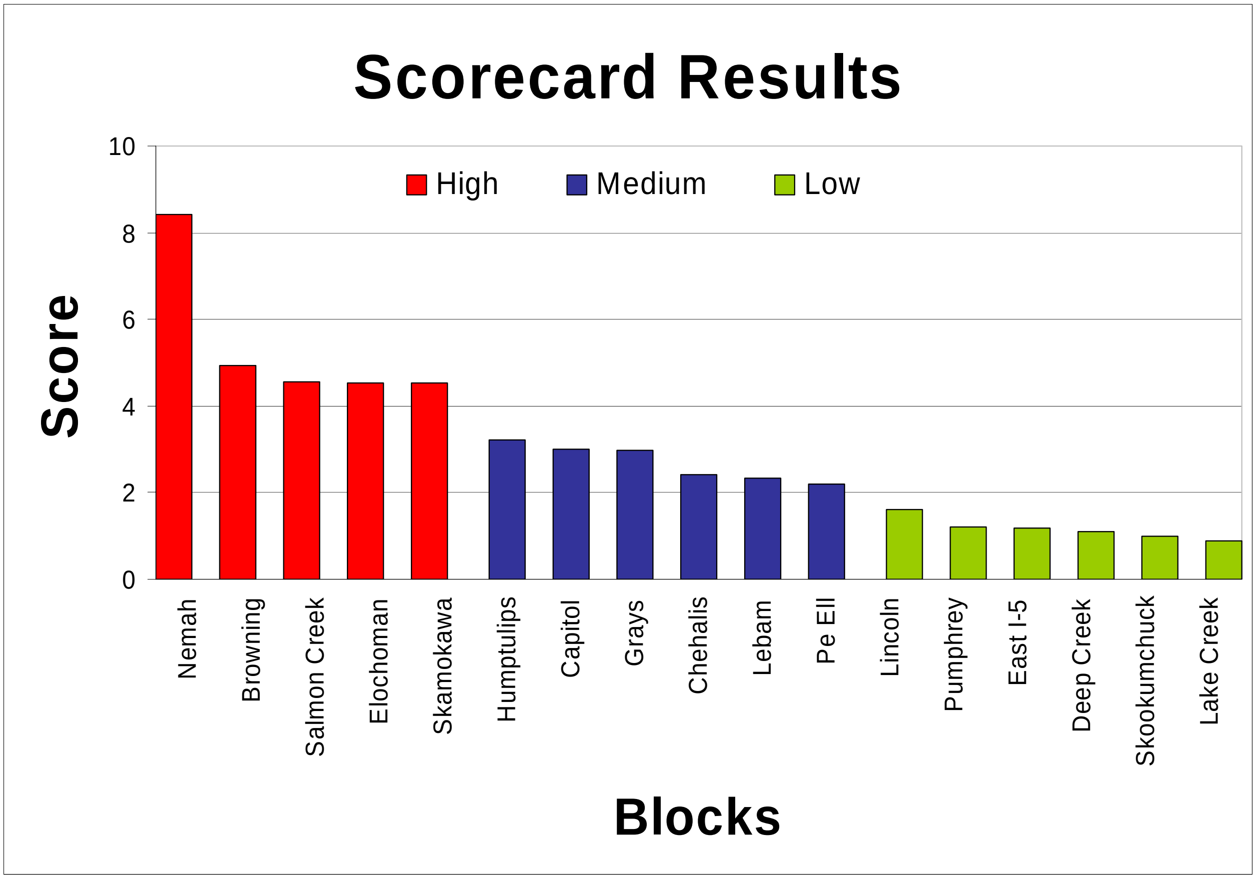


Figure 3-4. Overall Scorecard Results by Geographic Planning Block for the Southwest Washington Analysis Unit.

- Considered the size and configuration of each block within the matrix of privately managed forests.
- Considered the financial impacts on beneficiaries of Pacific County and Wahkiakum County forest board lands (see page 3-1).

The delineations follow known occupied sites, forest inventory units, the extent of DNR-managed lands, trust land ownership, roads, streams, orthophoto-interpreted forest stand types, and/or areas of more contiguous DNR management. In some areas, to keep the conservation edges simple, delineations are basic linear connections between the features just described. The following sections detail how each of the MMMAs are delineated.

Nemah MMMAs: The large MMMA is 13,748 acres (5,564 hectares), connects occupied sites, and blocks up disconnected areas of mature forest (Figure 3-5). All but the northeast section is delineated by the extent of DNR-managed lands. The northeast section of DNR-managed lands is omitted because it contains no known marbled murrelet activity and no late-successional forest, and because it shares a border with privately managed lands. All of the omitted area has at least 20% privately managed lands in the 1.24 mile (2.00 kilometer) moving-window analysis or neighborhood analysis (a value for each cell is established as a function of its neighboring cells within a specified distance, or window). The delineation of the northeast section follows streams, roads, forest inventory units, or a linear connection between them. Four isolated occupied sites, located south and west of the large Nemah MMMA, are included in four additional MMMAs, totaling 1,742 acres (705 hectares). These occupied sites are each buffered by a small amount of DNR-managed land. The land outside these occupied sites is included in the MMMAs.

Browning MMMAs: All four of the large MMMAs retain and buffer occupied sites and block up disconnected areas of mature forest (Figure 3-6). The northernmost management area of the Browning block is 646 acres (262 hectares) and is delineated by occupied sites, DNR-managed lands, forest inventory units, and the linear connection between forest inventory units. The next MMMA in the Browning block, traveling south, is 2,889 acres (1,169 hectares) and is delineated by DNR-managed lands, forest inventory units, roads, and, in some areas, the linear connection between forest inventory units. The next MMMA is 444 acres (180 hectares) and is simply a large buffer around an occupied site. It is delineated by roads, forest inventory units, and the linear connection between them. The southernmost MMMA of the Browning block is 5,134 acres (2,078 hectares) and is delineated by DNR-managed lands, forest inventory units, the linear connection between inventory units, as well as orthophoto-interpreted stand types. One isolated occupied site located on the west side of the Browning block is 113 acres (46 hectares) and is considered an additional MMMA. It is surrounded by a small amount of DNR-managed land that is not included in the MMMA.

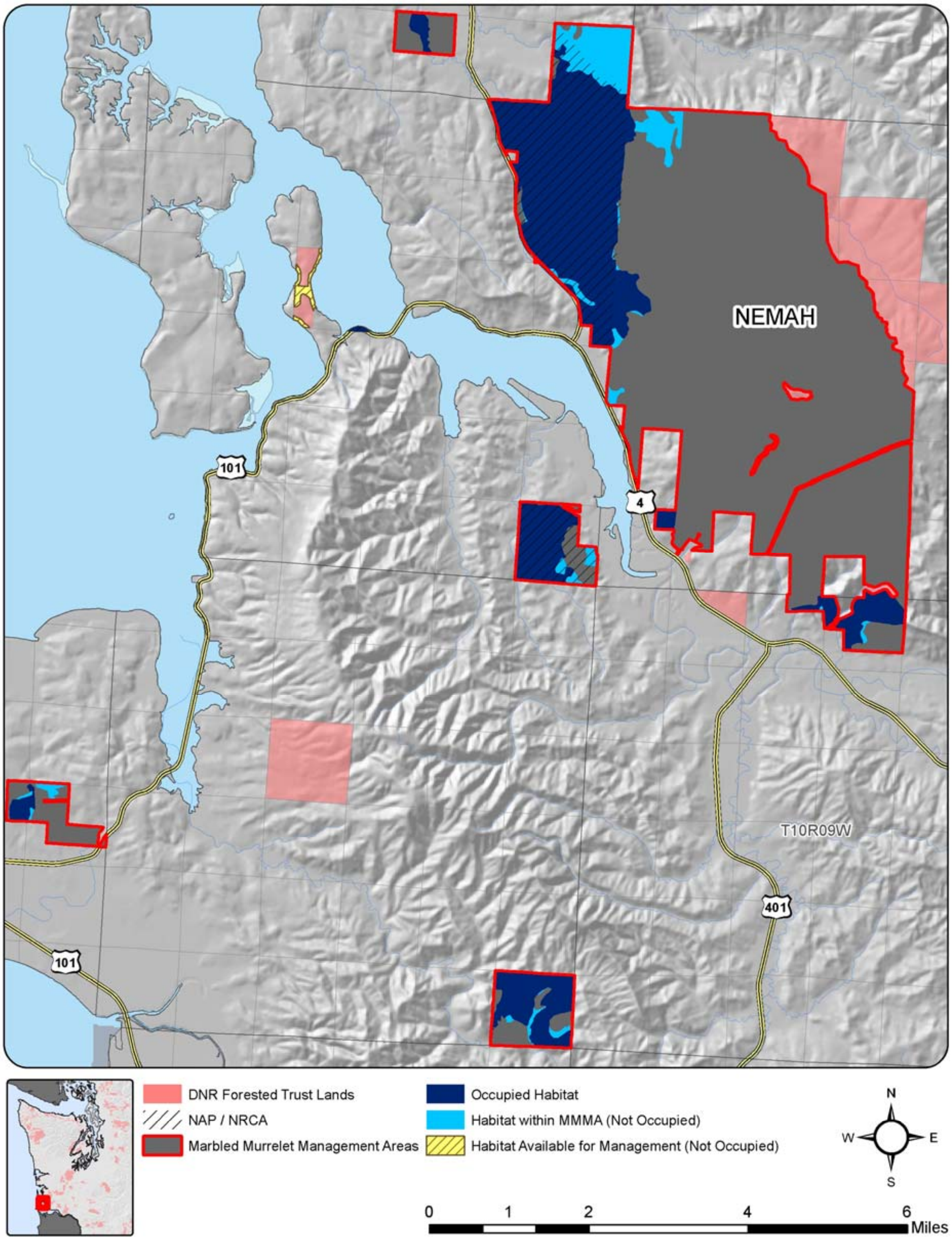


Figure 3-5 Proposed Science Team Land Allocations for Marbled Murrelet Management Areas in the Nemah Planning Block.

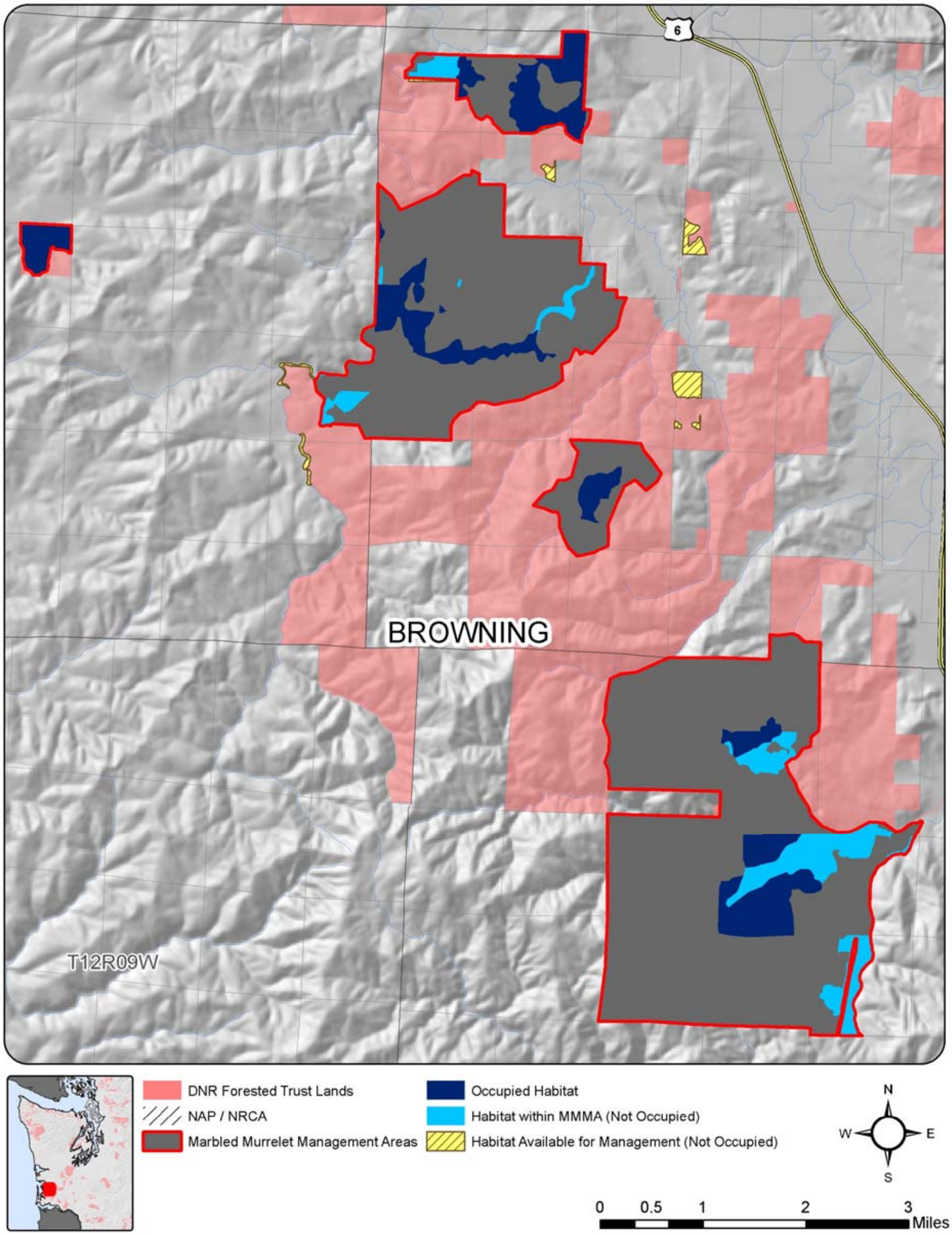


Figure 3-6. Proposed Science Team Land Allocations for Marbled Murrelet Management Areas in the Browning Planning Block.

Salmon Creek MMMAs: Both of the large MMMAs connect occupied sites and block up disconnected areas of mature forest (Figure 3-7). The first MMMA on the west side of the Salmon Creek block is 4,987 acres (2,018 hectares) and is delineated by the extent of DNR-managed lands, except the southern tip. The southern tip of DNR-managed lands is omitted because it contains no known marbled murrelet activity and no late-successional forest, and it borders privately managed lands. The entire omitted southern tip contains at least 50% privately managed lands in the 1.24 mile (2.00 kilometer) moving-window analysis. The delineation of the southern tip follows roads and forest inventory units. The eastern border of the western management area omits a large section of early successional forest because there is no known marbled murrelet activity. The delineation of the eastern border follows roads and forest inventory units. The second MMMA on the east side of the Salmon Creek block is 3,420 acres (1,384 hectares) and is delineated by the extent of DNR-managed lands. The western border of the MMMA encompasses areas of mature forest. The delineation of the western border follows forest inventory units. One isolated occupied site is located southwest of the Salmon Creek block. It is a quarter-section, 159 acres (64 hectares) that is not buffered by additional DNR-managed land; thus the entire occupied site is the MMMA.

Elochoman MMMAs: The southern MMMA of the Elochoman block is 491 acres (199 hectares) and is simply a large buffer around an occupied site, but also blocks up some disconnected areas of mature forest (Figure 3-8). It is delineated by DNR-managed lands, forest inventory units, and the linear connection between them. The large, northern MMMA is 9,734 acres (3,939 hectares), captures one occupied site, and blocks up many widespread areas of late-successional forest. The western border of the MMMA is delineated by DNR-managed lands. The northern border is delineated by forest inventory units. The eastern and southern borders are delineated by DNR-managed lands and by Wahkiakum County trust lands.

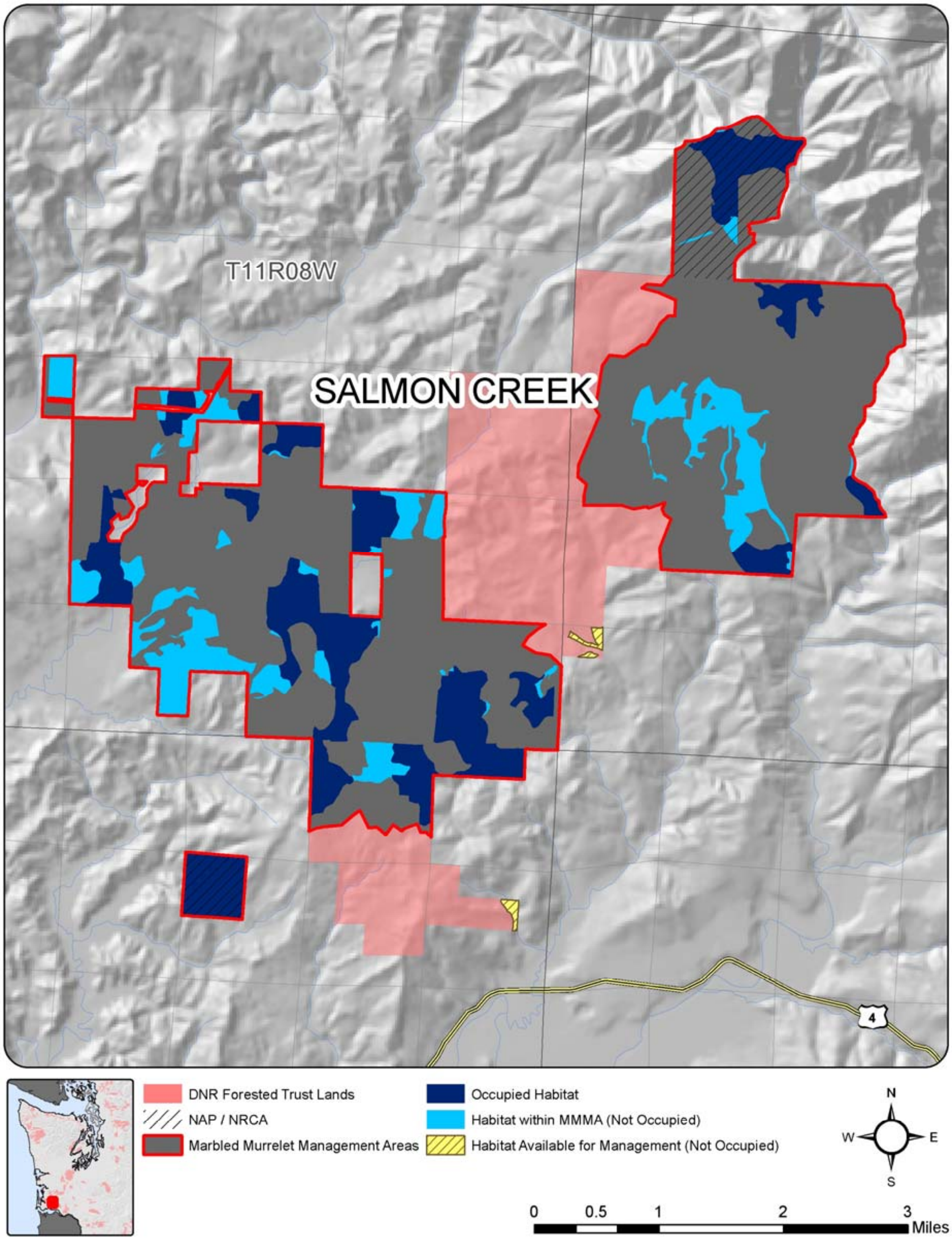


Figure 3-7. Proposed Science Team Land Allocations for Marbled Murrelet Management Areas in the Salmon Creek Planning Block.

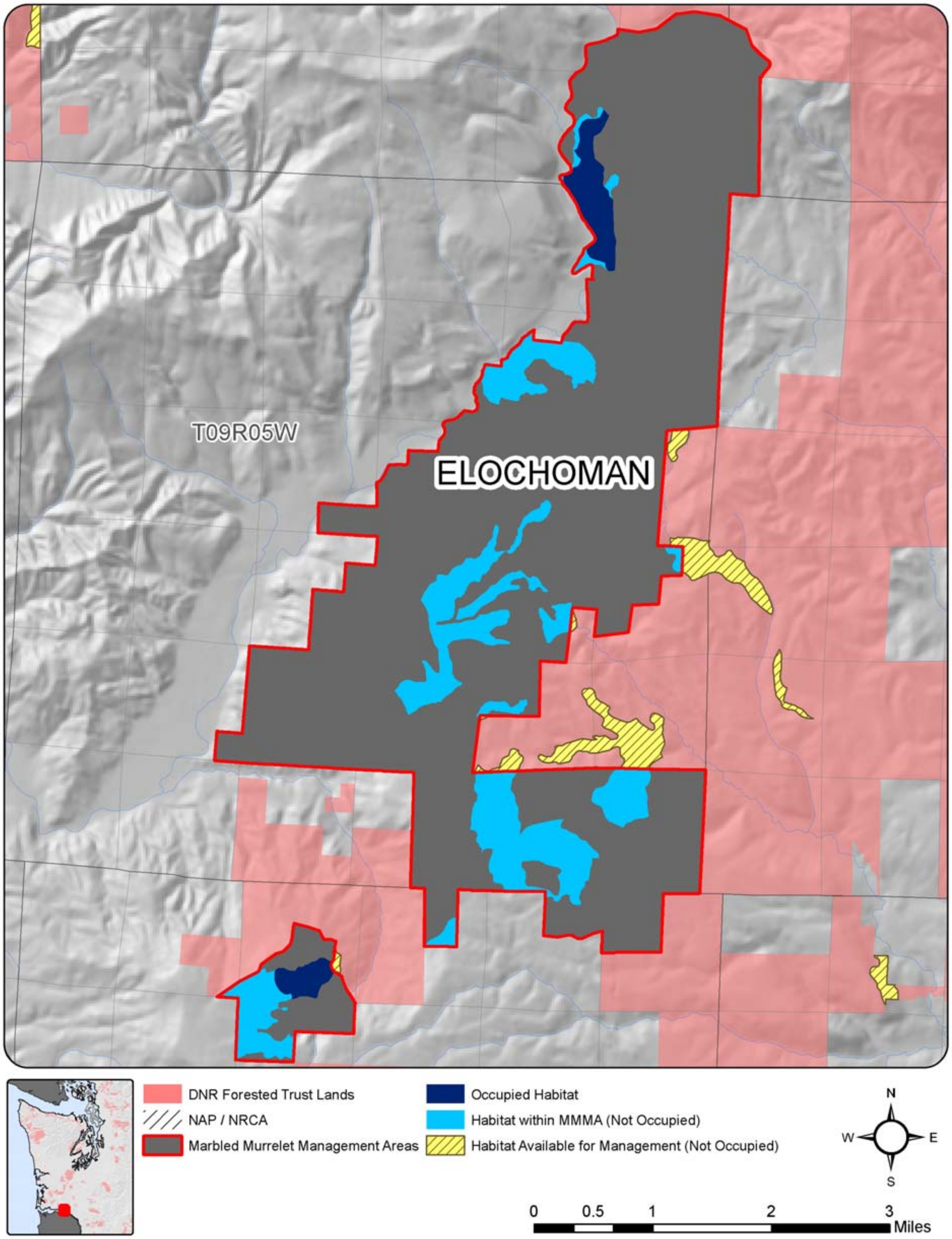


Figure 3-8. Proposed Science Team Land Allocations for Marbled Murrelet Management Areas in the Elochoman Planning Block.

Skamokawa MMMA: The MMMA is 13,763 acres (5,570 hectares), connects occupied sites, and blocks up disconnected areas of mature forest (Figure 3-9). All but the northwest, northeast, and southeast corners of the MMMA are delineated by the extent of DNR-managed lands. The three corners are omitted because they contain no known marbled murrelet activity and little to no late-successional forest, and because they border privately managed lands. The omitted northwest corner contains at least 60%, the northeast corner 40%, and the southeast corner 30% privately managed lands in the 1.24 mile (2.00 kilometer) moving-window analysis. The delineation of the corners follows forest inventory units and orthophoto-interpreted stand types. The southeast corner is also partially delineated by an occupied site and a linear connection between forest inventory units.

Humptulips MMMAs: Five isolated occupied sites located in the Humptulips block total 317 acres (128 hectares) and are considered additional MMMAs (Figure 3-10). They are surrounded by small amounts of DNR-managed land, but DNR-managed lands outside the occupied sites are not included in the MMMAs.

Grays MMMAs: These management areas include DNR-managed Natural Area Preserves Bone River and Niawiakum River (Figure 3-11). They total 3,371 acres (1,364 hectares) and encompass two occupied sites. They are delineated entirely by the extent of DNR-managed lands. One isolated occupied site northeast of the large MMMA is 34 acres (14 hectares) and is considered an additional MMMA. It is surrounded by a small amount of DNR-managed land that is not included in the MMMA.

Chehalis MMMAs: The northern and southeastern MMMAs of the Chehalis block are 1,132 and 828 acres (458 and 335 hectares), respectively, and are simply large buffers around occupied sites (Figure 3-12). They are delineated by DNR-managed lands, forest inventory units, and, in some areas, the linear connection between them. The southwestern MMMA is 3,282 acres (1,328 hectares), buffers one occupied site adjacent to DNR-managed lands, and retains a large area of mature forest. It is also delineated by DNR-managed lands and forest inventory units.

Lebam MMMA: One isolated occupied site located in the Lebam block is 187 acres (76 hectares) and is considered an additional MMMA (Figure 3-13). It is buffered by a large amount of DNR-managed land that is not included in the MMMA.

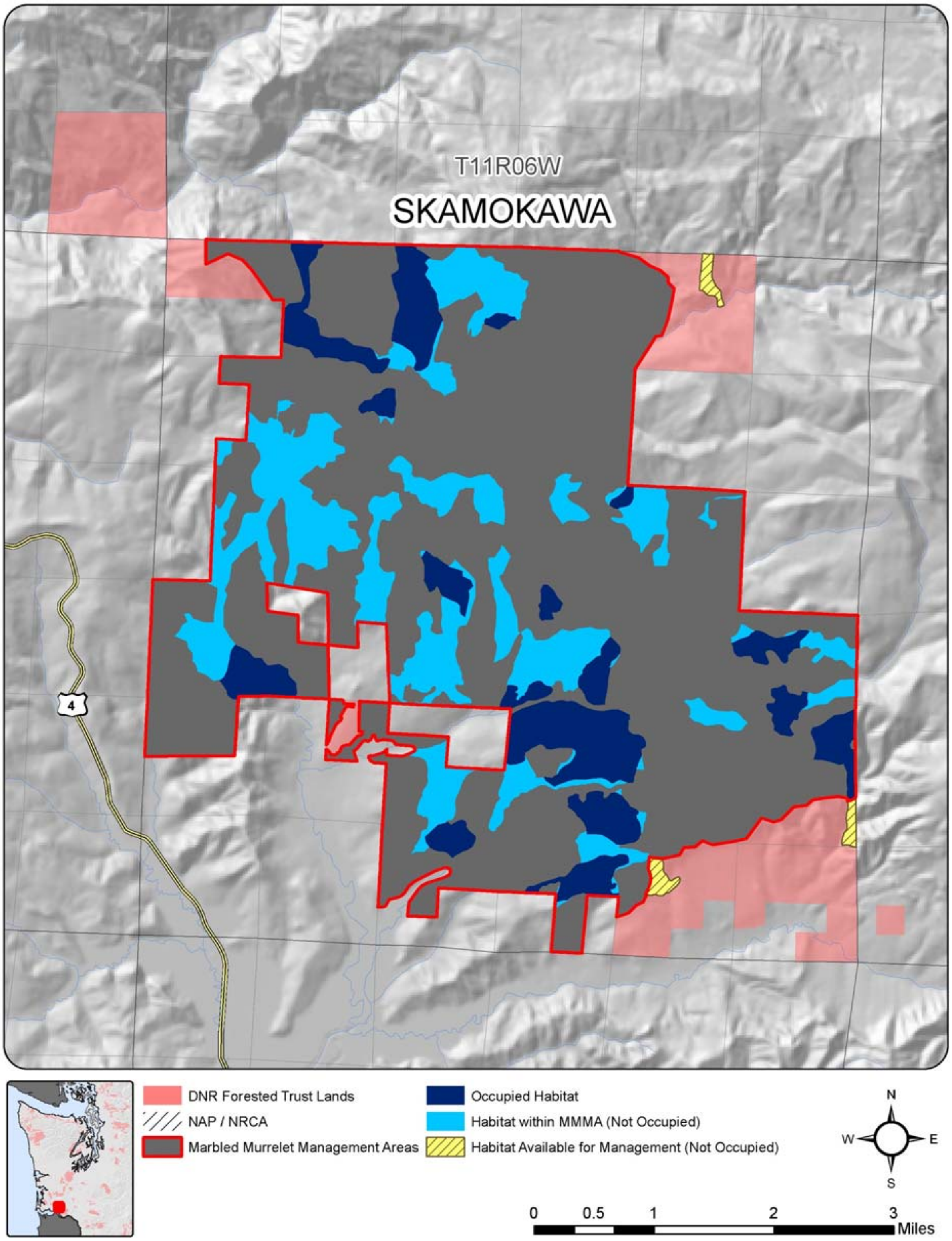


Figure 3-9. Proposed Science Team Land Allocations for Marbled Murrelet Management Areas in the Skamokawa Planning Block.

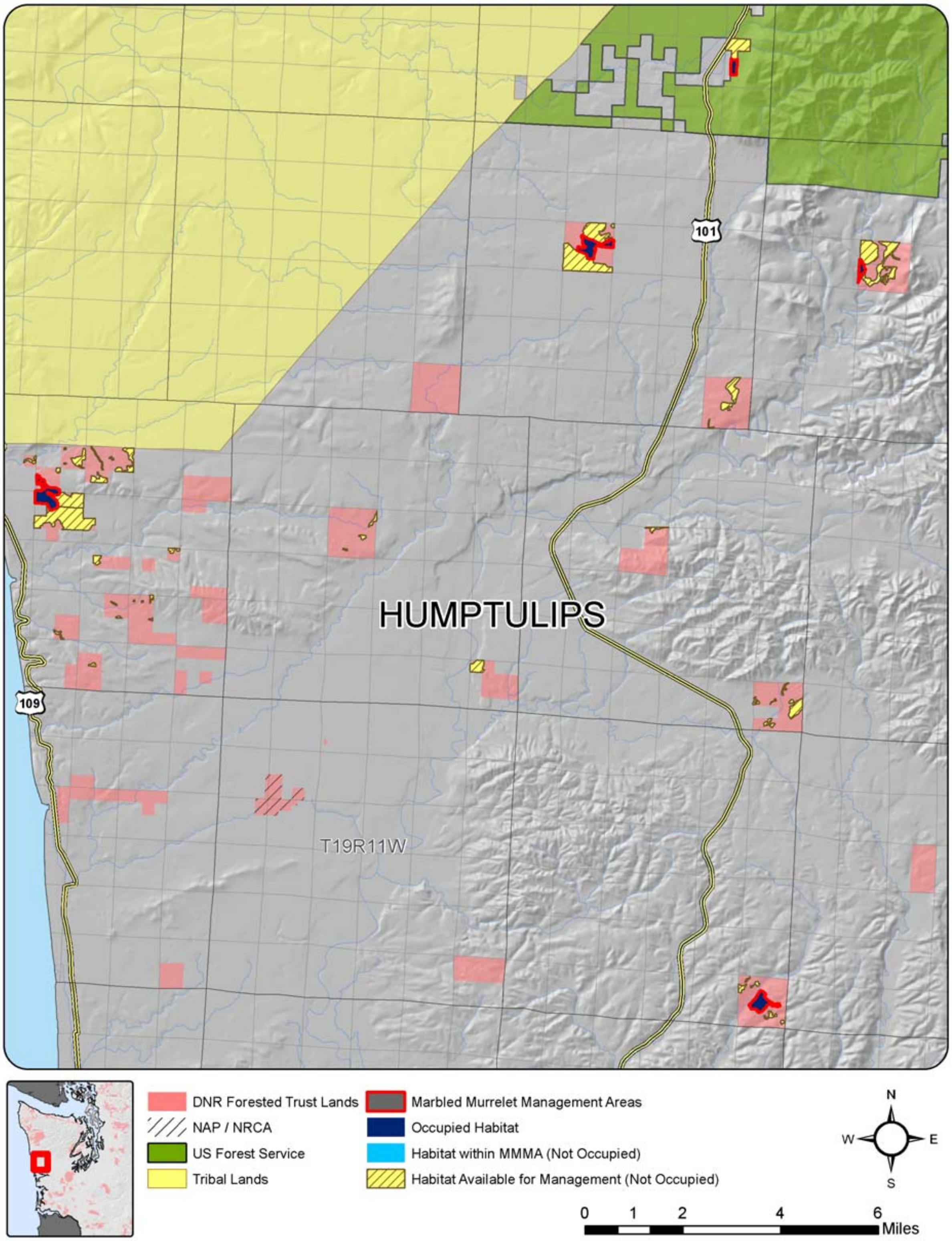


Figure 3-10. Proposed Science Team Land Allocations for Marbled Murrelet Management Areas in the Humptulips Planning Block.

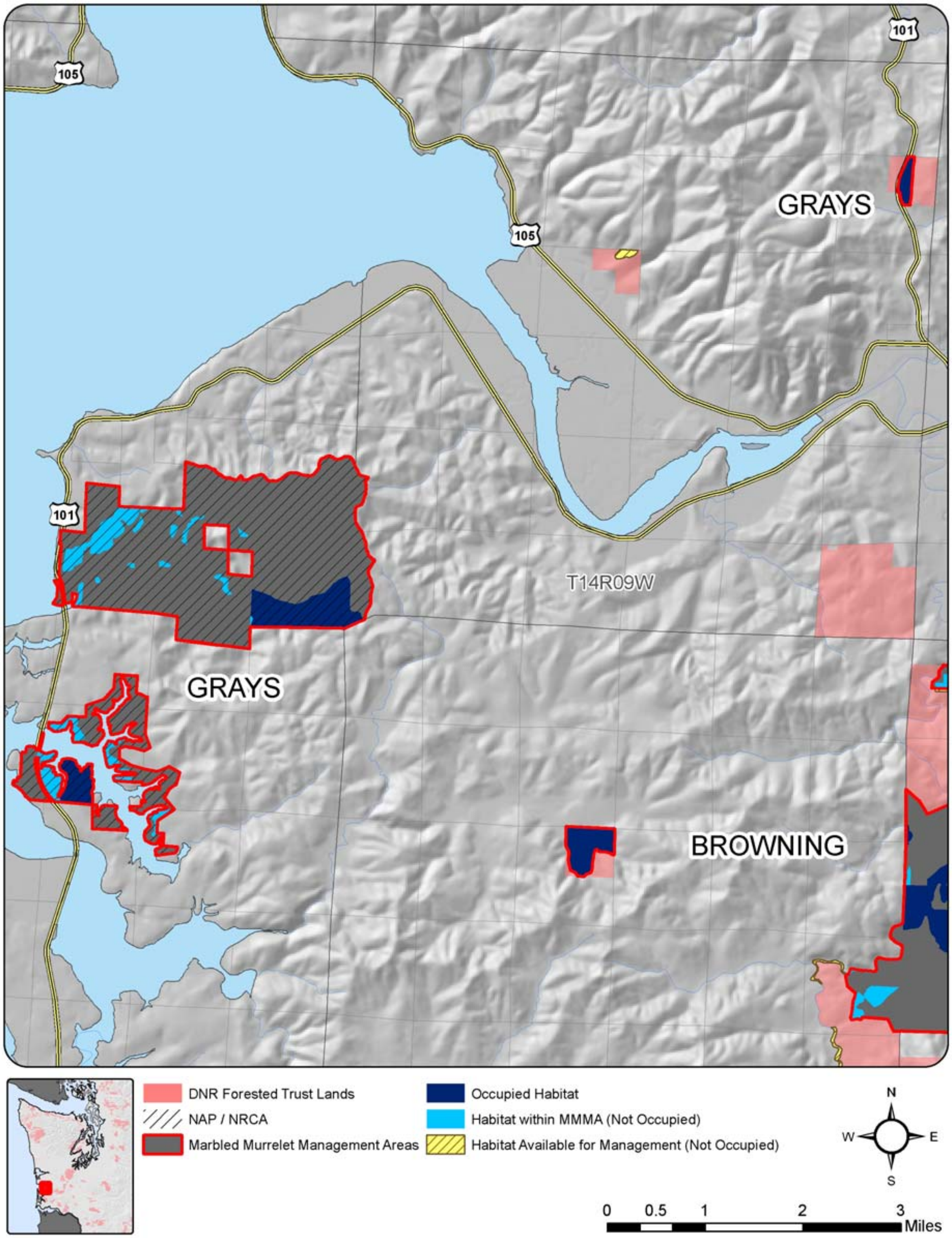


Figure 3-11. Proposed Science Team Land Allocations for Marbled Murrelet Management Areas in the Grays Planning Block.

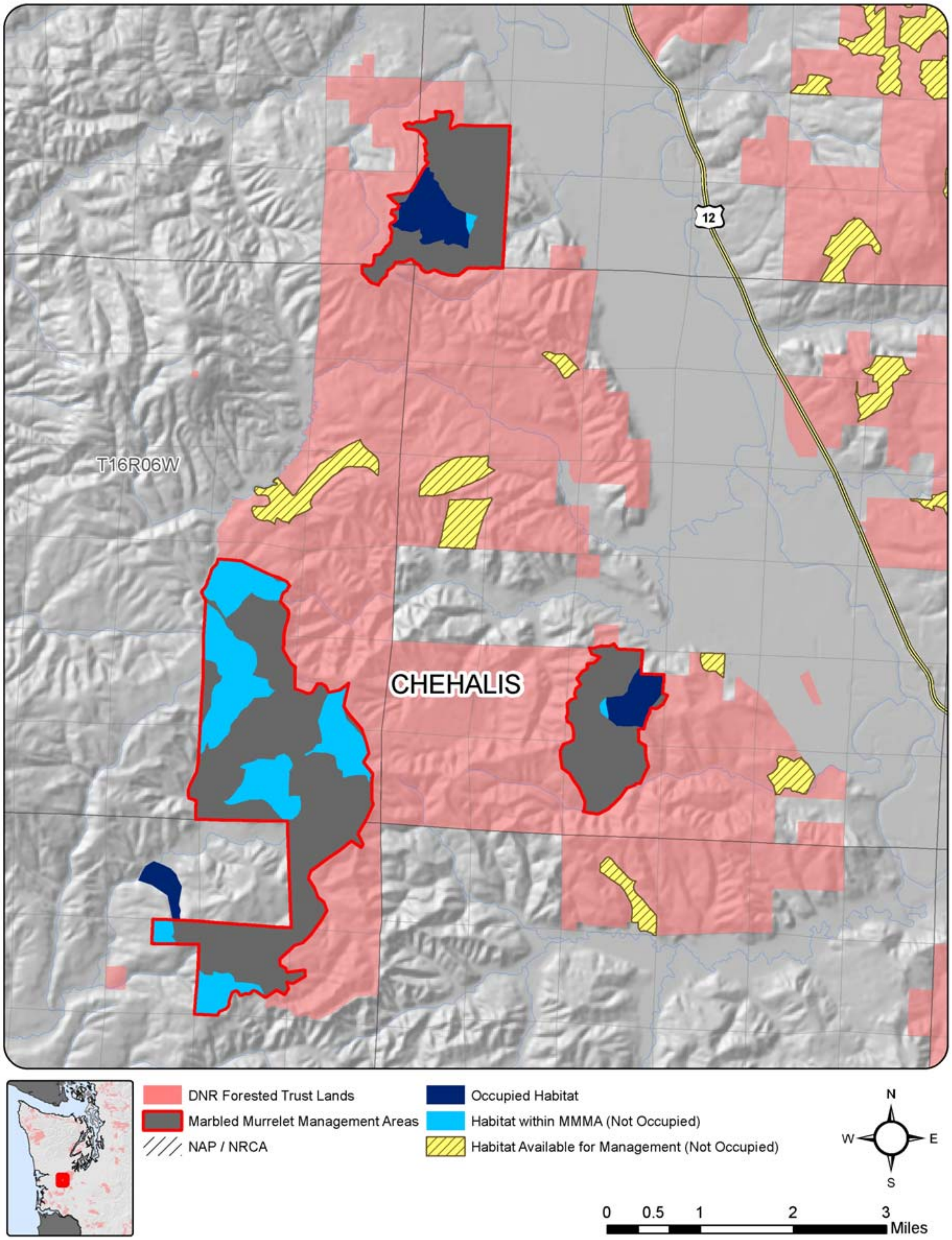


Figure 3-12. Proposed Science Team Land Allocations for Marbled Murrelet Management Areas in the Chehalis Planning Block.

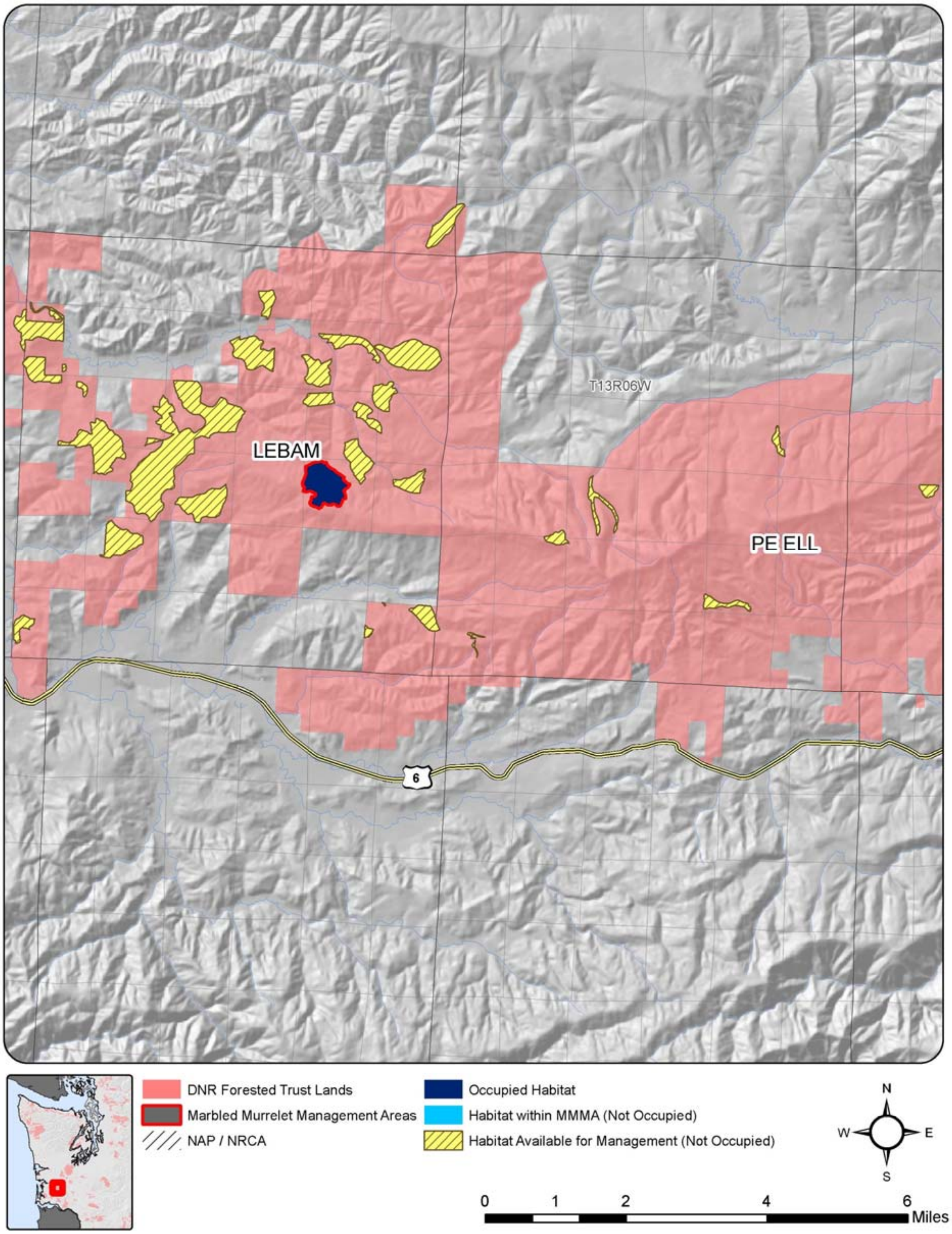


Figure 3-13. Proposed Science Team Land Allocations for Marbled Murrelet Management Area in the Lebam Planning Block.

3.3 Conservation Approach for a Marbled Murrelet Long-Term Conservation Strategy in the Olympic Experimental State Forest

The OESF Analysis Unit has unique conservation strategies as part of its mandate to learn how to achieve integration of old forest ecosystem functions with commercial forestry on state trust lands (DNR 1997a). The management strategy of the OESF is that of an “unzoned forest” (i.e., land management decisions are guided by earth, biological, and other sciences) to achieve multiple objectives across 11 intermediate-scale landscape planning units (LPUs) (Figure 3-14, Table 3-5).

The basic working hypothesis for the OESF is that DNR can conserve or restore old forest ecosystem functions by planning, applying, monitoring, and refining forest management activities at multiple spatial and temporal scales rather than working around constraints of administrative land allocations (Lindenmayer and Franklin 2002). Landscape-level analysis and planning are intended to set the spatial and temporal patterns for achieving conservation, revenue, and other objectives in each of the 11 LPUs. The OESF has unique conservation strategies for northern spotted owls and riparian ecosystems, and the HCP suggested unique marbled murrelet strategies for each planning unit (DNR 1997a). The nature and context of DNR lands in the OESF, as well as the OESF mission, suggest an “unzoned” approach to achieving biological goals for marbled murrelet conservation as well. The “unzoned” management approach was used as a guiding principal while the Science Team developed the OESF conservation objectives.

An effective unzoned approach to marbled murrelet conservation should consider the biological goals of a stable or increasing population size, increasing geographic distribution, and increased resilience to disturbances, in the context of other OESF objectives, and the OESF’s patterns of land cover, ownership, and forest zones.

Everett and Lehmkuhl (1999) provide an intellectual outline for this approach, in which they suggest three steps to achieve what they characterize as “whole-unit management.” First, they recommend “consolidate compatible allocations,” which in this context suggests that OESF’s objectives that direct maintenance or restoration of forests suitable for marbled murrelet habitat (e.g., riparian and northern spotted owl conservation) be coupled with marbled murrelet

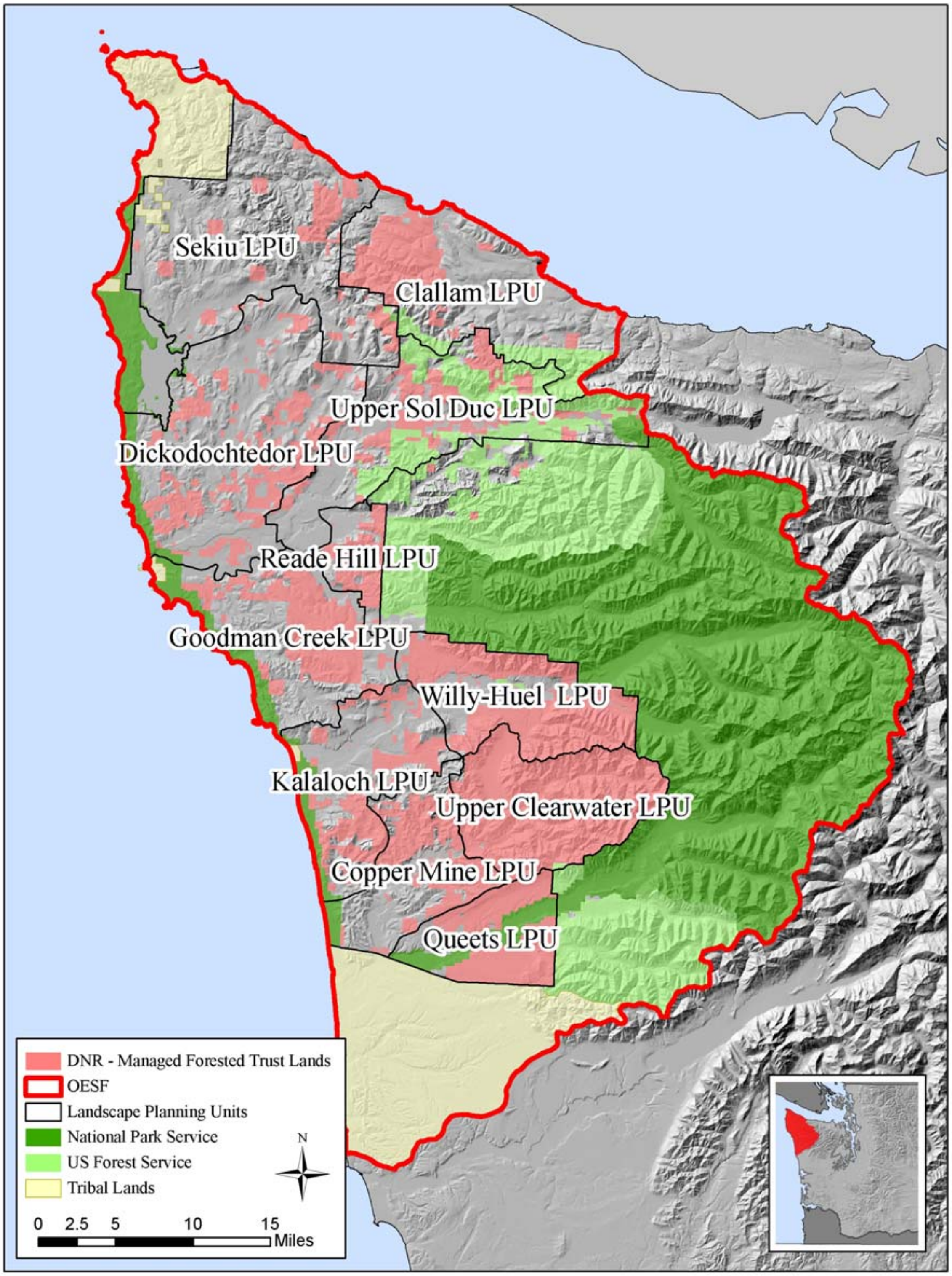


Figure 3-14. Olympic Experimental State Forest Landscape Planning Units within the OESF Analysis Unit.

conservation. Next, Everett and Lehmkuhl (1999) advise “integrate dissimilar allocations” through an “emphasis-use” approach (Everett et al. 1994) that protects emphasized uses but promotes integration of larger-scale objectives across allocations. This suggests an emphasis on marbled murrelet conservation in strategic areas that are managed to achieve a broad set of objectives. Finally, they suggest a “move to whole-unit management,” in which mid- to large-scale, ecologically defined units are managed with a consistent primary objective of ecological integrity, rather than compartmentalizing desired resource conditions among discrete land-use allocations. This is consistent with DNR’s approach of planning and implementing management for multiple objectives at the scale of ecologically similar, midsized LPUs based on watershed boundaries.

3.3a Biological Goals for Marbled Murrelet Conservation in the Context of the OESF

Marbled murrelets have been observed moving throughout the waters off the Olympic Peninsula, not just off the areas of adjacent habitat (Bloxton and Raphael 2007). These long-distance movements suggest that habitat abundance in the Straits and OESF Analysis Units should be considered in the context of the entire Olympic Peninsula. Table 3-1 shows that DNR-managed lands comprise 13% of the Olympic Peninsula (389,000 of 2.9 million acres [157,000 of 1.2 million hectares]), which is dominated by federal lands, most with congressional or administrative designations that emphasize conservation of old forests. In this context, DNR habitat conservation in the OESF can provide only a relatively minor contribution to the regional carrying capacity base for marbled murrelets (Table 5-2 and discussion in Chapter 5.0). DNR has already committed to increase the amount of old forest and to improve its function across the OESF through other DNR policies and objectives, most notably, northern spotted owl and riparian management commitments in the HCP, adding incrementally to the carrying capacity of the Olympic Peninsula for marbled murrelets. The Science Team assumes that the areas protected under the other conservation strategies will remain protected throughout the life of the HCP. The Science Team recommends that, if other conservation strategies change such that they discontinue benefits to the marbled murrelet, policy be updated to maintain protection of areas important to the marbled murrelet.

DNR-managed lands exist in a variety of settings, with a variety of land uses (e.g., timber management, surface mines, transportation network, leased communication sites, recreation and natural areas) that likely result in a wide range of fragmentation effects on the quality of nesting habitat. Thus, it is likely that habitat in the OESF will be variable in its success at contributing to the goal of population stability. Areas that will be managed for contiguous blocks of old forest will provide a higher contribution than areas where ownership patterns or management policies result in smaller patches of habitat.

From the conservation biology principle of "spreading the risk" (Den Boer 1981), perhaps the most important role the OESF can play, in addition to the maintenance of high-quality habitat, including occupied sites, is to broaden the ecological distribution of marbled murrelets on the Olympic Peninsula. Federal lands are scarce in the low-elevation Sitka spruce zone (Franklin and Dyrness 1988), and private land managers are unlikely to restore substantial marbled murrelet habitat capability within the OESF Analysis Unit. Thus, DNR's OESF conservation efforts in this low-elevation Sitka spruce zone will be disproportionately important. The Sitka spruce element of the OESF has the greatest potential to contribute to a resilient marbled murrelet population.

3.3b Approaches to Marbled Murrelet Conservation in the OESF

The 11 LPUs in the OESF (Table 3-5, Figure 3-14) vary in their overall size, area of DNR-managed lands, and context, which includes ownership patterns of DNR, federal, and private lands; landform and forest zones (Franklin and Dyrness 1988); and the amount, distribution, and condition of existing forest cover. These basic characteristics of LPUs in the OESF can be summarized as follows:

1. Land ownership occurs in several basic patterns:
    a. Large contiguous DNR-managed blocks adjacent to federal lands (e.g., Upper Clearwater LPU);
    b. Small DNR-managed blocks adjacent to federal lands (e.g., Upper Sol Duc LPU);
    c. Large DNR-managed blocks surrounded by private land (e.g., Clallam LPU);
    d. Small DNR-managed blocks surrounded by private land (e.g., Sekiu LPU).
2. Landform and forest zone are related; generally the higher elevations have more dissected topography and higher densities of unstable and/or riparian areas. The middle (~600 to 1,800 feet [183 to 549 meters]) and higher (~1,800 to 3,000 feet [549 to 914 meters]) elevations are

in the western hemlock and Pacific silver fir zones (Franklin and Dyrness 1988), respectively. Some of the lower elevation areas are in the Sitka spruce zone.

3. Current forest cover is the result of ecosystem properties, natural disturbance, and timber harvest history. The areas north of Forks were predominantly harvested during the railroad-logging era in the 1920s and 1930s; thus, little native forest remains there. These harvests were in the Sitka spruce and western hemlock zones. Harvest on DNR-managed lands south of Forks began in the mid-1960s and continued until the northern spotted owl was listed in 1990. Many of these harvests were in the middle and higher elevations. Thus, forests there are old-growth, younger stands that regenerated after catastrophic windthrow (e.g., the 1921 windstorm), and modern managed stands 15 to 40 years old.

Table 3-5. Properties of Landscape Planning Units (LPUs) in the Olympic Experimental State Forest Analysis Unit. These properties help portray the differences among the LPUs with respect to ownership, landform, and forest cover.

Conservation Objective	Landscape Planning Unit	Acres		Percent of DNR-managed area		
		Total Area	DNR-Managed Area	Riparian	Old Forest[1]	Biomapper[2]
Conservation through existing policy	Upper Clearwater	58,233	57,357	47	27	34
	Willy-Huel	52,039	39,313	50	20	31
Intermediate approach for smaller landscapes	Reade Hill	15,809	8,809	55	17	48
	Queets	34,028	22,048	27	23	28
	Copper Mine	44,483	20,249	55	16	25
Intermediate approach for northern landscapes	Upper Sol Duc	83,748	19,210	37	5	32
	Clallam	79,471	18,031	39	2	35
	Sekiu	109,270	10,689	39	1	23
Emphasis on marbled murrelet conservation	Dickodochtedor	111,721	29,410	39	10	28
	Goodman Creek	66,260	24,860	48	19	31
	Kalaloch	54,387	19,165	52	13	23

[1]The term "old forest habitat" is used in the HCP to help define northern spotted owl habitat in the conservation strategy for the OESF (DNR 1997a, p. IV.88). Old forest habitat was identified in the OESF in fulfillment of that strategy, and was then used by the Science Team to help identify areas likely to provide nesting habitat and therefore make a contribution to marbled murrelet conservation.

[2]Biomapper estimates are from Raphael et al. (2006) who used this program to build an Ecological Niche Factor Analysis Model (ENFA) of marbled murrelet habitat suitability. Model inputs were GIS-based rasters of ecogeographical variables (forest cover derived from satellite imagery, as well as topography, solar radiation, and distance to coastline) and species presence data. Habitat estimates are based on an ENFA habitat suitability index greater than 60.

The strategic approach of Everett and Lehmkuhl (1999) suggests using two basic approaches to achieve the biological goals for marbled murrelet conservation in an unzoned OESF, with its particular land ownership and biophysical patterns. While marbled murrelet conservation will occur in all LPUs, the two approaches represent opposite ends of a gradient; at one end, marbled murrelet conservation would occur through existing policy and procedures (e.g., riparian and northern spotted owl conservation strategies). At the other end, LPUs exist where marbled murrelet conservation would be emphasized as a guiding element in landscape design and management. Due to the above three sets of LPU characteristics, there are several variations on intermediate approaches.

3.3c Guiding Elements for Landscape Design within the 11 Landscape Planning Units for Marbled Murrelet Conservation in an Unzoned OESF

The following four marbled murrelet conservation objectives are recommended as a guiding element for use in landscape design and management in an unzoned OESF.

1. ***<u>Conservation through existing policy and procedure model</u>***: (Upper Clearwater and Willy-Huel LPUs). The conservation through existing policy and procedure model is proposed for large contiguous blocks of DNR-managed lands adjacent to large federal reserves. These LPUs are at middle to upper elevations, with high densities of dissected, unstable landforms and with high densities of existing marbled murrelet habitat on DNR-managed lands (Table 3-5). These relatively abundant old forests help achieve HCP objectives for northern spotted owl conservation. Maturation and generally more conservative management of adjacent stands will result in diminishing negative edge effects during the lengthy period of habitat restoration in riparian and unstable areas. Conservation objectives for riparian ecosystems direct DNR to grow older forests in riparian and unstable areas (DNR 1997a), which will eventually contribute substantial amounts of potential nesting habitat. Retention of current nesting habitat, habitat restoration, and overall maturation of early-seral forests in these landscapes which will diminish fragmentation effects are, in combination, predicted to help achieve the goals of population stability and increasing size.
2. ***<u>Intermediate approach for smaller landscapes</u>:*** (Reade Hill, Copper Mine and the Queets LPUs). One type of intermediate approach is proposed for smaller landscapes at generally lower elevations with less, but still significant, amounts of old forests. Objectives for

northern spotted owl (old forest) and riparian conservation will direct substantial retention and restoration of old forests in riparian (DNR 1997a), unstable slopes, and other areas of the Reade Hill and Copper Mine LPUs (Table 3-5). Active management to limit fragmentation around existing stands of suitable structure in Reade Hill and Copper Mine, and broader areas of the Queets LPU, is hypothesized to improve their contribution to achieving the goal of population stability.

3. ***Intermediate approach for the northern landscapes:*** (Upper Sol Duc, Clallam, and Sekiu LPUs). Another intermediate approach is in the northern LPUs with very little old forest remaining (Figure 3-14). These LPUs are largely in lower to middle elevations and vary in the size of DNR-managed blocks and their adjacency to federal reserves. Northern spotted owl and riparian conservation objectives apply in these LPUs as well; thus, substantial restoration of old forests, especially in riparian and unstable areas (Table 3-5) will hypothetically provide marbled murrelet habitat in the future. Additionally, riparian and unstable areas adjacent to current habitat will buffer suitable habitat as they mature. Current nesting habitat will thus incur diminishing fragmentation effects over time. Active management for marbled murrelet conservation is proposed for a portion of the Upper Sol Duc adjacent to federal lands, which is also a focal area for restoration of northern spotted owl habitat capability. Similar to the first conservation objective (conservation through existing policy and procedure model), marbled murrelet conservation will largely be a product of existing management policy and procedures for other objectives in these LPUs as well, but the nature of these landscapes (fragmented ownership, and amount, distribution, and condition of existing habitat) is such that they will likely contribute less to the biological goals than the Upper Clearwater and Willy-Huel LPUs.

4. ***Emphasis on marbled murrelet conservation model:*** (Dickodochtedor, Goodman Creek, and Kalaloch LPUs). The "emphasis on marbled murrelet conservation" model will apply in the Sitka spruce zone of three coastal plain LPUs with some existing old forest. To limit potential negative fragmentation effects, MMMAs were located adjacent to federal lands or in areas with a high density of DNR-managed lands and avoided areas of higher human impact with enriched corvid populations. Northern spotted owl and riparian conservation objectives also apply in these LPUs, so retention and restoration of old forests will occur in the emphasis areas and throughout the LPUs, especially in the riparian and unstable areas

(Table 3-5). Active management in the emphasis areas is hypothesized to improve their contribution to achieving the goal of population stability, while their location in the Sitka spruce zone is intended to contribute to distribution and resilience goals.

The specific elements of these approaches are detailed and mapped for each of the 11 LPUs in the next section.

3.3d Marbled Murrelet Long-Term Conservation Approach by LPU in the OESF

The Science Team recommends protection of all known marbled murrelet occupied sites, most of which are located inside the Marbled Murrelet Management Areas (MMMAs) (Table 3-2). Tables 3-6 through 3-12 outline conservation approaches and recommendations for marbled murrelet conservation in the respective LPUs in the OESF.

The following recommendations are shared by all LPUs:

- Defer from harvest existing old forest stands and occupied sites.
- Manage a buffer area within 328 feet (100 meters) of existing old forest stands and occupied sites to provide conservation benefits to existing high-quality nesting habitat.
- Manage riparian and unstable slope areas according to the HCP (DNR 1997a) to provide additional marbled murrelet nesting habitat.

Table 3-6. Conservation Approaches and Recommendations—Upper Clearwater and Willy-Huel LPUs.

Conservation Approach	Recommendations
Conservation through existing policy and procedure model.	1. Remaining habitat (Table 3-13) will be managed according to broad DNR policies and procedures, including commitments for northern spotted owl and riparian conservation.

Note: see also Figures 3-15 and 3-16.

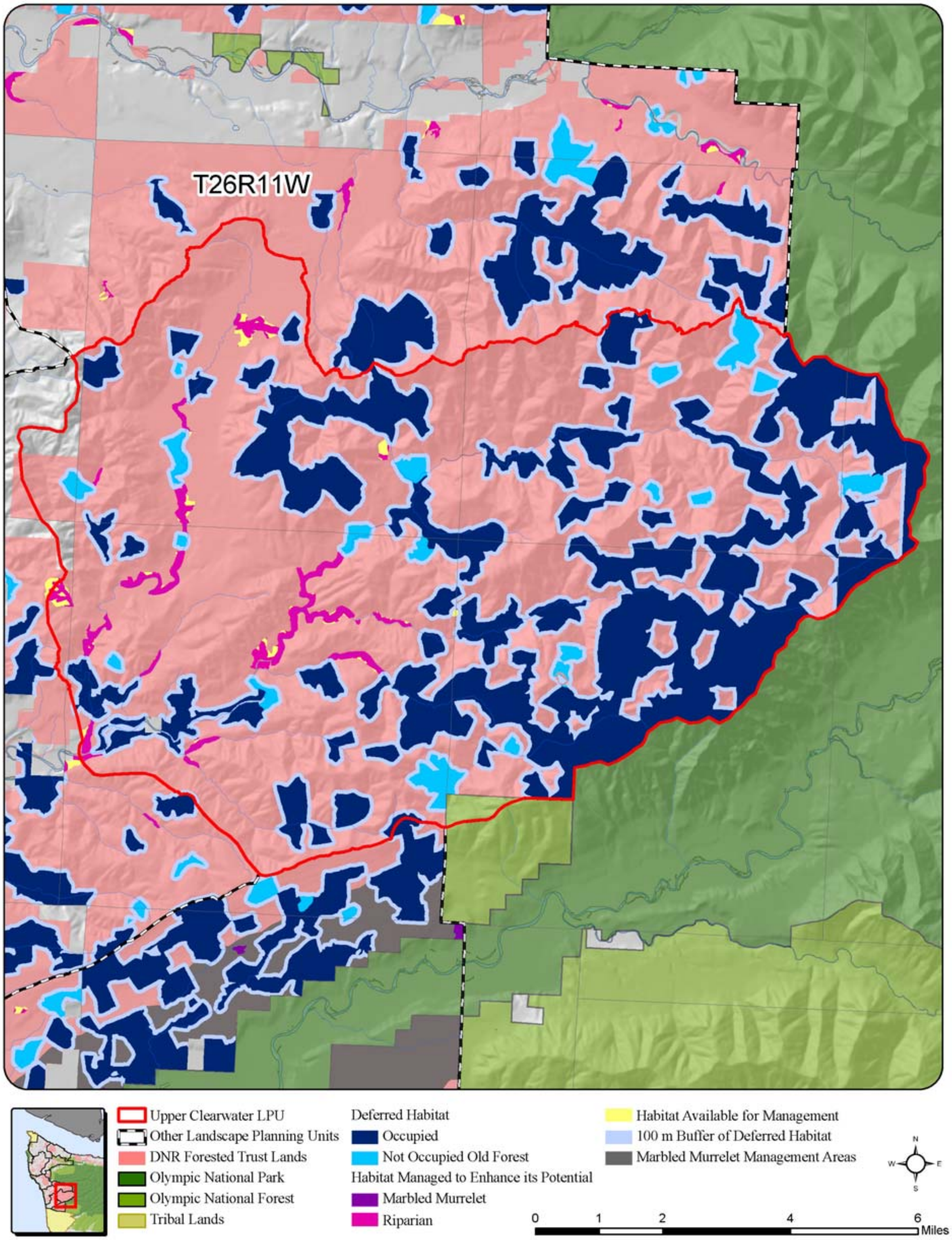


Figure 3-15. Proposed Science Team Land Allocations for Upper Clearwater LPU.

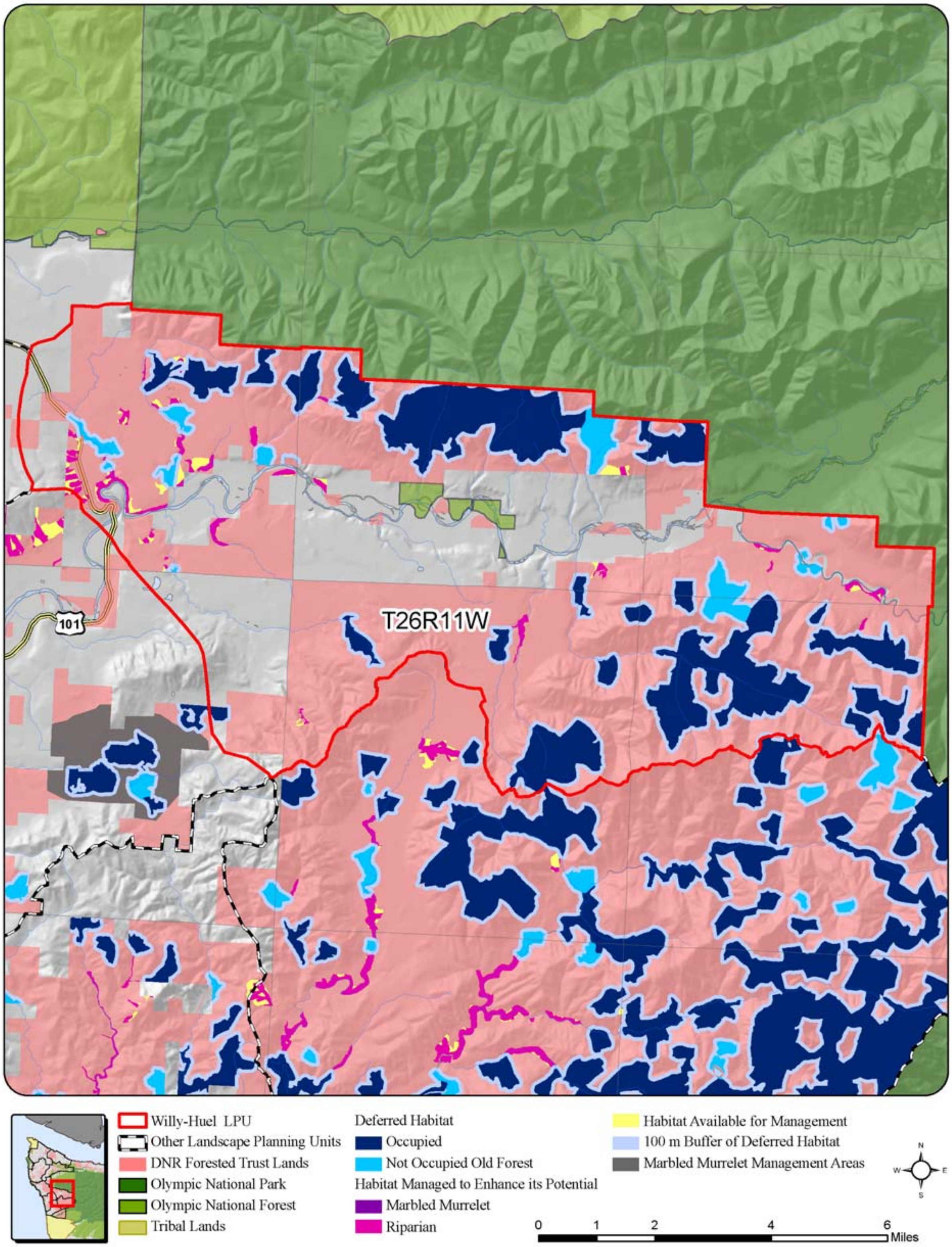


Figure 3-16. Proposed Science Team Land Allocations for Willy-Huel LPU.

Table 3-7. Conservation Approaches and Recommendations—Reade Hill LPU.

Conservation Approach	Recommendations
Intermediate approach for smaller landscapes model.	1. Remaining habitat adjacent to existing old forest stands will be deferred from harvest or managed to accelerate development of old forest northern spotted owl habitat, based on the assumption that this also provides good marbled murrelet habitat. 2. Remaining habitat not identified (Table 3-13) will be managed according to broad DNR policies and procedures, including commitments for northern spotted owl and riparian conservation.

Note: see also Figure 3-17.

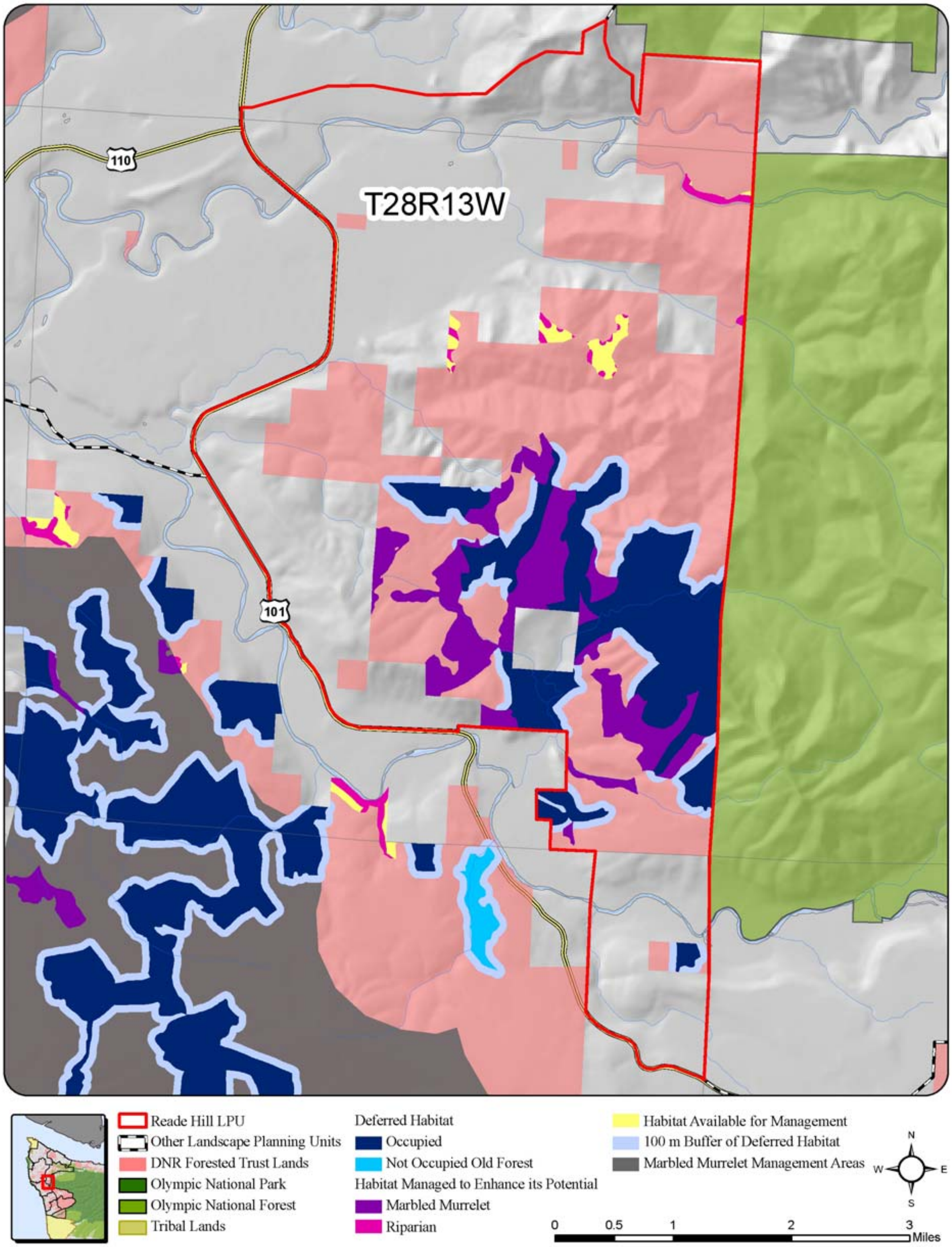


Figure 3-17. Proposed Science Team Land Allocations for Reade Hill LPU.

Table 3-8. Conservation Approaches and Recommendations—Queets LPU.

Conservation Approach	Recommendations
Intermediate approach for smaller landscapes model.	1. Some stands of old forest were possibly misclassified. If review of these stands finds them not to be old forest (according to DNR's old-growth index, HCP definitions for old forest owl habitat, or other approved procedure), they will be managed according to broad DNR policies and procedures. 2. The area within one mile of Olympic National Park will be managed as an MMMA. Habitat within the MMMA will be deferred from harvest or managed to accelerate development of old forest northern spotted owl habitat, based on the assumption that this also provides good marbled murrelet habitat. 3. Two-thirds of the remaining area within the MMMA will be managed to be in stands with the tallest 40 trees per acre at least 80 feet tall. 4. Remaining habitat outside the MMMA (Table 3-13) will be managed according to broad DNR policies and procedures, including commitments for northern spotted owl and riparian conservation.

Note: see also Figure 3-18.

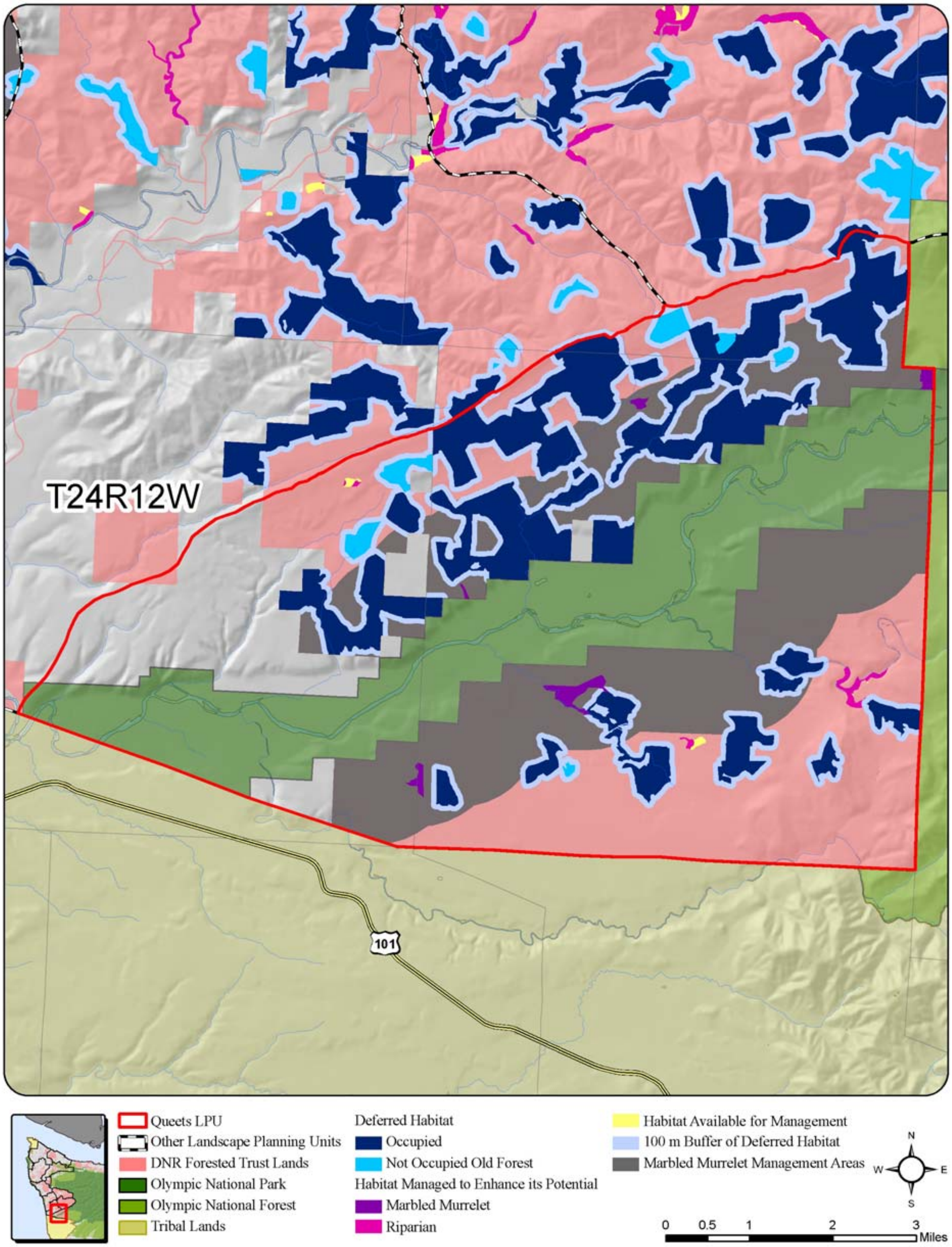


Figure 3-18. Proposed Science Team Land Allocations for Queets LPU.

Table 3-9. Conservation Approaches and Recommendations—Copper Mine LPU.

Conservation Approach	Recommendations
Intermediate approach for smaller landscapes model.	1. Remaining habitat (Table 3-13) will be managed according to broad DNR policies and procedures, including commitments for northern spotted owl and riparian conservation.

Note: see also Figure 3-19.

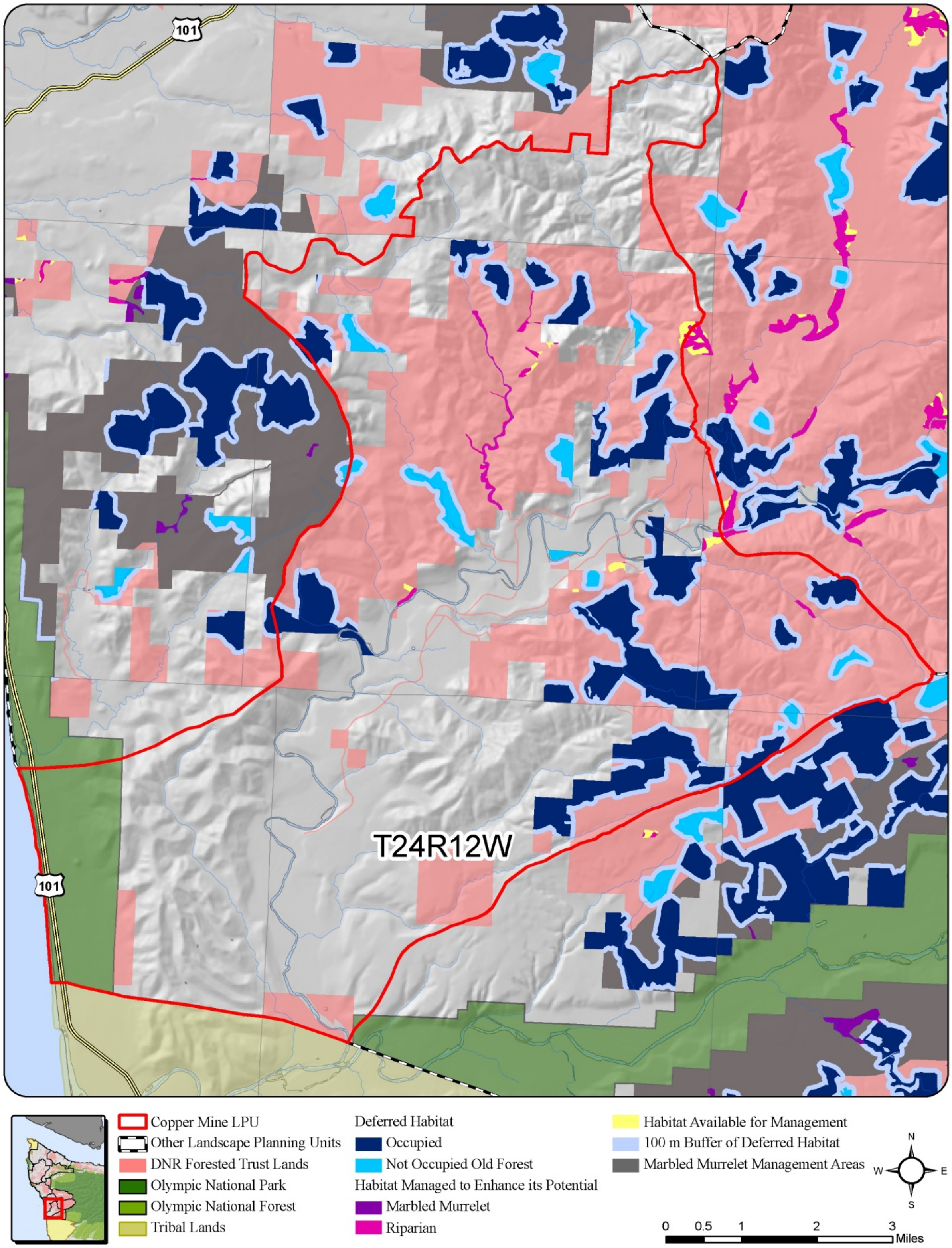


Figure 3-19. Proposed Science Team Land Allocations for Copper Mine LPU.

Table 3-10. Conservation Approaches and Recommendations—Upper Sol Duc LPU.

Conservation Approach	Recommendations
Intermediate approach for the northern landscapes model.	1. Designated stands of habitat (Figure 3-20) will be deferred from harvest or managed to accelerate development of old forest northern spotted owl habitat, based on the assumption that this also provides good marbled murrelet habitat. 2. Remaining habitat (Table 3-13) not designated will be managed according to broad DNR policies and procedures, including commitments for northern spotted owl and riparian conservation.

Note: see also Figure 3-20.

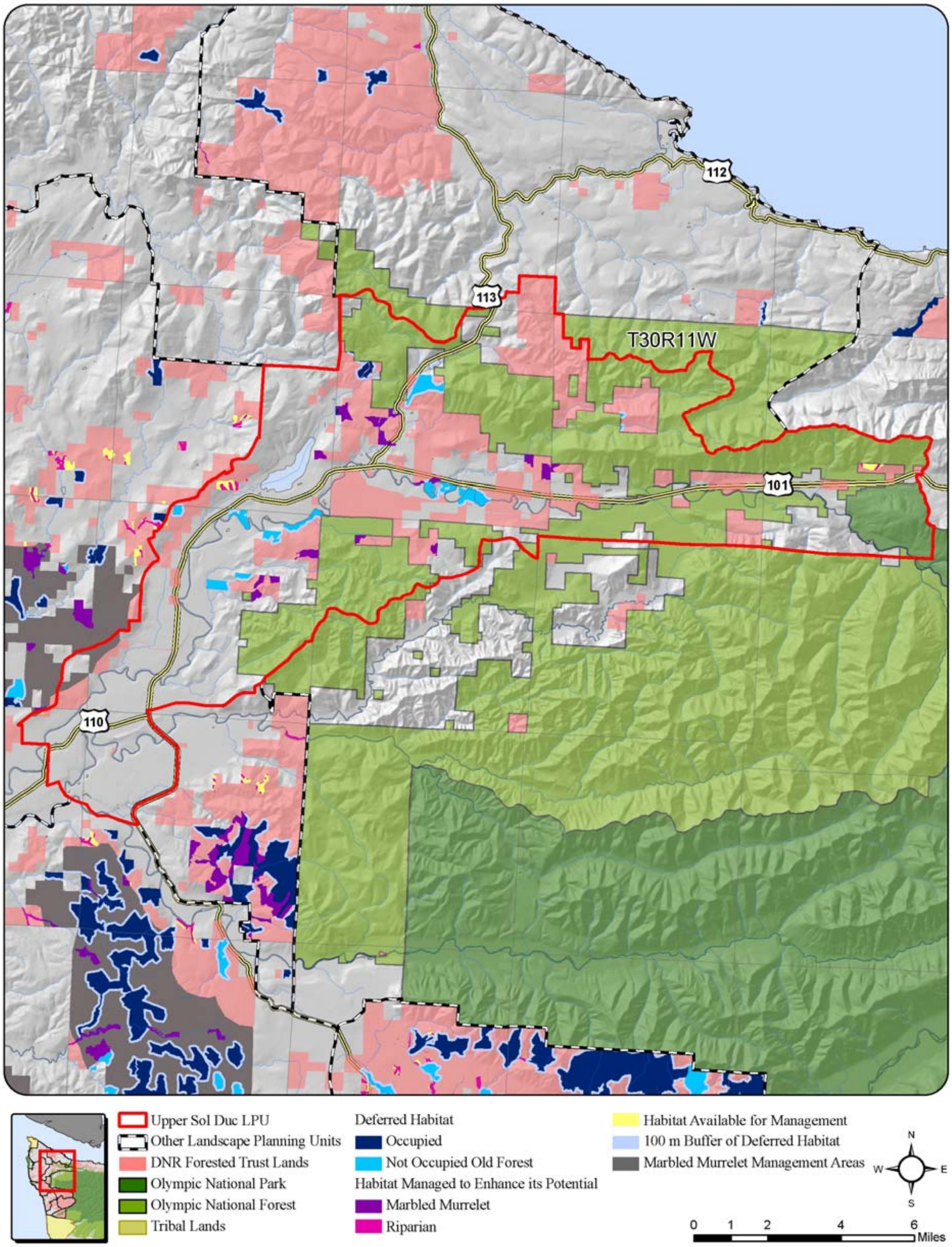


Figure 3-20. Proposed Science Team Land Allocations for Upper Sol Duc LPU.

Table 3-11. Conservation Approaches and Recommendations—Clallam and Sekiu LPUs.

Conservation Approach	Recommendations
Intermediate approach for the northern landscapes model.	1. Remaining habitat (Table 3-13) will be managed according to broad DNR policies and procedures, including commitments for northern spotted owl and riparian conservation.

Note: see also Figures 3-21 and 3-22.

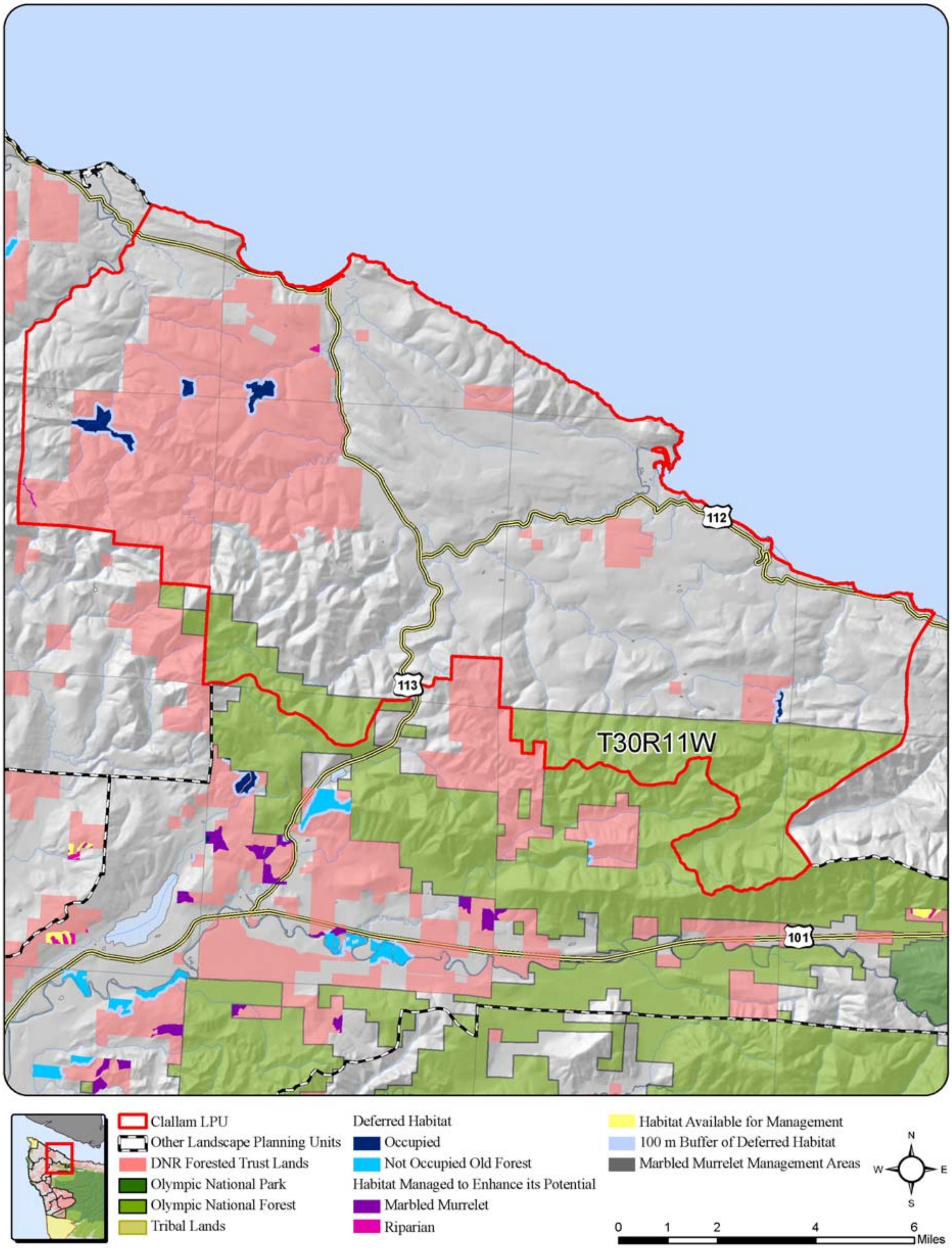


Figure 3-21. Proposed Science Team Land Allocations for Clallam LPU.

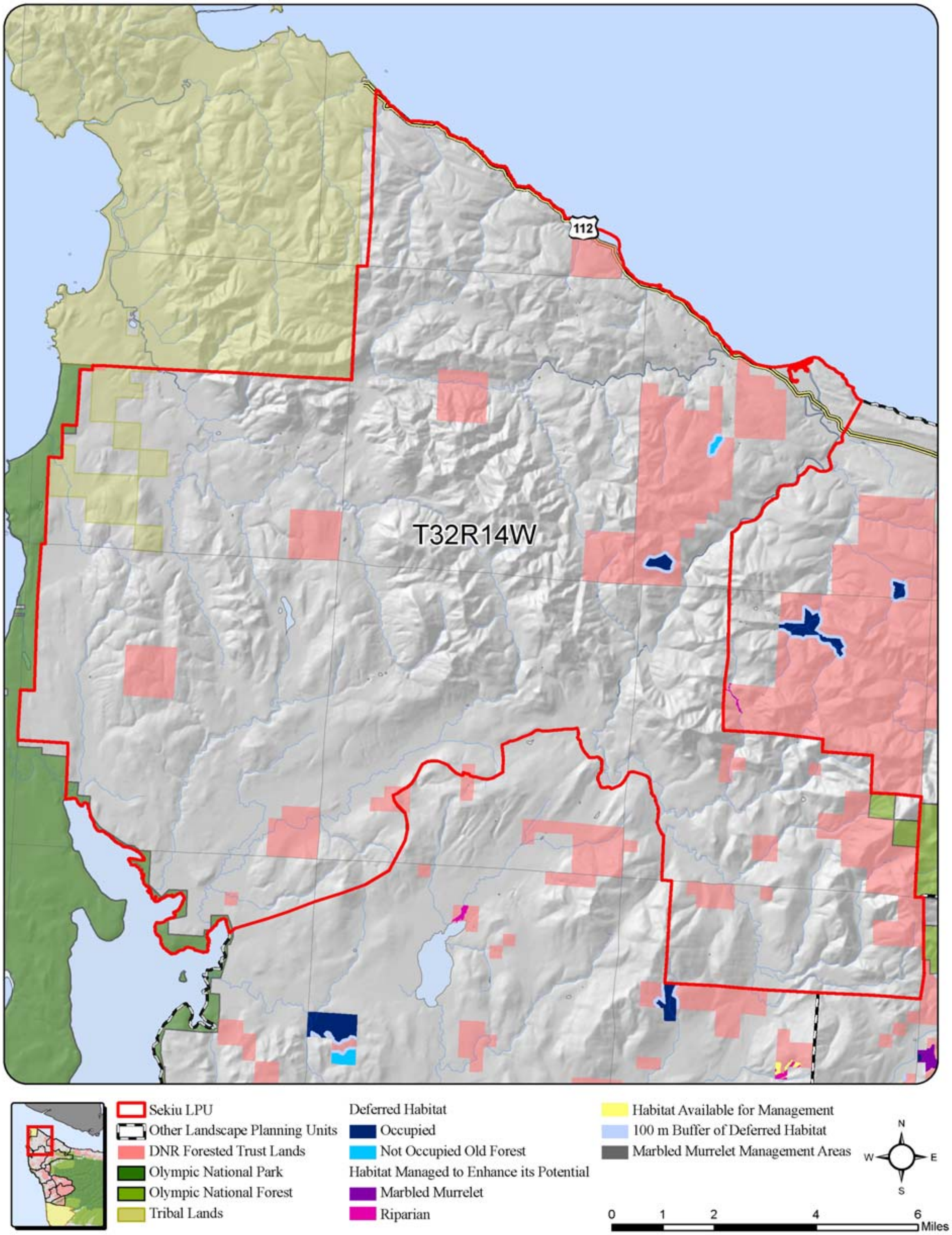


Figure 3-22. Proposed Science Team Land Allocations for Sekiu LPU.

Table 3-12. Conservation Approaches and Recommendations—Dickodochtedor, Goodman Creek, and Kalaloch LPUs.

Conservation Approach	Recommendations
Emphasis on marbled murrelet conservation model.	1. MMMAs are intended to provide abundant high-quality nesting habitat in a minimally fragmented context. Each MMMA will be managed to achieve and maintain at least 50% of the MMMA (maximizing interior area) in habitat, and maintain at least 2/3 of the remaining areas in stands with the tallest 40 trees per acre at least 80 feet tall. 2. Remaining habitat within MMMAs will be deferred from harvest or managed to enhance their potential as marbled murrelet nesting habitat. 3. Remaining habitat outside MMMAs (Table 3-13) will be managed according to broad DNR policies and procedures, including commitments for northern spotted owl and riparian conservation.

Note: see also Figures 3-23, 3-24, and 3-25.

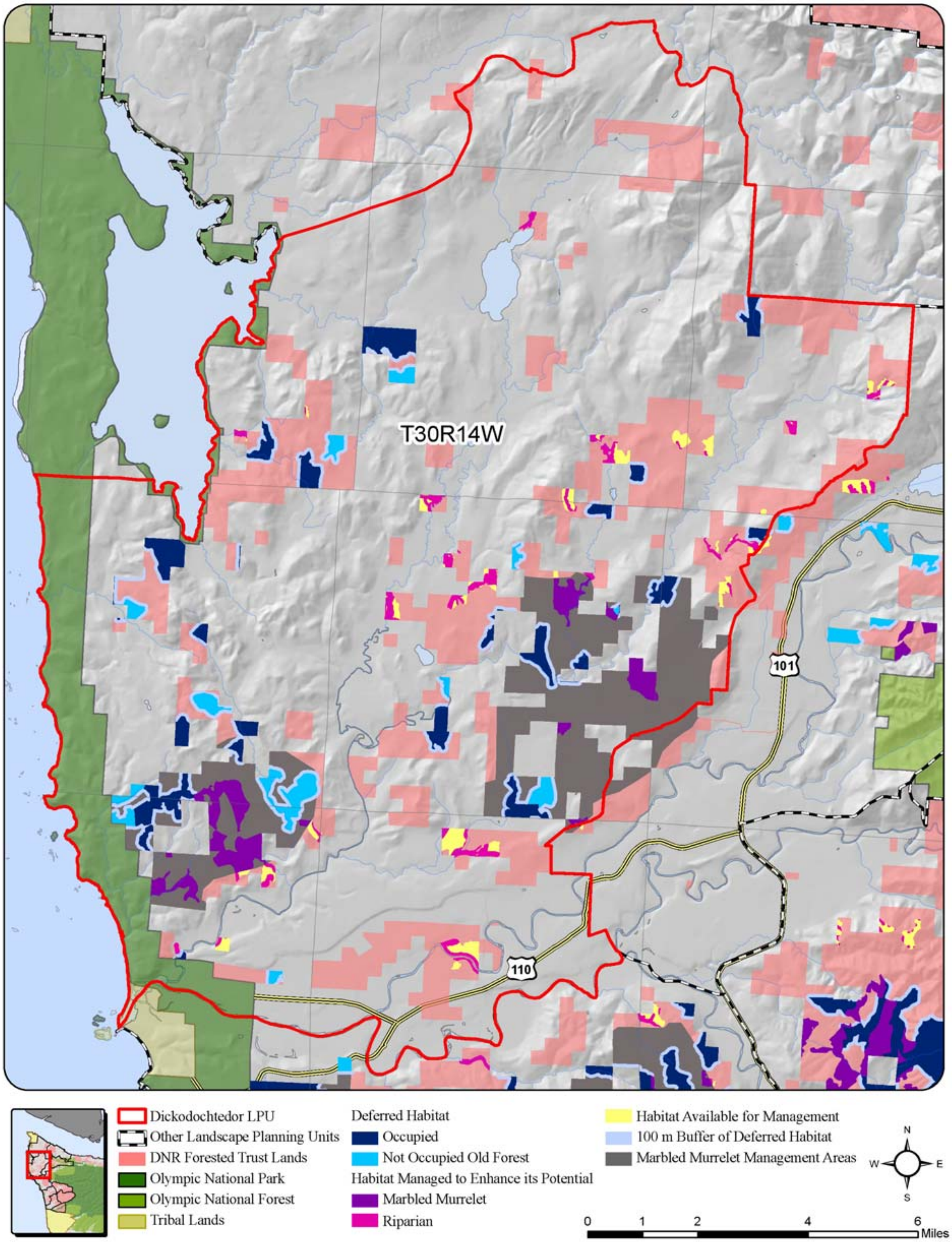


Figure 3-23. Proposed Science Team Land Allocations for Dickodochtedor LPU.

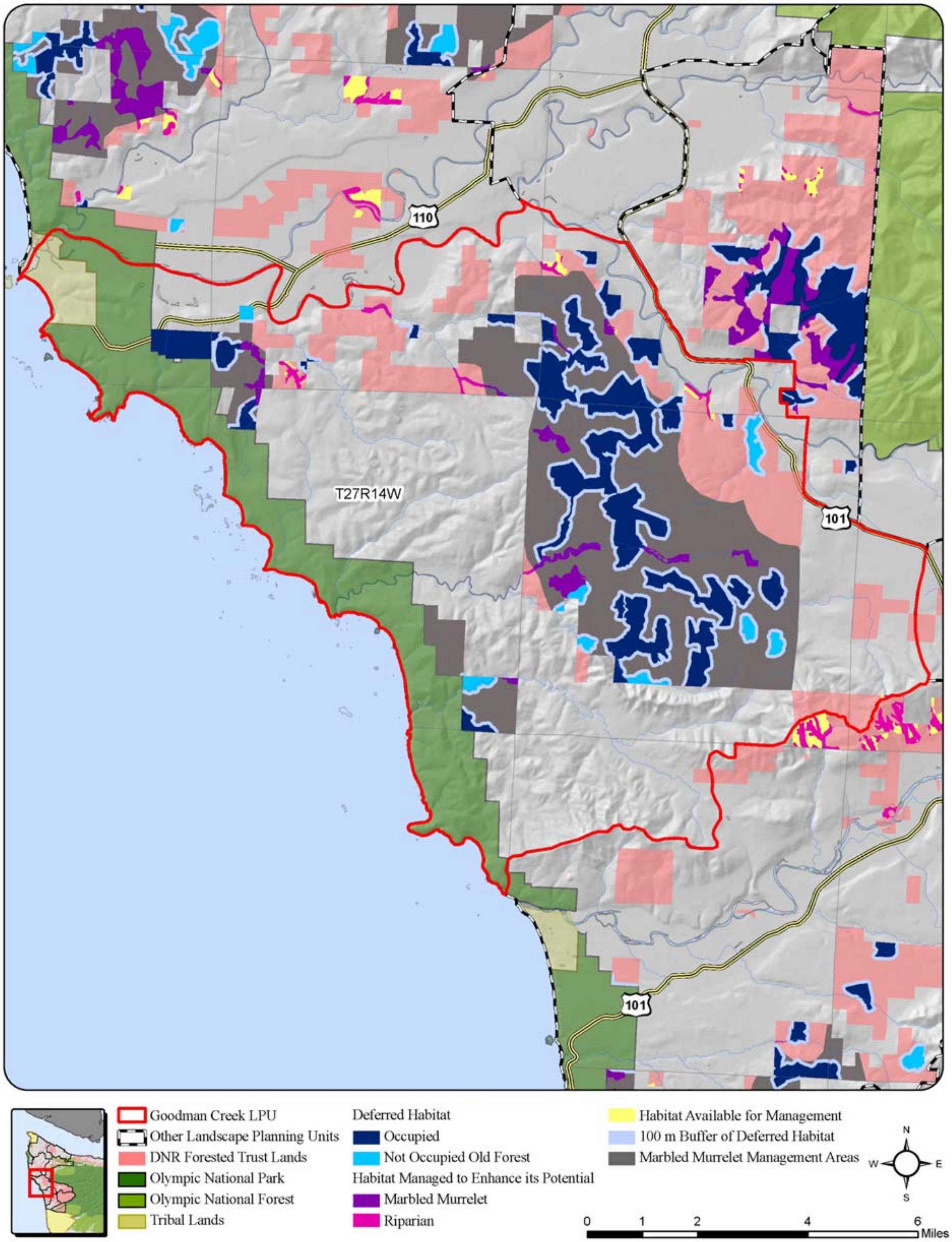


Figure 3-24. Proposed Science Team Land Allocations for Goodman Creek LPU.

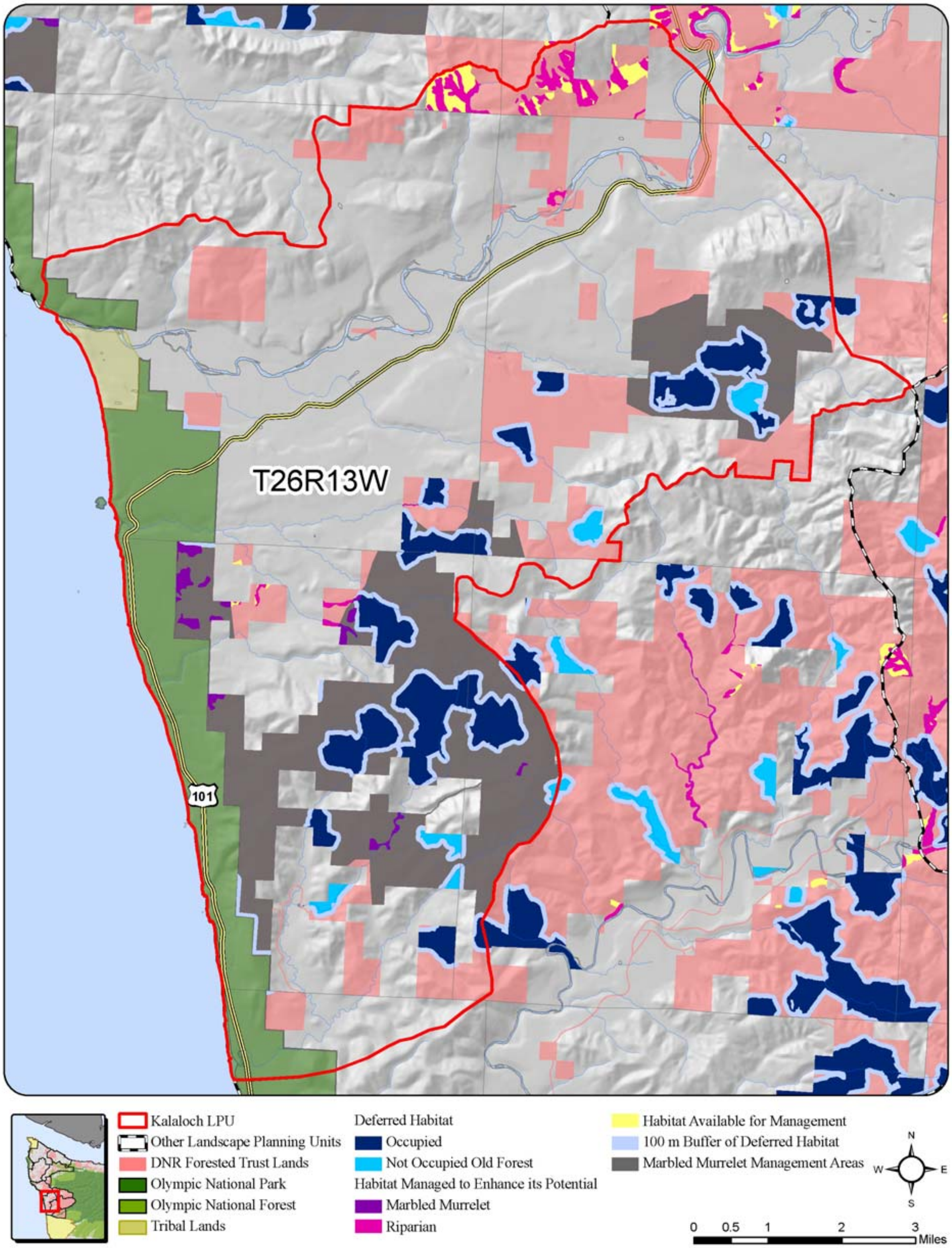


Figure 3-25. Proposed Science Team Land Allocations for Kalaloch LPU.

3.3e Evaluation of Unsurveyed Habitat

As noted in chapter 1.0, not all reclassified habitat in the OESF, identified by the habitat relationship study predictive model (Prenzlow Escene 1999), was surveyed during the inventory phase of the Interim Conservation Strategy. Approximately 39,000 acres (15,800 hectares) of reclassified habitat have been surveyed whereas approximately 15,000 acres (6,100 hectares) remain unsurveyed in the OESF. Marbled murrelets were detected at 92% of the survey sites and occupied behaviors were observed at 52% of the sites with detections (see Appendix F for a discussion regarding DNR's inventory survey effort). DNR and USFWS mutually agreed to move forward with the LTCS planning without these survey results (DNR/USFWS Letter of Concurrence, April 8, 2003). The Science Team paid additional attention to these unsurveyed stands as conservation approaches were developed in the OESF.

Because the inventory phase of the Interim Conservation Strategy focused its survey effort in stands of old forest, most of the surveyed area in the OESF is old forest, and conversely much of the unsurveyed acres in the OESF are not old forest. Table 3-13 summarizes acres of habitat in the OESF by LPU and status under these proposed conservation recommendations. Recall, habitat refers to reclassified habitat that has been evaluated based on an orthophotograph inspection (dated 2005 for OESF) and limited field verification and, subsequently, "adjusted" with subtractions and additions to the original reclassified designation. The final column of Table 3-13 summarizes the acres of habitat for each LPU that are not occupied, not considered to be old forest, not designated for marbled murrelet conservation emphasis, and not within a riparian buffer. While, some of these remaining acres have been surveyed, the majority of them have not.

Under the Science Team recommendations, the amount of habitat that would remain in the OESF without explicit conservation is 1,698 acres (687 hectares). These areas were not deemed critical for achieving the biological goals established by the Science Team.

Table 3-13. Olympic Experimental State Forest Landscape Planning Unit Habitat Calculations.

Landscape	Acres of DNR-Managed Forestland					
	Total Habitat	Deferred		Not Occupied Non-Old Forest Habitat		
		Occupied	Not Occupied Old Forest[1]	Managed to Enhance Habitat Potential[2]		Available for Management
				Marbled Murrelet	Riparian[3]	
OESF Map Legend Color		*Dark Blue*	*Blue*	*Purple*	*Pink*	*Yellow*
Upper Clearwater	16,608	14,266	1,183	0	995	164
Willy-Huel	8,675	6,960	833	0	592	290
Reade Hill	2,558	1,470	0	954	52	82
Queets	5,220	4,752	255	137	59	17
Copper Mine	3,422	2,820	389	0	148	65
Upper Sol Duc	1,669	42	797	663	48	119
Clallam	348	319	0	0	28	1
Sekiu	85	62	23	0	0	0
Dickodochtedor	5,259	2,005	829	1,141	656	628
Goodman Creek	5,586	4,310	432	577	188	79
Kalaloch	3,391	2,255	291	198	394	253
Grand Total	**52,821**	**39,261**	**5,033**	**3,670**	**3,160**	**1,698**

[1] The term "old forest habitat" is used in the HCP to help define northern spotted owl habitat in the conservation strategy for the OESF (DNR 1997a, p. IV.88). Old forest habitat was identified in the OESF in fulfillment of that strategy, and was then used by the Science Team to help identify areas likely to provide nesting habitat and therefore make a contribution to marbled murrelet conservation.
[2] The acre summary columns (except Total Habitat) are mutually exclusive.
[3] All riparian habitat will be managed according to the DNR riparian conservation strategy for the Olympic Experimental State Forest (DNR 1997a).

3.4 Conservation Approach for a Marbled Murrelet Long-Term Conservation Strategy in the Straits

Non-federal lands in the Straits Analysis Unit occur in a narrow peripheral band, approximately four to nine miles (6 to 14 kilometers) wide, on the northern and eastern Olympic Peninsula (Figures 3-26 and 3-27). DNR-managed lands (118,000 acres [47,753 hectares]) comprise approximately one-fourth of the non-federal land base in the analysis unit (Table 3-1, Figures 3-26 and 3-27). Similar to the other non-federal forests, they are almost exclusively second- and third-growth forests that regenerated after commercial timber harvest, land-clearing, and associated wildfires in the late 19th and early 20th centuries, and from subsequent commercial harvests and reforestation. Thus, high-quality inland habitat for the marbled murrelet is scarce on state and private forestlands in the Straits Analysis Unit. Low-density residential is supplanting commercial forestry as the dominant land use in the non-federal lands, with several small cities and limited agriculture making up the remainder. Federal lands in Olympic National Park and Olympic National Forest make up 60% of the 1.2 million acre (485,600 hectare) analysis unit and are estimated to contain 75% of existing marbled murrelet habitat (Table 3-1). Much of this is high-quality habitat in old-growth forests in a wilderness setting.

Marbled murrelets have been observed moving throughout the waters surrounding the Olympic Peninsula and engaging in very long commuting flights (over 50 miles [80 kilometers] one-way) between nesting and foraging areas (Bloxton and Raphael 2006, 2007). These long-distance movements suggest that marbled murrelet nesting habitat in the Straits Analysis Unit should be considered in the context of the entire Olympic Peninsula. The nature and abundance of existing potential marbled murrelet habitat on federal and DNR-managed forests, as well as results of comprehensive inland surveys for marbled murrelets on DNR-managed lands (Harrison et al. 2003), suggest that state forests currently provide a relatively minor contribution to the carrying capacity for marbled murrelets in the Straits Analysis Unit. The habitat known to be occupied on DNR-managed lands in the Straits Analysis Unit occurs predominantly in smaller, isolated stands compared to the adjacent, extensive old-growth forests found on federal lands. Additionally, the quality of these occupied stands is almost exclusively second growth, Douglas-fir forest. Consequently, the Science Team recommends that all currently known occupied marbled murrelet sites be managed to retain habitat capability and be buffered with closed canopy forest strips at least 328 feet (100 meters) wide and does not recommend further measures to meet their conservation objectives.

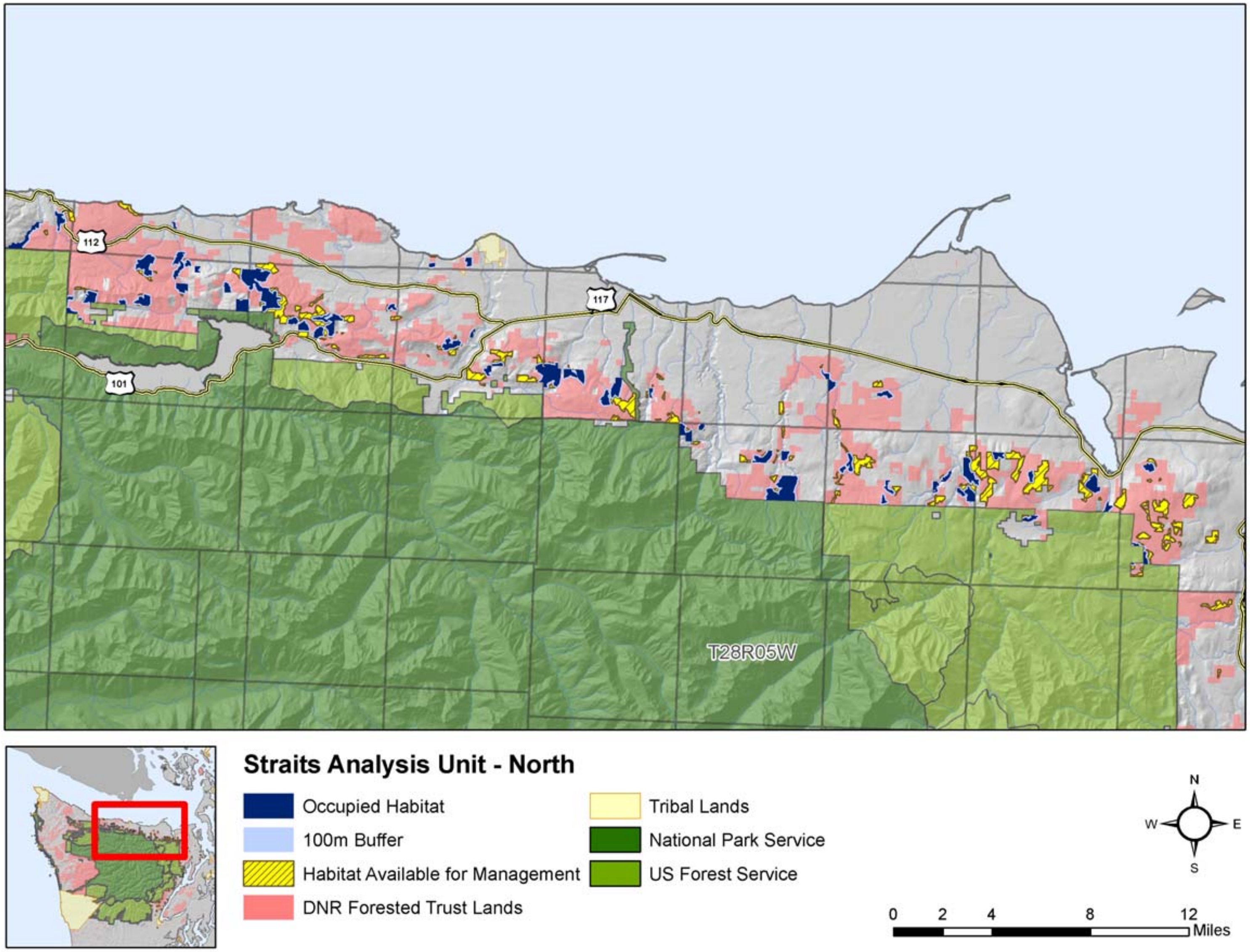


Figure 3-26. Overview of the Proposed Science Team Land Allocations for the North Portion of the Straits Analysis Unit.

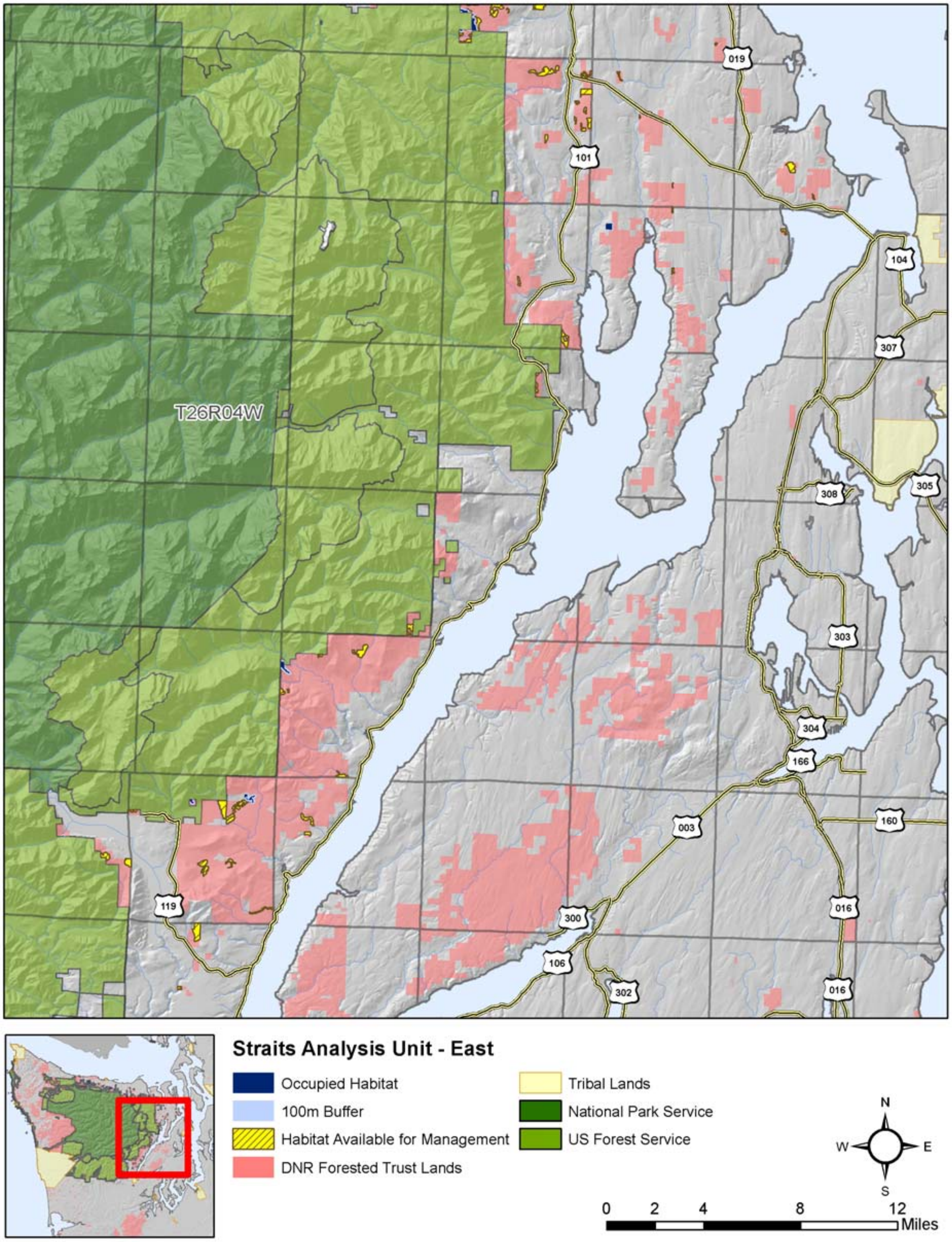


Figure 3-27. Overview of the Proposed Science Team Land Allocations for the East Portion of the Straits Analysis Unit.

4.0 HABITAT ASSESSMENT METHODS

I. ESTIMATING POTENTIAL MARBLED MURRELET POPULATION RESPONSES TO CURRENT AND PROJECTED FOREST HABITAT

This section documents the Science Team's methods to describe the potential for current and projected forest habitat to support populations of marbled murrelets. These methods were applied to the Science Team's recommended conservation approach to conduct the analyses presented in chapter 5.0, although any alternative recommendations for marbled murrelet conservation can be evaluated using these methods. The objectives of the analyses applied to the Science Team's recommendation are to present objective, repeatable, quantitative comparisons of current and projected forest habitat for marbled murrelets on DNR-managed lands and other ownerships; and to illustrate potential responses of marbled murrelets to current and projected habitat using an index for carrying capacity. Results of these analyses will be provided to DNR and USFWS managers to assist in the evaluation of the Science Team's recommendations and for alternatives that are subsequently considered.

4.1 Population Responses to Habitat

Both the quality and quantity of nesting habitat are hypothesized as factors limiting the marbled murrelet population because of their influences on nesting rates and nest success. Forest stands differ in their functionality as potential habitat. Several elements of stand structure and composition that often increase with successional development, particularly potential nesting platforms and complex canopy architecture, are important for providing accessible, secure nest sites (Nelson 1997).

At the scale of large segments of the North American coast from British Columbia, Canada south to San Francisco, Raphael (2006) found that at-sea murrelet population size increased linearly with increasing amounts of adjacent higher quality potential nesting habitat. Similarly, at the scale of watersheds, the abundance of nesting marbled murrelets appears to be a function of the abundance of potential nesting habitat because five radar studies in British Columbia (reviewed by Burger 2002) and one on the Olympic Peninsula (Raphael et al. 2002a) consistently found linear relationships between the amount of habitat in watersheds and the numbers of marbled murrelets detected flying into them. At a finer scale, nesting rates (nests per acre per year) have been hypothesized to decrease with diminishing size and contiguity of habitat patches (Meyer et al. 2002) because, as shown with other species, reduced nest success in smaller habitat patches in fragmented landscapes may eventually increase breeding dispersal (Haas 1998, Newton 2001, Kokko et al. 2004) or limit nesting attempts (Ripple et al. 2003).

Nest success has been hypothesized to be greatest in interior forest, because of increased predation at edges, and in landscapes with lower levels of fragmentation because of relatively lower predator abundance (reviewed by McShane et al. 2004). Life-cycle modeling (Morris and Doak 2002) can be used to predict habitat influences on overall population performance (Budy and Schaller 2007). A model that linked performance at each stage of the marbled murrelet life cycle with habitat conditions (Horton 2008) was developed to predict effects of the amount and configuration of forest habitat on marbled murrelet populations. However, there is considerable uncertainty about how the amount, stand-level characteristics, and configuration of forest habitat influence key elements of population biology, nesting rates, nest success, and adult survival of marbled murrelets (Raphael 2006). Thus the Science Team decided to quantify the potential influence of current and projected nesting habitat using a conceptually simpler approach that was not directly linked to the marbled murrelet's life cycle—a single index that integrated habitat abundance, stand-level quality, and negative edge effects. The development and application of this index is described below.

4.2 An Index of the Potential Influence of Habitat Quality and Quantity on Marbled Murrelet Populations in Washington

The index incorporates four elements of marbled murrelet relationships with forest habitat:

- Broad-scale correlation of numbers of marbled murrelets to area of habitat.
- The gradient in habitat quality caused by variation in stand structure and composition.
- The apparent reduction in habitat quality by edge effects.
- The influence of distance from their marine habitat.

These elements can be expressed as mathematical relationships among area, structure, composition, and context of forest stands across the plan area to predict the capability of current and projected habitat to support marbled murrelet populations. However, the index should not be considered an explicit prediction of current or future marbled murrelet numbers; rather, it should be viewed as an objective, repeatable, qualitative index that can be used to judge relative conservation values of DNR-managed lands as well as all other lands across the planning area. This chapter describes the rationale, derivation, and application of this index.

4.3 The Relationship of Habitat Area with Marbled Murrelet Abundance

Carrying capacity, symbolized as *K*, is a core concept in population ecology and describes the relationship that occurs between population size and the abundance of environmental resources (Odum and Barrett 2005). This concept appears to apply to marbled murrelet populations and the abundance of their potential nesting habitat because of the consistent linear relationships between numbers of marbled murrelets detected with radar and the amount of habitat in the watersheds they access (Burger 2002, Raphael et al. 2002a). Although Raphael et al. (2002a) referred to this relationship as the "ecological density" of marbled murrelets on the Olympic Peninsula, it can also be thought of as a reflection of the carrying capacity (i.e., the numbers of marbled murrelets that can be supported by a given area of nesting habitat).

Raphael et al. (2006) estimated that, on average, 396 acres (160 hectares) of nesting habitat were available per marbled murrelet detected by radar during their 2002 study. However, radar only predictably detects inland-flying marbled murrelets, so additional information is needed to relate habitat area to the entire marbled murrelet population. Radiotelemetry studies of marbled murrelet inland flight behavior (Peery et al. 2004b) found that in a sample of 46 tagged marbled murrelets, breeding birds flew inland on 82% of sampling occasions while non-breeding birds that were physiologically capable of breeding flew inland on 41% of sampled days. Non-breeders that were not in breeding condition almost never flew inland. The 46 tagged birds were approximately equally distributed among those three categories (28% breeders, 38% "potential breeders", and 34% non-breeders; Peery et al. 2004b). If one assumes that the radar studies of Raphael et al. (2002a) examined the inland flight patterns of a marbled murrelet population that was equally distributed among breeders, potential breeders, and non-breeders (i.e., breeders = B, potential breeders = P, non-breeders = N, total population = T/3), and that those birds behaved approximately (rounding conservatively 82% to 85% and 41% to 45%) as did the radio-tagged birds studied by Peery et al. (2004b), then one can calculate that approximately 43% of the population is likely to be detected with radar, as

$$(B * 0.85) + (P * 0.45) = (1/3 * 0.85) + (1/3 * 0.45) = 0.43.$$

Thus using these assumptions, *K* (carrying capacity) is approximately 170 acres (69 hectares) (i.e., 396 acres * 0.43) of potential nesting habitat per marbled murrelet. Applying this relationship to the habitat estimates from Raphael et al. (2006) predicts a Washington population of 12,680 individuals, compared to Washington at-sea counts from the 2001 to 2005 breeding-season surveys that estimated the population at 8,540 to 12,340 (average 10,760) (Miller et al. 2006).

4.4 The Relationship of the Structure and Composition of Forest Stands with Their Potential Contribution to Carrying Capacity for Marbled Murrelets

The estimate of *K* for marbled murrelets in Washington is based on a classification of marbled murrelet habitat above and below a certain threshold (Raphael et al. 2006). Raphael et al. (2006) used this approach to meet the objectives of their analysis that was applied to satellite imagery and calculated a habitat index value from 0 to 100 for each 82-foot x 82-foot (25-meter x 25-meter) pixel within the marbled murrelet's range. That index reflected their estimate of a gradient in habitat quality that was caused in large part by variability in stand structure and composition. However, their methods were not directly applicable to predicting habitat suitability from DNR's high-resolution forest resource inventory system (FRIS) or projections of that inventory into the future. Thus, the Science Team developed a method to estimate stand-level habitat quality that was appropriate to DNR's forest inventory.

Forests managed by DNR were assumed to provide carrying capacity at the spatial scale of stands (i.e., discrete units of forest that are relatively homogenous with respect to their structure and composition). Stands are approximated in FRIS as Resource Inventory Units (RIUs) that average 60 acres (24 hectares) across the SWWA, OESF, and Straits Analysis Units. These RIUs and their associated forest inventory are mapped and cataloged in DNR's GIS. This inventory includes robust estimates of the abundance, species composition, diameter, and height of live trees for each RIU (DNR 2002b). These data can be used to estimate the relationship between the current and projected structure of RIUs and their respective contributions to *K*, based on the assumption that at the stand level, *K* is a function of habitat quality that can be inferred from the relationship between marbled murrelet use and stand characteristics (see reviews in Burger 2002 and McShane et al. 2004).

Two stand characteristics are directly related to the abundance and availability of potential nest sites: platforms and canopy complexity. Stands with abundant platforms and multilayered canopies have been consistently found to have the greatest likelihood of marbled murrelet use (reviewed by Burger 2002 and McShane et al. 2004). Neither of these characteristics were directly measured during DNR's forest inventory; instead they were inferred from inventory-based stand tables.

The number of canopy layers was estimated with the methods of Crookston and Stage (1999), while platform abundance was estimated with a model (Duke 1997) developed from field studies in SWWA in support of the Washington Forest Practices protocols for identifying marbled murrelet habitat (Washington Forest Practices Board 2005 [WAC 222-12-090]). Murrelet use (i.e., "occupancy") was estimated in inland surveys (Ralph et al. 1994) at 355 sites conducted from 1994 to 2001 on DNR-managed lands in the SWWA Analysis Unit (see Prenzlow Escene 1999 and Harrison et al. 2003 for survey reports).

Logistic regression models were built from all possible subsets of three independent variables (platforms per acre [ppa], numbers of canopy layers [lyr], and their interaction [ppa * lyr]) against the dependent variable of occupancy. Number of survey visits and number of visits with at least one detection of occupancy were used to incorporate the uncertainty of detecting occupancy with inland surveys (J. Baldwin, pers. comm.). The model with the lowest AIC value (model one in Table 4-1) provided the best fit to the marbled murrelet survey results, while five of the other models (models two through six) fit reasonably well and therefore provide some empirical support (Burnham and Anderson 2002).

Only the model with exclusively canopy layers (model seven) failed to provide a good fit to the survey data; models that incorporated ppa and/or the interaction of ppa and lyr were reasonably supported by the data. Thus, model selection and averaging techniques (Burnham and Anderson

Table 4-1. All Possible Logistic Models Fit to the Marbled Murrelet Survey Results, their ΔAIC Values, and a Normalized Measure of the Weight of Evidence that Model *i* was the Best among the Set (*w*).

Model	**Variables**			**ΔAIC**	***w*(*i*)**
1		lyr	ppa * layer	0.0	0.58
2	ppa	lyr	ppa * layer	1.3	0.30
3	ppa			4.8	0.05
4	ppa	lyr		6.1	0.03
5	ppa		ppa * layer	6.5	0.02
6	ppa		ppa * layer	8.1	0.01
7		lyr		29.2	0.00

2002) were used to incorporate predictions from models one through six about the probability that marbled murrelets occupy DNR-managed stands, based on their structure and composition (Prenzlow Escene et al. 2006).

These models demonstrated an increasing probability of occupancy—increased habitat quality or greater contribution of stands to *K*—with increasing density of platforms and numbers of canopy layers. Figure 4-1 illustrates this relationship, plotting the multivariate, model-averaged predicted probability of occupancy against the interaction term (ppa * lyr) for all 355 occupied and not occupied sites in the analysis. Note that the predictions cluster along three separate curves on the graph—illustrating predictions for stands with one, two, or three canopy layers—and that higher probabilities of occupancy are achieved only in stands with more complex canopy structures. These data and model-averaged predictions were used to generalize the probability of occupancy to a description of stand development stages (SDS) (Carey et al. 1996, Brodie et al. 2004).

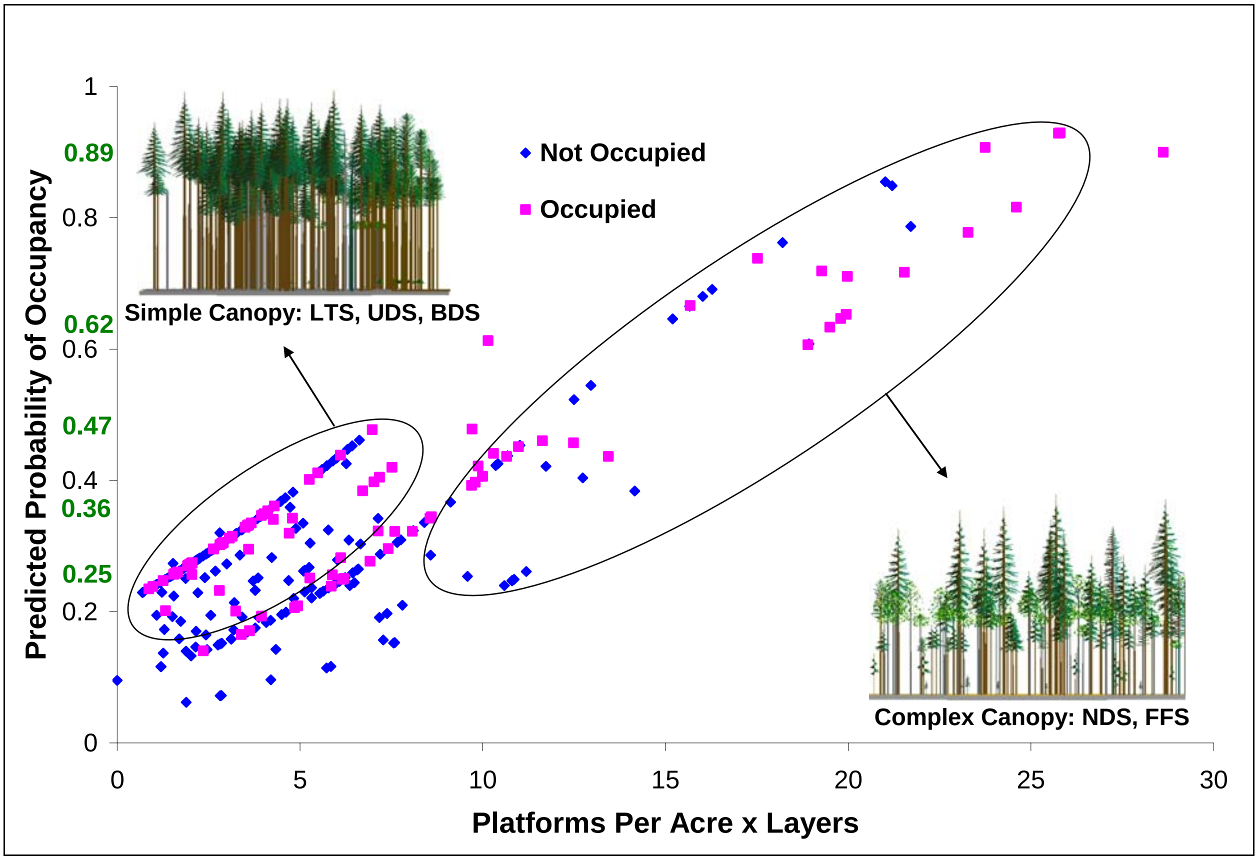


Figure 4-1. Model-Averaged Predicted Probability of Marbled Murrelet Occupancy Compared with the Interaction of Platforms per Acre and Canopy Layers. LTS Refers to Large Tree Exclusion, UDS to Understory Development, BDS to Botanically Diverse, NDS to Niche Diversification, and FFS to the Fully Functional Stages of Stand Development (See Appendix B).

This generalization enabled the use of forest growth models that DNR developed and employed in examining alternatives for sustainable forest management (DNR 2004b).

After a thorough investigation of DNR's habitat relationships data in SWWA (Prenzlow Escene 1999) and information provided by Washington State Forest Practices Board and the Oregon Department of Forestry regarding platform abundance in second-growth forests, the SDS of Large Tree Exclusion (LTS) was estimated to approximate minimum potential nesting habitat, or suitable habitat (having two or more platforms per acre). These stands can be characterized as having simple structure without multiple canopy layers, yet having some expression of large trees capable of providing potential nesting platforms. Sites in our analysis which clustered around two platforms per acre and one canopy layer had a mean model-averaged predicted probability of occupancy of 0.25; thus LTS stands were assumed to have a 0.25 probability of use by marbled murrelets.

The Botanically Diverse (BDS) stage of stand development was assumed to correspond to simple-structured stands, i.e., with a single canopy layer, but having a greater abundance of large trees capable of providing potential nesting platforms. The maximum model-averaged predicted probability of occupancy for all but one simple-structured site in our analysis was 0.47; thus BDS stands were assumed to have a 0.47 probability of use by murrelets. Understory Development (UDS) is a developmentally-intermediate stage between LTS and BDS; therefore, UDS stands were assumed to have a 0.36 probability of marbled murrelet use because that value is half-way between 0.25 and 0.47.

The Fully Functional (FFS) stage of stand development describes stands with multiple canopy layers and abundant large trees that provide potential nesting platforms. The highest model-averaged predicted probabilities of occupancy among sites with multiple canopy layers and abundant platforms was approximately 0.89; thus FFS was assumed to have a 0.89 probability of marbled murrelet use. Niche Diversification (NDS) is the developmentally-intermediate stage between BDS and FFS; thus it was assumed to have an intermediate probability of murrelet use of 0.62.

To summarize, these generalizations of the probability of occupancy to a description of stand development stages resulted in predicted probabilities of marbled murrelet use of 0.25, 0.36, 0.47, 0.62, and 0.89 for the Large Tree Exclusion, Understory Development, Botanically

Diverse, Niche Diversification, and Fully Functional stages of stand development, respectively (Brodie et al. 2004, Appendix B). These probabilities (P_{stage}) were used to modify the predicted contribution to K of current and projected future habitat in DNR-managed stands as $K_{stage} = K * P_{stage}$. For example, applying this concept to the Botanically Diverse stage (P=0.47), K_{BDS} = (170 acres/marbled murrelet) * 0.47 = 1 acre / 0.00295597 marbled murrelets, which translates to 338.3 acres (136.9 hectares) of Botanically Diverse forest / 1 marbled murrelet. Extending this concept to a 100-acre (40-hectare) Botanically Diverse stand, K_{stand} = (170 acres/marbled murrelet) * 0.47 * 100 acres = 0.296 "marbled murrelet units."

The same concepts were applied to forest cover across the entire planning area to assess current and future marbled murrelet habitat on all other forestlands with methods broadly consistent with those used for DNR-managed lands. The need to estimate edge effects and to project forest succession across the analysis units required the use of classified satellite imagery (82-foot x 82-foot [25-meter x 25-meter] pixels) developed by the Interagency Vegetation Mapping Project (IVMP) (http://www.blm.gov/or/gis/index.php) from images collected between 1992 and 1996 (estimation of edge effects are discussed in section 4.8). These IVMP data were also used by Bloxton and Raphael (2007) as input data to their marbled murrelet habitat estimates. The methods of Green et al. (1993) were used with the IVMP data to classify land cover on non-DNR ownerships. Land cover was assigned to six classes: late-, mid-, and early-seral conifer; a non-conifer class that included early clearcuts, meadows, and hardwoods; non-forest; and water.

Forest land managers on the Olympic Peninsula and SWWA can be broadly classified as DNR, federal, and other. Federally managed forests are in Olympic National Park, a wilderness area, and Olympic National Forest, which has much congressionally-designated wilderness as well as other areas, most of which are currently managed to maintain or restore late-successional forests (USDA and USDI 1994). Other forest managers include forest industry, Native American tribes, and small private landowners. Based on two separate habitat estimates reported by Raphael et al. (2006) and the considerable local knowledge of the Science Team, existing late-seral conifer on federally managed forests was assigned P=0.68. (The midpoint of the P applied to the more structurally complex stages, Botanically Diverse, Niche Diversification, and Fully Functional.) Meanwhile, existing late-seral conifer on other forests (DNR- and privately managed lands) was assigned P=0.31. (The midpoint of the P applied to the less structurally complex stages that could provide marbled murrelet habitat, including Large Tree Exclusion and Understory Development.)

4.5 Estimating Current and Future Marbled Murrelet Habitat

Current conditions were estimated using 2004 forest inventory data for DNR-managed lands and IVMP data (1992 to 1996), classified as described above and projected to 2004, for other ownerships. Future conditions were evaluated for the years 2013, 2031, and 2067 using (a) projections for management of the MMMAs to achieve the habitat conditions recommended by the Science Team, and (b) growth and harvest projections from DNR's 2004 sustainable harvest calculation preferred alternative (DNR 2004b) for DNR-managed lands without explicit marbled murrelet conservation roles.

Land cover estimates for many non-DNR lands were held static through these projections. This was based on two assumptions: growth and harvest were relatively proportionally constant in private and tribal commercial forests; and that conditions in federally managed wilderness areas reflected a natural disturbance regime, so that the 1992 to 1996 satellite images broadly represented future conditions as well. That is, in those portions of the 5.5-million-acre (2.2-million-hectare) analysis landscape that encompassed 158,200 acres (64,021 hectares) of MMMAs, landscape patterns would vary unpredictably at finer scales over the analysis period, but landscape composition and pattern would remain relatively unchanged overall.

Forest succession was projected for several portions of the analysis landscape according to the following assumptions. Riparian non-DNR forestlands would mature according to Washington Forest Practices rules (Washington State Forest Practices Board 2002 [WAC 222-30-021]), as would previously harvested areas in Late Successional Reserves and Adaptive Management Areas of the Olympic National Forest (USDA and USDI 1994). Thus, clearcut, early-seral, and mid-seral conifer stands advanced to late-seral (Green et al. 1993) according to growth projections for modal stands in the analysis area. Those projections are summarized in Table 4-2 below. Late-seral forests that were projected to develop over time in those areas were conservatively assumed to be in the Large Tree Exclusion stage (P=0.25). Late-seral forest that was projected to develop in non-federal riparian forests was assumed to have P=0.13 (0.25 * 0.5), reflecting biophysical limitations on the development of late-seral forests in riparian areas and disturbance-related processes (e.g., windthrow) that would also limit its development. Late seral forest that was projected to develop in previously harvested areas in Late Successional Reserves and Adaptive Management Areas of the Olympic National Forest (USDA and USDI 1994) was assumed to have *P*=0.20 (0.25 * 0.8), reflecting biophysical limitations on the development of late-seral forests across the landscape in general.

Table 4-2. Projections of Forest Succession among Seral Stages for Previously Harvested Areas on Non-DNR-Managed Lands. (See Appendix B for an Explanation of Green et al. [1993] Forest Successional Stages.)

1992–1996	2004	2013	2031	2067
Clearcut	Early-Seral	Early-Seral	Mid-Seral	Late-Seral
Early-Seral	Mid-Seral	Mid-Seral	Late-Seral	Late-Seral
Mid-Seral	Mid-Seral	Late-Seral	Late-Seral	Late-Seral
Late-Seral	Late-Seral	Late-Seral	Late-Seral	Late-Seral

Note: This table reflects forest succession among the stages described by Green et al. (1993) for previously harvested areas in late successional reserves and adaptive management areas of the Olympic National Forest (USDA and USDI 1994) and riparian forests on private and tribal forestlands.

4.6 Projecting Marbled Murrelet Habitat Development on DNR-Managed Lands

A brief summary of the basis for projecting forest growth and a description of the stages of stand development (Carey et al. 1996, Brodie et al. 2004) is necessary to describe how marbled murrelet habitat development was projected for DNR-managed forests.

To expedite these analyses and to make use of the comprehensive analyses DNR had recently conducted in support of the sustainable harvest calculation (DNR 2004b), the Science Team used the system of stand development stages (SDS), which was developed to describe the transition through functionally based stages of forest stand development (Brodie et al. 2004). The SDS model was the result of several independent lines of investigation and consultations among a diverse group of experts and stakeholders; it was not specific to the development of nesting habitat requirements of the marbled murrelet. Brodie et al. (2004) provide a detailed description and illustration of these stand development processes and stages. Structural indicators, P_{stage} values (as described above), and predictors for transition among these stages are summarized in Table 4-3.

Table 4-3. Structural Indicators and Estimated Proportions of Marbled Murrelet Carrying Capacity based on Stand Development Stages (Brodie et al. 2004).

Stand Development Stage	Structural Indicators	Relative Murrelet Habitat Potential (P_{stage})
Ecosystem Initiation	QMD < 2 in	0
Sapling Exclusion	2 in ≤ QMD < 5 in	0
Pole Exclusion	5 in ≤ QMD < 11 in	0
Large Tree Exclusion	QMD ≥ 11 in	0.25
Understory Development	Multi-layer canopy or past peak RD	0.36
Botanically Diverse	Multi-layer canopy or 60 years past peak RD	0.47
Niche Diversification	Snag ratio > 0.07 and CWD ≥ 2,400 ft^3/acre or 80 years past peak RD	0.62
Fully Functional and Murrelet Desired Future Forest Conditions share similar components.	Snag ratio > 0.07 and CWD ≥ 2,400 ft^3/acre or 160 years past peak RD	0.89
Note: CWD = coarse woody debris; QMD = quadratic mean diameter; RD = relative density.		

Table 4-3 summarizes several elements of stand structure and composition that are important elements of northern spotted owl habitat. The snag ratio refers to the proportion of standing dead to live trees while coarse woody debris (CWD) refers to the volume of dead trees on the forest floor. Although dead wood is not directly a component of marbled murrelet habitat, it is correlated with the stand processes of differentiation and decadence, which entail increasing the size of dominant trees and the formation of a complex canopy structure (Franklin et al. 2002). Relative density (RD) measures present stand density in relation to a hypothetical maximum (Woodall et al. 2006). Quadratic Mean Diameter (QMD) is the hypothetical diameter of the tree with the average cross-sectional stem area (basal area) in the stand (Curtis and Marshall 2000). QMD is different from the arithmetic mean diameter in that it is weighted toward the larger trees (whose areas increase at a higher rate as their diameters increase) and accounts for diameter variance, thus giving a more detailed idea of stand characteristics (Curtis and Marshall 2000). However, the stand QMD does not necessarily indicate the presence of large trees (e.g., scattered old growth) because a range of stand compositions can have the same QMD. Stand QMD may be low due to the presence of many smaller trees; yet this does not exclude the possibility of the presence of some large trees with platforms which provide the habitat for marbled murrelets. The

QMD, snag ratio, CWD, and canopy layers were estimated from FRIS data to classify stands with the SDS. The higher P_{stands} were assumed for the latter stages with increasingly larger trees and more complex canopies as illustrated by the models described above.

An illustration of the process of stand development is provided for an exemplary stand of naturally regenerated mixed-species/western hemlock with a western hemlock 50-year site index of 110 (Figure 4-2). The figure illustrates how expected QMD and relative density vary over 200 years of stand development, as well as the predicted transitions among SDS classes. Relative density (RD) is a measure of the relationship between stand-level basal area and QMD, and provides an index to the level of inter-tree competition. Note that the working hypothesis is that the transition from a simple to a complex canopy occurs when the site reaches maximum RD, as this is the point at which density-dependent mortality becomes secondary to density-independent mortality within the stand (Franklin et al. 2002). Density-independent mortality is the process by which canopy gaps develop in forest succession (Franklin et al. 2002). Canopy gaps are integral to the development of marbled murrelet habitat as they increase forest accessibility (Burger 2002, McShane et al. 2004).

Assumptions used to develop and support DNR's 10-year timber harvest plan (DNR 2004b) lead to a conclusion that once the threshold of maximum RD is crossed, the exemplary stand would develop Botanically Diverse characteristics within 60 years, Niche Diversification in 80 years, and a Fully Functional state in 160 years. To achieve greater predicted quality of marbled murrelet habitat (i.e., P_{stage}), there must be a greater abundance of very large-diameter trees in addition to complex canopy structure, because such trees provide the platforms necessary for marbled murrelet nest sites. The development of these trees is a function of multiple factors including inter-tree competition. In a no-harvest regime for a western hemlock stand this could mean waiting until competition-induced mortality in the stand begins to wane (i.e., peak RD at 110 to 120 years). DNR simulated these processes for its entire forest inventory with growth models adjusted for stand-specific site indices and existing structure and composition.

To broadly define the stand-level characteristics of high-quality marbled murrelet habitat so the development of such habitat could be projected, the Science Team developed a Desired Future Forest Condition (DFFC). A DFFC, by definition (Holmberg et al. 2005), is a visionary but incompletely defined end state. The Science Team described an initial DFFC for stand-level marbled murrelet habitat on DNR-managed lands as having very large, tall trees with broad, deep crowns that support potential nest platforms, in a stand with multiple canopy layers and canopy gaps. The DFFC is not a rigorously defined forest development stage, but rather a benchmark by which managers can measure progress toward a structurally complex forest that will have the minimal habitat elements necessary to support successful marbled murrelet nesting. Depending on the physical situation of a stand on the landscape, site productivity and other environmental conditions, it may take hundreds of years to reach the forest complexity, and therefore provide the ecological function, to support nesting marbled murrelets.

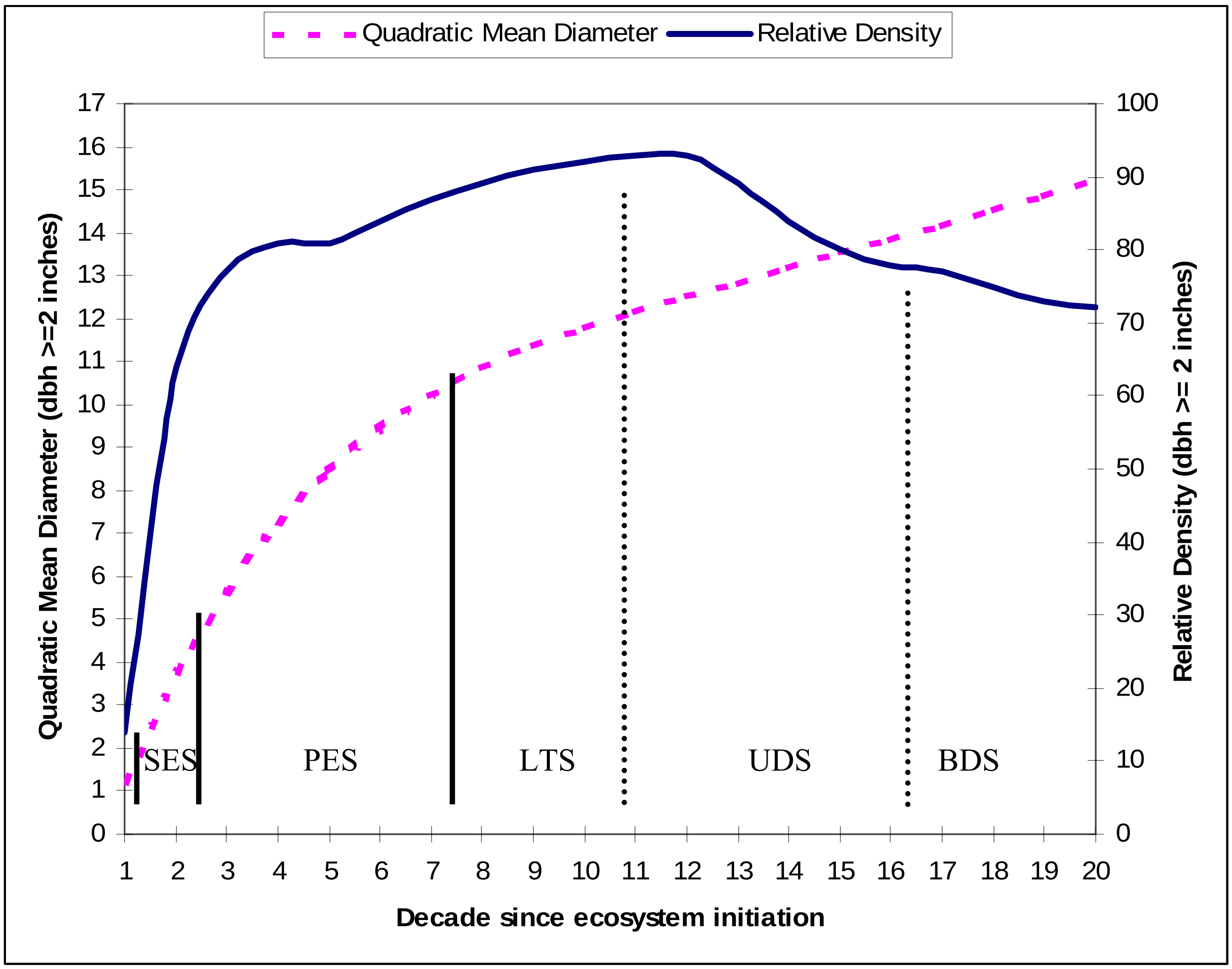


Figure 4-2. Development Stages for a Stand of Naturally Regenerated Mixed-Species/Western Hemlock with a Western Hemlock 50-Year Site Index of 110. Stand Development Stages are Abbreviated as Follows: SES, Sapling Exclusion Stage; PES, Pole Exclusion Stage; LTS, Large Tree Exclusion; UDS, Understory Development; and BDS, Botanically Diverse (Appendix B).

Though the DFFC is a visionary goal that does not contain specific thresholds for habitat characteristics in a stand, these characteristics can be estimated using existing DNR data. Based on an analysis of the structural conditions of inventoried DNR-managed stands in SWWA known to be occupied by marbled murrelets (n=220), the top 25% of this data set had four or more 7 inch (18 centimeter) diameter platforms per acre; two or more canopy layers; and trees with diameter at breast height (dbh) at least 36 inches (91 centimeters), height at least 140 feet (43 meters), crown ratio (height of live crown divided by tree height) at least 50%, and crown width at least 30 feet (9 meters). Trees with these characteristics were considered a critical element of stands achieving the DFFC.

The structural development of stands was simulated in a series of modeling exercises designed to understand the role of active silviculture in achieving the DFFC for marbled murrelet habitat (Reimer et al. 2004). Stands in the MMMAs that were simulated as being treated with these proactive regimes were tracked through the SDS and consequent series of P_{stage} values according to predictions of those models (see section II below). Stands outside the MMMAs were assigned the projections and predicted P_{stage} values that resulted from the forest growth and harvest modeling that described the 2004 sustainable harvest calculation preferred alternative for DNR's plan to implement its 10-year schedule for sustainable timber harvest (DNR 2004b). Nelson and Wilson (2002) found that western hemlock trees used for nesting by marbled murrelets were younger than Douglas-fir nest trees. Western hemlocks frequently develop the large limbs necessary to provide nesting platforms at earlier ages, in part due to dwarf mistletoe infections (Hamer and Nelson 1995). To acknowledge these differences, rates of transition among P_{stage} values were adjusted according to the assumptions summarized in Figure 4-3. An important consequence of these assumptions was that no marbled murrelet habitat capability was projected to develop in Douglas-fir plantations because their transition to the lowest P_{stage} class occurred after the end of the simulation period (2067). Conversely, the more rapid development of habitat characteristics assumed for western hemlock led to the prediction that plantations dominated by western hemlock could achieve a low level of habitat capability (P_{stage}=0.25, Table 4-4) by 2067.

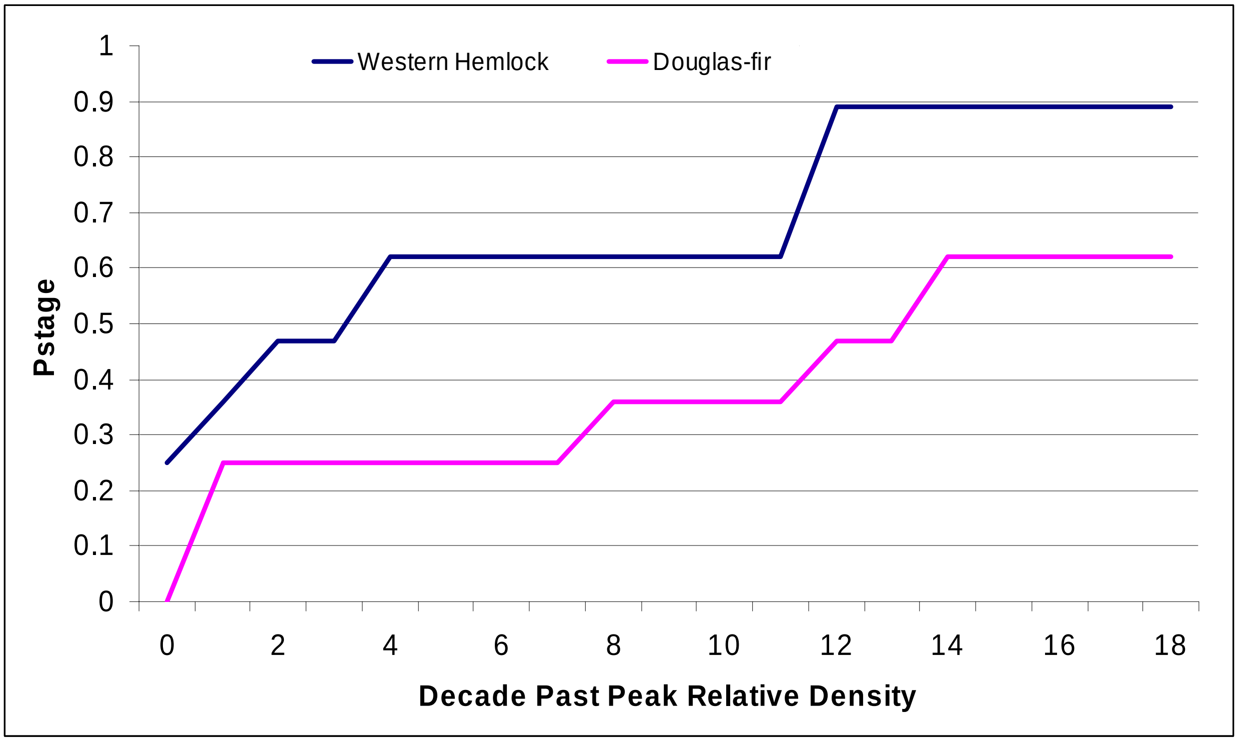


Figure 4-3. Science Team Assumptions Regarding the Rate at which Transitions Occur among Categories of P_{stage} Values for Marbled Murrelet Habitat Quality in Western Hemlock and Douglas-Fir Dominated Stands.

4.7 Summary of the Projected Current and Future Contribution of Forest Stands to Marbled Murrelet Carrying Capacity

The series of relationships and assumptions described above lead to a set of explicit assumptions regarding the P_{stage} values, which vary according to three dimensions: land ownership, existing versus projected land cover, and the application of a variety of projected management regimes for DNR-managed lands (see section II below). The P_{stage} values that are assumed to result from the relationship with these dimensions are summarized in Table 4-4. The influence of uncertainty in the classification of habitat to a particular stand development stage on *K'* is examined in a sensitivity analysis in Appendix H.

Projections of the capability of new habitat to support additional marbled murrelets depend on individuals immigrating to and breeding in these new habitats. The extent to which this will occur will depend on reproductive success and the reduced influence of environmental factors such as corvid presence, although reductions in edge effects could reduce predation.

Table 4-4. Summary Assumptions Regarding Marbled Murrelet Habitat Potential (P_{stage}) for Two Classifications of Forest Successional Stages.

Stand Development Stages (Brodie et al. 2004)	Seral Stages (Green et al. 1993)	Relative Marbled Murrelet Habitat Potential (P_{stage})				
		Existing and Projected Future Conifer Stands on DNR-Managed Land	Existing Conifer Forest in Olympic National Park and Olympic National Forest	Other[1] Existing Conifer Forests	Projected Future Conifer Forests in Previously Harvested Areas of Olympic National Forest	Projected Future Riparian Conifer Forests in Previously Harvested Riparian Areas Outside of Olympic National Forest
Ecosystem Initiation	Non-conifer (in part)	0	0	0	0	0
Sapling Exclusion	Early-seral	0	0	0	0	0
Pole Exclusion	Mid-seral	0	0	0	0	0
Large Tree Exclusion	Late-seral	0.25	0.68[2]	0.31[2]	0.20[3]	0.13[3]
Understory Development	Late-seral	0.36	0.68	0.31	0.20	0.13
Botanically Diverse	Late-seral	0.47	0.68	0.31	0.20	0.13
Niche Diversification	Late-seral	0.62	0.68	0.31	0.20	0.13
Fully Functional	Late-seral	0.89	0.68	0.31	0.20	0.13

[1] Predominantly private and tribal land.
[2] See discussion for these calculations in section 4.4.
[3] See discussion for these calculations in section 4.5.
Note: Assumptions on the influence of land ownership, existing versus projected land cover on non-DNR ownerships, and several potential forest management regimes for DNR-managed lands on P_{stage} are discussed in the preceding section. The influence of uncertainty in the classification of habitat to a particular stand development stage on *K'* is examined in a sensitivity analysis in Appendix H.

4.8 Edge Effects on Quality of Marbled Murrelet Habitat and Its Potential Influence on Carrying Capacity

Edge is believed to be an important factor influencing marbled murrelet nesting success; it is also a complex and poorly understood phenomenon. The method of addressing edge effects employed by the Science Team was strongly influenced by studies by Nelson and Hamer (1995) and Manley and Nelson (1999).

The Science Team reviewed and attempted to apply landscape-level predation effects as investigated in studies on the Olympic Peninsula in Washington State (Marzluff et al.1999). Analysis from this unpublished study suggests that edge effects influencing marbled murrelet nesting are more complex than the simple negative relationship that forms the basis for the nest predation analysis outlined below. While negative effects can be expected at most forest edges bordering clearcuts or young forest, other factors such as forest structure, human influence, elevation (Bradley [2002] found fewer predators at higher elevations), distance from edge and type of edge (natural edges such as avalanche chutes seem to produce less severe edge impacts [Malt and Lank 2007]) can change this relationship.

The Science Team is not aware of any peer reviewed research documenting a more complex model for understanding influences of edge on nesting marbled murrelets. The Science Team was therefore unable to incorporate a more sophisticated model into their analysis.

Manley and Nelson (1999) found that for a collection of well-observed marbled murrelet nests in British Columbia, Washington, Oregon, and California, nest success within 164 feet (50 meters) of the forest edge was 38% (n=29 nests) while nest success at greater distances was 55% (n=29 nests). Sixty percent of all nests failed because of predation. These observations, coupled with hypotheses that edges between early and late-seral forest support increased predator abundance and/or lead to decreased concealment of nests (Nelson and Hamer 1995b), suggested to the Science Team that current and projected edge effects on habitat quality should be considered as a criterion for evaluating potential outcomes of alternatives for DNR's LTCS.

The Science Team decided to employ a simple assumption regarding edge effects while acknowledging the considerable uncertainty that surrounds the core hypothesis of a simple relationship between proximity to stand edge and nest success. Elements of this uncertainty include the definition of what constitutes an "edge" and observations of the absence of a negative edge effect at a large sample (n=137) of marbled murrelet nests located with radiotelemetry in southwestern British Columbia (Malt and Lank 2007, Zharikov et al. 2006, Bradley 2002). Additional uncertainty derives from the apparently complicated relationship among the interaction of human residential, agricultural, and recreational developments with edge effects (Raphael et al. 2002b).

Based on the observed relationship of diminished nest success with stand edges (Manley and Nelson 1999), the Science Team determined to discount the predicted contribution of edge-influenced potential marbled murrelet habitat to carrying capacity. A 164-foot (50-meter) distance reflecting edge effects (Manley and Nelson 1999) and the values for low and high nest success hypothesized by McShane et al. (2004) (0.38 and 0.54, respectively) were used together to determine a discount factor, or P_{edge}, of 0.70 (0.38 / 0.54 = 0.70; i.e. success at edges is assumed to be 70% of forest interior values). This discount factor (0.70) was used to modify the predicted contribution to *K* of current or potential future edge-influenced habitat as $K_{edge} = K_{stage} * P_{edge}$. Predictions of *K* across edge and interior ($K_{interior}=K_{stage}$) habitat are summarized as $K' = K_{edge} + K_{interior}$. Thus for example, applying this concept to a 100-acre (40-hectare) stand in the Botanically Diverse (Appendix B) stage (*P*=0.47) with 50 acres (20 hectares) of interior and 50 acres (20 hectares) of edge influence, K' = (170 acres / marbled murrelet) * [(0.47 * 50 acres) + (0.47 * 0.70 * 50 acres)] = 0.251 “marbled murrelet units.” In this example, *K’* is 85% of the estimated *K* of 0.296 presented in the earlier example (see section 4.4), which did not consider the negative influence of edges.

Areas of potential marbled murrelet habitat subject to edge effects were identified and summarized using the 82-foot (25-meter) resolution GIS grids that represented current and projected land cover. The land cover categories of Green et al. (1993) were the basis for determining edge-influenced areas of potential marbled murrelet habitat that occurred only in the late-seral category. Non-forest, non-conifer, and early-seral conifer were considered “edge-creating” categories. Among DNR’s SDS categories, Ecosystem Initiation and Sapling Exclusion were considered edge-creating when adjacent to categories that provided some *K*. The influence of uncertainty in the estimation of the edge coefficient (0.70) on *K’* is examined in a sensitivity analysis in Appendix H.

4.9 The Habitat Capability (*K'*) Equation

The variables described above for habitat capability (*K'*) are summarized in equations here:

$K_{interior} = (P_{stage}$ * Interior Acres) / 170 acres/murrelet

$K_{edge} = (P_{stage} * P_{edge}$ * Edge Acres) / 170 acres/murrelet

$K' = K_{edge} + K_{interior}$

4.10 The Influence of Distance from Marine Habitat on the Quality of Inland Marbled Murrelet Habitat and its Effects on Carrying Capacity

Radiotelemetry studies in southwestern British Columbia (Hull et al. 2001) suggest that 40 miles (64 kilometers) is a reasonable one-way commuting distance for nesting marbled murrelets. The at-sea distribution of marbled murrelets during the breeding season (Miller et al. 2006) and results of DNR's inland marbled murrelet surveys in the South Coast and Columbia HCP Planning Units (see Prenzlow Escene 1999 and Harrison et al. 2003 for survey reports) confirm that the value of inland habitat declines dramatically beyond 40 miles (64 kilometers) from marine foraging areas.

The Science Team applied an arbitrary discount factor of 0.25 to reflect the diminished potential contribution to *K'* of stands more than 40 miles (64 kilometers) from marine waters with an observed high density of marbled murrelets during the breeding season (see Figure 3-1, Miller et al. 2006). Thus, in the previous calculation of *K',* which resulted in an estimate of 0.251, if that stand were more than 40 miles (64 kilometers) from a marine foraging area, its adjusted *K'* would be 0.251 * 0.25 = 0.063 "marbled murrelet units." Within the analysis areas, locations distant from marine foraging areas were exclusively in the far eastern portion of the SWWA Analysis Unit (Figure 3-1). The influence of uncertainty in the estimation of the coefficient for distance from marine waters (0.25) on *K'* is examined in a sensitivity analysis in Appendix H.

II. METHODS FOR PROJECTING THE DEVELOPMENT OF MARBLED MURRELET HABITAT UNDER THE SCIENCE TEAM'S RECOMMENDED CONSERVATION APPROACH

As described in chapter 3.0, the Science Team designated the total area of all MMMAs as approximately 116,000 acres (47,000 hectares) of forested state trust lands. These MMMAs were designated so that management within them would have the explicit objective of enhancing existing lower-quality habitat and developing new habitat in areas that have not been found to be occupied. This section summarizes the methods and assumptions used to project forest growth and response to silviculture in those MMMAs (see Appendix C for specific model inputs). The principal objective of this modeling exercise was to provide an objective, repeatable, quantitative assessment of the results of proactive silviculture intended to maximize the quality and quantity of marbled murrelet habitat, according to the unique conditions desired for each MMMA, within the 70-year term of the HCP. Since recommendations for the development of marbled murrelet habitat in the Straits Analysis Unit are to provide solely passive management, these exercises were not conducted there. Two scenarios, "No Management" and "Habitat Management," were modeled to provide the reference comparison reported in chapter 5.0. These scenarios demonstrate simulated forest growth and consequent development of marbled murrelet habitat in response to a conservative approach of no silvicultural intervention and an approach involving silviculture intended to maximize habitat quality and quantity.

4.11 Goals and Objective Criteria

The goal of this exercise was to create as much potential nesting habitat for marbled murrelets as possible, as rapidly as possible within the seven-decade HCP agreement. Habitat was identified using the SDS criteria summarized in the previous section; thus, the solution led to the maximum *K* summed over all stands in the MMMAs in decade seven. The Science Team's recommended conservation approach (see section IV in chapter 3.0) was analyzed at three scales in order to illustrate the application of this approach in evaluating different scenarios: analysis units, defined here as SWWA and OESF; sub-planning units (planning blocks in SWWA and landscape planning units [LPUs] in OESF), and smaller units of forest ranging from parts of stands to groups of adjacent stands. However, for the purpose of demonstrating the process of applying these tools and interpreting the results, habitat was merely summed across all scales so that it was maximized within units of forest, blocks or LPUs, and ultimately within and across the analysis units.

4.12 Model Structure

A sophisticated, spatially explicit optimization model using Spatial Woodstock (Remsoft, Inc. 2005) was applied to illustrate the outcomes of two silvicultural pathways for carrying out the Science Team's recommendations for conservation in the MMMAs. The Spatial Woodstock software uses linear programming methods to arrive at optimal solutions to forest planning problems in which large sets of spatially explicit input data, multiple objectives, and constraints present otherwise-intractable complexity. The first step in analyzing forest planning problems is to identify goals that can be described with objective criteria that are used to judge when the goals have been achieved (Remsoft, Inc. 2005). The analyst then defines actions and forest responses to them, and the software generates outputs that are assessed for their contribution toward those goals. Resource, policy, and multiple-goal constraints are entered into the problem statement so that feasible solutions to these problems can be found (Remsoft, Inc. 2005).

4.13 Model Development

To frame what the Science Team recommended as "biologically appropriate silviculture," a series of preliminary modeling exercises examined several simplistic silvicultural approaches for achieving and improving nesting habitat. These exercises inspected outcomes of five hypothetical management approaches (scenarios) for achieving as much habitat as rapidly as possible: "No Management," "Light Thinning Only," "Heavy Thinning Only," "Conversion Only," and "Combination." The Combination approach found a solution that freely selected among the other approaches to maximize habitat. The silvicultural characteristics of each of these approaches are described below.

Results of all five trial approaches demonstrated a steady increase in the abundance and quality of marbled murrelet habitat, but the scenarios could be lumped into two groups based on their performance. One group, consisting of No Management, Light Thinning Only, and Conversion Only, showed initial, more rapid gains in habitat, seen mainly in the first decade. Heavy Thinning and Combination comprised the other group, predicted to produce more high-quality habitat by decade seven.

Results of these initial trials were evaluated and integrated, acknowledging biophysical limitations on the effectiveness of silviculture, to form the "Habitat Management" scenario. Biophysical limitations refer to the capacity of the site's soil, light, and other nutrients to support a particular forest stand structure growing at a particular rate, as well as taking into consideration species composition, competition, and windthrow risk. All the listed silvicultural approaches were combined in the Habitat Management scenario to include considerations of how the interaction of stand density and the structural properties of trees could influence outcomes of silvicultural manipulations designed to create and/or improve marbled murrelet habitat. The No Management scenario was merely a simulation of forest development without active silvicultural intervention and was developed to provide a point of reference that reflected a preservation approach to habitat management. Subsequent descriptions and discussion refer exclusively to the Habitat Management scenario.

4.14 Management Scenarios: Silvicultural Activities and Projected Forest Responses

A broad range of silvicultural activities was available for modeling, from no management to regeneration harvests that converted stands to different species and stocking densities. A range of thinning treatments was also modeled, from lighter removals (possibly with multiple entries) to heavier thinnings or group selection harvests. Predicted forest responses to these activities were determined during comprehensive analyses of forest growth and yield as influenced by a broad range of input variables including species composition, stocking levels, and a variety of tree and site characteristics (Reimer et al. 2004).

Silviculture can be defined as the art and science of cultivating forests to deliberately attain desired end states. A brief description of the various silvicultural treatments available within the Habitat Management scenario follows. Note that the Habitat Management scenario is computer optimized, meaning the computer chooses which of the following treatments to apply in specific locations.

4.14a No Management

- No active silvicultural intervention is involved because existing marbled murrelet habitat is assumed not to be improved by silviculture within the seven-decade analysis window.

4.14b Light Thinning Only

- Treatment is aimed at increasing habitat quality and quantity by increasing tree diameter, improving stem form, and increasing crown length. It is expected to result in increases of lower to mid-quality nesting habitat in the first seven decades.

- Actual and simulated removals typically emphasize the harvest of smaller-diameter suppressed trees with shallower crowns and poor tree form, resulting in 30% to 40% removals of basal area, in an attempt to maintain tree vigor and growing space for the residual cohorts. Operationally, individual trees or groups of trees with unique characteristics such as deformities, deeper crowns, and lower stocking would likely be retained to serve as future nesting trees.

4.14b Heavy Thinning or Partial Harvesting

- Treatment is aimed at increasing abundance of habitat by creating gaps; increasing crown length, diversity in tree diameter, heights, and canopy structure; and improving stem form and crown length. It is expected to result in increases of mid- to higher quality nesting habitat in the first seven decades.
- Patterns of removals and specific management strategies may vary depending on the proximity of riparian and upland areas. The emphasis is on harvesting smaller-diameter suppressed trees with shallower crowns and poor tree form, resulting in 50% to 70% removal of basal area, including meso-scale group selection (2- to 20-acre [0.8- to 8-hectare] openings). The desired result is to maintain tree vigor and growing space for the residual cohort in thinned areas, and aid the development of multiple tree canopies.
- Operationally, individual trees or groups of trees with unique characteristics such as deformities, deeper crowns, and lower stocking may be retained to serve as future nesting trees. Actual techniques applied on the ground can be more spatially sensitive (i.e., applying both light and heavy thinning within the same stand).

4.14c Conversion

- Treatment is aimed at increasing abundance of habitat by regenerating upland portions of stands with tree species and planting densities that perform better in terms of habitat development (e.g., lower [70% to 80% of full] stocking with western hemlock/Sitka spruce versus higher stocking of Douglas-fir/western hemlock).
- Increases of lower to mid-quality nesting habitat are expected to result. Higher quality habitat is expected to develop over longer time frames than the first seven decades.
- Operationally, individual trees or groups of trees with unique characteristics such as deformities, deeper crowns, and lower stocking may be retained to serve as future nesting trees.

4.14d Habitat Management Scenario

The principal difference between the Habitat Management scenario (evaluated in chapter 5.0) and the Combination scenario (evaluated as a preliminary step in the process of model development) was the more complex, but realistic, application of silvicultural evaluation tools in determining how to implement thinning treatments in the face of windthrow risk in the Habitat Management scenario. These evaluations are exemplified with the stand density management diagram (SDMD, Figure 4-4). An SDMD is one of several tools for evaluating stand structures and determining appropriate habitat enhancement activities. Figure 4-4 presents an SDMD (Mitchell 2000) that illustrates stand development pathways under a range of stocking levels and thresholds for potential windthrow risk (high, moderate, and low), which is particularly important in determining the potential efficacy of thinning treatments. Although this figure is presented for illustration purposes only, these concepts were used to identify stands with structural conditions suitable for one or more of the three broadly defined treatments (light thinning, heavier thinning with meso-scale group selection, and conversion) as part of the modeling exercise.

In interpreting the complex information presented in an SDMD, the highly dense stands that have poor tree form (height relative to diameter) and shallow crowns are within the “high” windthrow susceptibility zone of the SDMD and are not suitable for thinning treatments (except very early stocking control treatments in stands approximately 15 years old). As illustrated by trajectory three (T3) in Figure 4-4, moderately susceptible stands may receive multiple thinning entries of varying removal percentages and treatment timings to sustain vigor and improve tree form, thus reducing windthrow hazard by staying in the medium hazard class for a longer period of time. The vertical line of trajectory one (T1) demonstrates a pathway to high-quality habitat in the shortest time possible. Cross and Comnick (2006) identified old forest habitat for northern spotted owls in the OESF (which encompasses much high-quality marbled murrelet habitat) as being located in the upper left-hand pinnacle of the SDMD, which coincides with a low density of large trees. Marbled murrelet habitat of lower quality (e.g. Large Tree Exclusion and Understory Development stand development stages [see Appendix B]) coincides with the middle of the gray band indicating high windthrow risk.

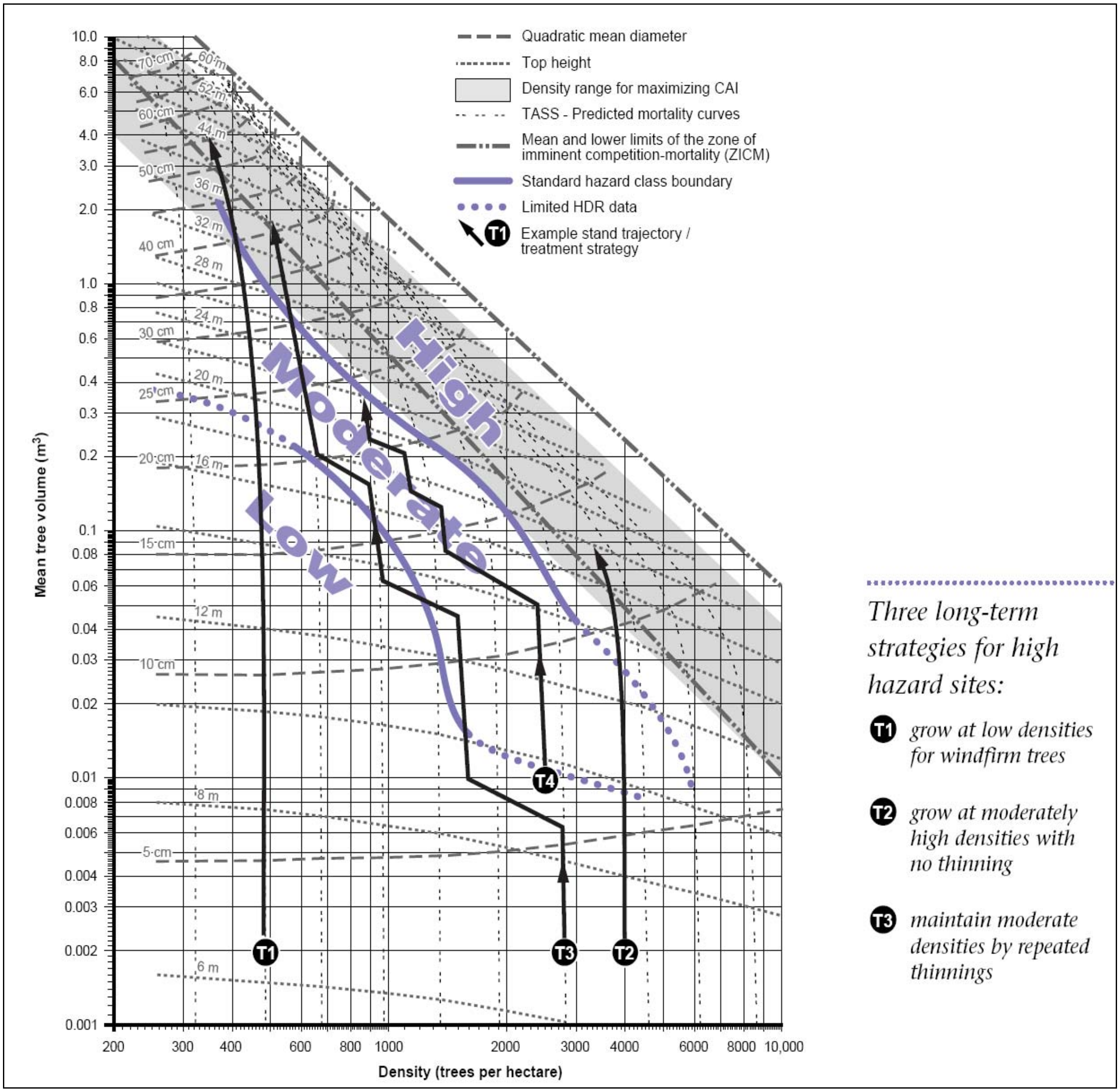


Figure 4-4. Stand Density Management Diagram (Figure from Mitchell 2000). Trajectory Four (T4) in the Figure Represents Light Thinning in "Tall, Dense, Previously Unmanaged Stands" in order to Maintain Dominant Trees (Mitchell 2000, p. 12).

4.15 Model Limitations

Because of computing limitations, model formulation was limited to two thinning entries within the first seven decades. Although they were not considered in this modeling exercise, more frequent entries may be employed operationally to achieve the desired conditions with the third or subsequent entries starting around the seventh decade. Likewise, the potential negative effects of edge were not considered in discovering an optimum solution to maximizing habitat quality and quantity (i.e., the solution maximized *K* rather than *K'*).

Additional issues not considered in this forest modeling exercise because of scope limitations include:

- Operational-level definitions of the silviculture options available for each scenario.
- Basic operational constraints, such as realistic staffing and activity levels given current agency resources.
- The potential for weather patterns, physiography, and the pattern of forest cover to influence the risk for windthrow and consequent effects on development of marbled murrelet habitat.
- Legal mandates that regulate the amount of harvest over time.
- The effect of silvicultural activities designed to create and/or enhance habitat beyond the term of the HCP.
- Any negative impacts to the marbled murrelet (these will be examined in the environmental impact statement and implementation document).

Modeling assumptions for the SWWA, OESF, and Straits Analysis Units are presented in Appendix C.

4.16 Management Scenario Analysis Results

Results of both the No Management simulation and the Habitat Management scenario provided spatially explicit (i.e., mappable) predictions of forest cover in the MMMAs at three points in the future: 2013, 2031, and 2067. The predictive maps and associated tabular data provided the basis for the results presented in chapter 5.0, using the methods and assumptions described in section I of this chapter. A comprehensive summary of the results from the management scenario analysis can be found in Appendix G.

5.0 HABITAT ASSESSMENT RESULTS: PROJECTIONS OF MARBLED MURRELET HABITAT AND POTENTIAL POPULATION RESPONSE RESULTING FROM THE SCIENCE TEAM'S CONSERVATION RECOMMENDATIONS

This chapter presents and discusses results from analyses of the current and projected future quantity and quality of marbled murrelet habitat and the potential for this habitat to contribute to the objective from the Washington State Department of Natural Resources (DNR) for marbled murrelet conservation in the Southwest Washington (SWWA), Olympic Experimental State Forest (OESF), and Straits Analysis Units. That objective, broadly stated, is "[to] make a significant contribution to maintaining and protecting marbled murrelet populations in western Washington over the life of the HCP [Habitat Conservation Plan]" (DNR 1997a, p. IV.44). The Science Team translated this objective into biological goals for DNR, which are to manage forest habitat to contribute to:

- A stable or increasing population;
- An increasing geographic distribution; and thus
- A population that is resilient to disturbances.

The analyses presented are intended 1) to provide objective, repeatable, quantitative comparisons of current and projected future forest habitat for marbled murrelets on DNR-managed lands and on other land ownerships; and 2) to estimate potential marbled murrelet population responses to current and projected future habitat under the Science Team's proposed approach using an index of the capability of forest habitat to support marbled murrelets (*K'*). *K'* is scaled to approximate DNR's current understanding of marbled murrelet population responses to forest habitat. Results from the *K'* analyses are presented in "marbled murrelet units" (see section 4.4); however, those values should not be viewed as explicit predictions of current or future marbled murrelet population numbers. Rather, *K'* provides an objective, repeatable index that can be used to judge relative conservation values of future projected marbled murrelet habitat on DNR-managed and other lands across the area of analysis. This exercise may be used by DNR in the future to evaluate revisions to this approach or any alternative recommendations for the Marbled Murrelet Long-Term Conservation Strategy (LTCS).

Results of these analyses are presented for the three analysis units (Southwest Washington [SWWA], the Olympic Experimental State Forest [OESF], and Straits; see Figure 3-1) and have been organized into five sections.

1. An examination of the broader role of DNR's conservation strategy, comparing marbled murrelet habitat among analysis units and among major landowners within analysis units, and of how the Science Team's conservation approach addresses distribution and population objectives. Result: DNR plays a large role with an especially significant impact in SWWA.
2. A description and discussion of the rate at which habitat develops (the discussion focuses primarily on DNR-managed lands). Result: habitat develops over time with more habitat capability in higher quality habitat.
3. A comparison of the No Management and Habitat Management scenarios applied to the Science Team's recommended Marbled Murrelet Management Areas (MMMAs), and the outcome of these scenarios for all DNR-managed lands within each analysis unit. Result: high-quality habitat develops faster through the Habitat Management scenario.
4. A comparison of marbled murrelet habitat on DNR-managed lands within and outside MMMAs. Result: higher quality habitat develops faster inside MMMAs, especially in SWWA.
5. A summary and brief discussion of these results with thoughts on future directions.

Appendix G provides a complete summary of the analysis outputs in acres and habitat capability (*K'*) by analysis unit, year, landowner, MMMA or non-MMMA, forest stage, closer than or farther than 40 miles (64 kilometers) from marbled murrelet-dense marine waters, and forest edge or interior. Tables in Appendix G are the source of the summarized information in this chapter.

5.1 Comparison of Current and Projected Future Marbled Murrelet Habitat and Its Potential for Population Support among Analysis Units and of DNR's Relative Role within Analysis Units

The quality and quantity of current and projected future marbled murrelet habitat differs markedly among the analysis units. Currently, habitat is most abundant in the OESF, followed by the Straits and then the SWWA Analysis Unit (Figure 5-1A; see section 4.4 for projected habitat calculation). However, since habitat is of higher quality in the largely native forests on federal lands on the Olympic Peninsula (see section IV in chapter 3.0), the OESF and Straits provide substantially greater support to the broader marbled murrelet population than do the managed forests in SWWA (Figure 5-1B). Projected increases in the amounts of habitat (Table 5-1, Figure 5-1A) reflect current laws and policies guiding management of public and private lands that will allow habitat development in areas that are currently non-habitat due to previous timber harvests. These areas are greatest in the OESF and SWWA because timber harvest was much more extensive there relative to the Straits which is largely wilderness. These increases are greatest in the SWWA Analysis Unit such that by 2067, habitat is projected to be most abundant there. However, habitat capability (*K'*) is projected to increase at a slower rate than habitat amount (Figures 5-1B and 5-1A, respectively) because projected increases in habitat will largely occur in the lower-quality stages within the analysis period (Table 5-1). Thus projections for *K'* suggest that OESF and Straits will have much greater capability to support murrelets than SWWA (Figure 5-1B).

Forests managed by DNR comprise a minority of the land base in all analysis units, ranging from 10% in Straits to 21% in the OESF (Table 3-1). The relative contribution of DNR-managed

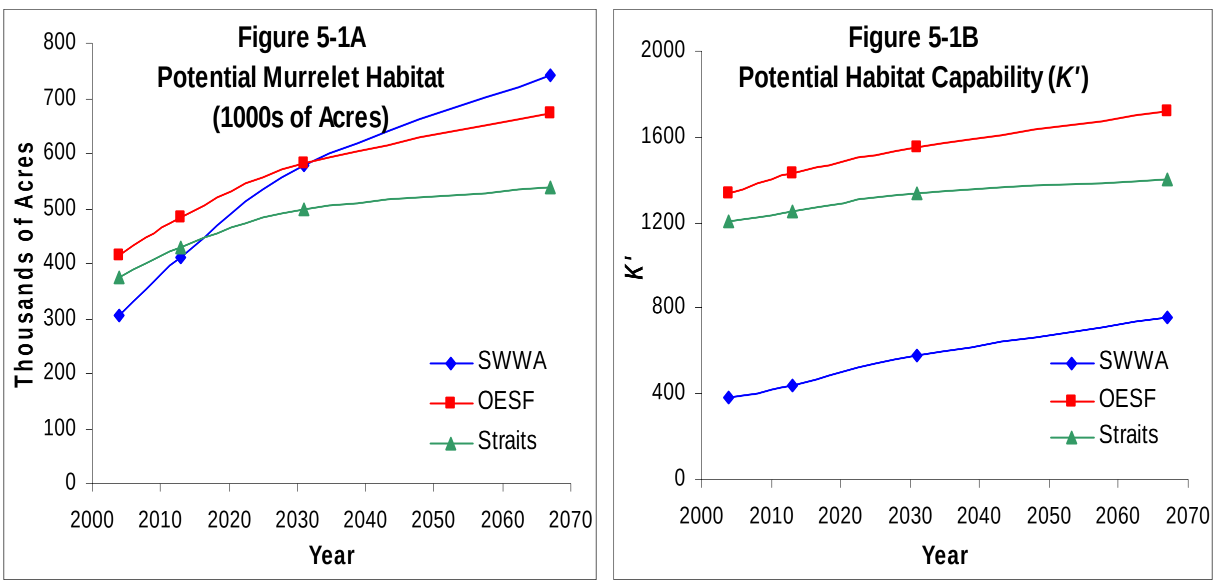


Figure 5-1. The Estimated Current and Projected Future Area of Forest Cover That Has Potential to Provide Marbled Murrelet Nesting Habitat (Figure 5-1A) and the Estimated Capability of That Habitat to Support Marbled Murrelet Populations Based on Its Quality and Abundance (Figure 5-1B) Across All Ownerships within Each Analysis Unit (under the Habitat Management Scenario).

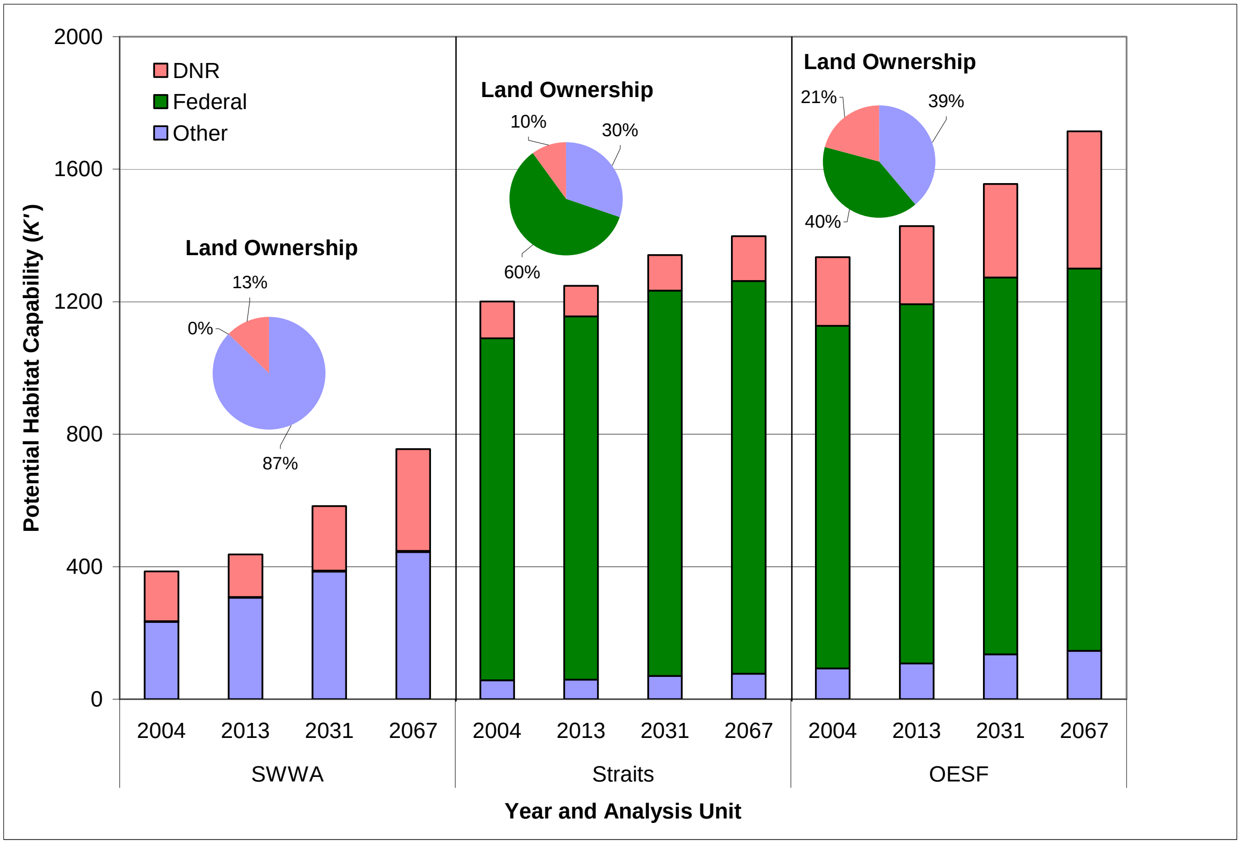


Figure 5-2. The Current and Projected Future Capability of Forests Managed by DNR, Federal Agencies, and Other Landowners to Support Marbled Murrelet Populations (*K'*) and Pattern of Land Ownership (Expressed as a Percentage of Total Landscape) in the SWWA, Straits, and OESF Analysis Units (under the Habitat Management Scenario).

forests to support local marbled murrelet populations depends on patterns of land ownership and land use within each analysis unit (Figure 5-2). In SWWA, where nearly all public forestlands occur on the 13% of the land base managed by DNR (Table 3-1, Figure 5-2), almost 40% of the current habitat capability is on DNR-managed lands (Figure 5-2). DNR-managed forests make such a significant contribution to *K'* because the abundance and quality of habitat on DNR-managed lands is relatively greater, particularly than that of other landowners (Table 5-1). This trend also holds for projected future forests. This abundance and quality of potential habitat can be seen when viewed as averaged over area by ownership (Figure 5-3). When averaged on a per-1000 acre (405 hectare) basis, DNR-managed forests provide substantially more potential habitat capability than other landowners, with federal lands providing the most projected benefit on a per-area basis, particularly in the OESF Analysis Unit. The Olympic Peninsula is dominated by

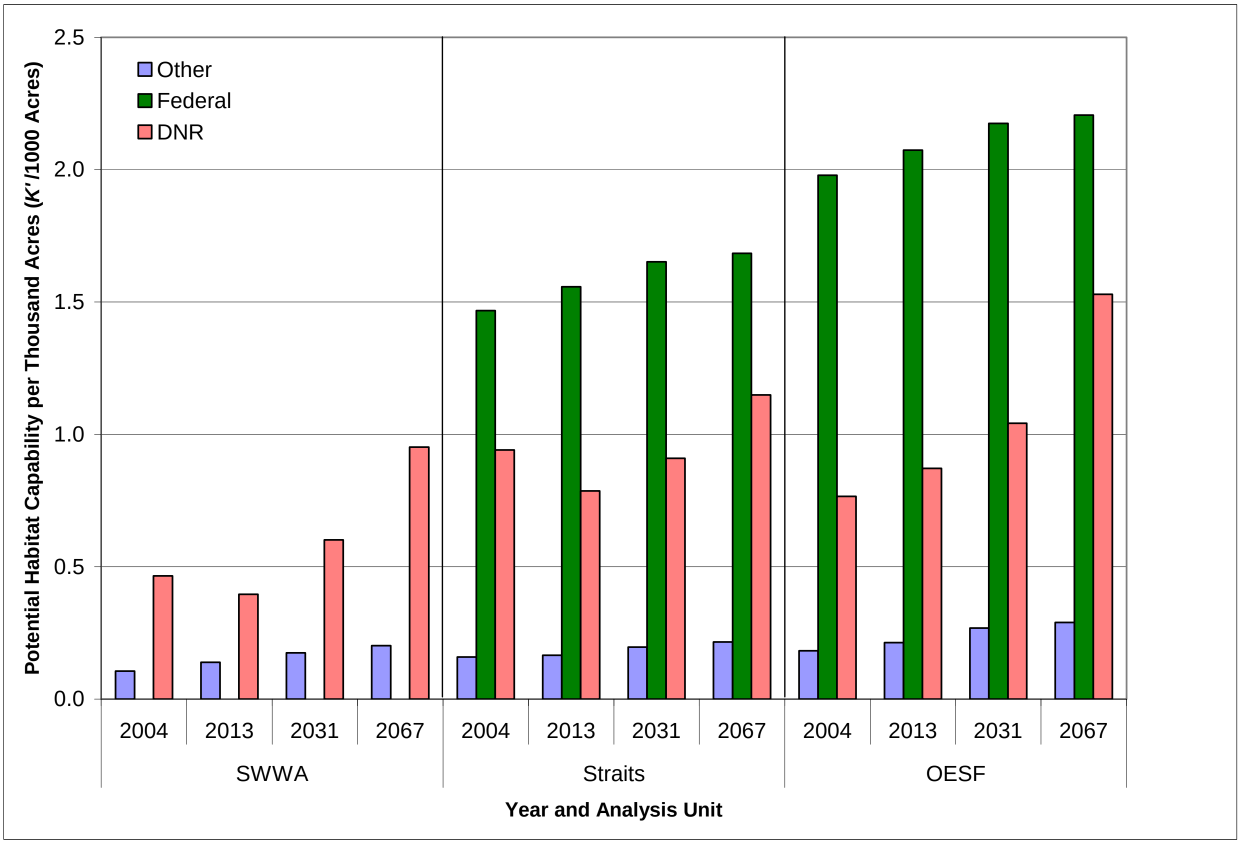


Figure 5-3. The Relative Current and Projected Future Capability of Forests Managed by DNR, Federal Agencies, and Other Landowners to Support Marbled Murrelet Populations (Averaged over the Area of that Ownership, or *K'*/1000 Acres [405 Hectares]) in the SWWA, Straits, and OESF Analysis Units (under the Habitat Management Scenario).

public forestlands, with the federally managed Olympic National Park and Olympic National Forest comprising half the land base (Table 3-1). Those federal lands provide the majority of support for marbled murrelet populations in the Straits and the OESF (Figure 5-2, Table 5-1).

Under the Science Team's conservation approach, marbled murrelet habitat and its estimated capability to support marbled murrelet populations is projected to increase in all analysis units, assuming marbled murrelets move into and successfully nest in newly created habitat. Those projections, illustrated in Figures 5-1, 5-2 and 5-3, are based on the Habitat Management scenario for MMMAs on DNR-managed land. At the scale of these analyses, differences between the No Management and Habitat Management scenarios are not discernable and therefore were not shown graphically (see Appendix G). The relative difference in these increases is greatest in SWWA, where *K'* is projected to nearly double by 2067 (Table 5-2),

Table 5-1. Current and Projected Future Acreage of Forests Managed by DNR, Federal Agencies, and Other Landowners That Could Provide Habitat to Support Marbled Murrelet Populations in the SWWA, Straits, and OESF Analysis Units (under the Habitat Management Scenario; See Appendix B for a Description of Stand Development Stages). Numbers Represent Thousands of Acres.

Landowner	Cover Type	SWWA				Straits				OESF			
		2004	2013	2031	2067	2004	2013	2031	2067	2004	2013	2031	2067
		Thousands of Acres											
DNR-Managed Lands	Large Tree Exclusion	51.1	38.7	28.5	25.8	8.5	7.7	5.2	5.9	8.2	8.4	7.5	37.2
	Understory Development	43.7	41.4	43.0	45.5	21.3	18.2	13.5	21.0	10.2	10.0	10.2	18.7
	Botanically Diverse	29.5	25.2	31.6	30.2	21.6	17.0	17.5	16.6	20.5	18.9	19.3	23.6
	Niche Diversification	0.9	3.4	19.4	33.5	0.2	1.5	8.8	2.4	26.9	23.7	31.0	32.9
	Fully Functional	0.1	0.2	0.4	22.0	0.0	0.0	0.0	7.5	5.6	14.1	17.7	30.6
Federal Lands	Existing Late-Seral	0.5	0.5	0.5	0.5	286.2	286.2	286.2	286.2	282.6	282.6	282.6	282.6
	Projected Late-Seral	-	0.4	0.9	1.0	-	55.3	106.1	125.9	-	43.6	83.9	98.3
Other Landowners	Existing Late-Seral	179.5	179.5	179.5	179.5	38.0	38.0	38.0	38.0	59.5	59.5	59.5	59.5
	Projected Late-Seral	-	121.8	270.8	400.1	-	4.0	23.2	34.6	-	23.7	69.5	88.1

Table 5-2. The Current (2004) and Projected Future (2013, 2031, and 2067) Capability of Forests Managed by DNR, Federal Agencies, and Other Landowners to Support Marbled Murrelet Populations (*K'*) in the SWWA, Straits, and OESF Analysis Units (under the Habitat Management Scenario). (Note: Overall *K'* is High for Other Land Ownerships Due to the Substantial Number of Acres of Land in this Category [See Table 3-1].)

Land Ownership	Potential Habitat Capability (*K'*)											
	SWWA				Straits				OESF			
	2004	2013	2031	2067	2004	2013	2031	2067	2004	2013	2031	2067
DNR	151	128	195	308	111	92	107	135	207	236	282	414
Federal[1]	2	2	3	3	1,033	1,097	1,163	1,186	1,035	1,085	1,137	1,154
Other	233	306	385	444	56	59	70	76	92	107	135	146
Total	386	437	582	754	1,200	1,248	1,340	1,397	1,335	1,428	1,555	1,714

[1] Includes lands managed by National Park Service or U.S. Forest Service. Lands managed by other federal agencies are not included.

of the combined effects of new management practices on private forestlands (i.e., Forest and Fish Rules [Washington State Forest Practices Board 2002], which mandate managing streamside forests for future conditions that could potentially provide some capability as marbled murrelet habitat), management of state forests under current DNR policies, and the Science Team's recommended approach for marbled murrelet conservation. The increase and the strengthening of habitat capability on DNR-managed forests indicate that the Science Team's recommended approach contributes to an increased geographic distribution of marbled murrelet habitat and presumably of their population as well.

Projected habitat quality is influenced mostly by stand structure, however, edge effects were also assumed to be detrimental. Habitat near edges currently provides the greatest contribution to *K'* in SWWA (33%) relative to Olympic Peninsula areas, where edge habitat contributes about one-fourth the projected habitat capability, with 21% and 26% for the OESF and Straits, respectively. Interior habitat (non-edge) is projected to increase in abundance in all areas by 73% (SWWA), 61% (OESF), and 52% (Straits), with associated projected increases in *K'* from interior forests. In concert with all projected changes across the landscape, a slight decrease in the proportional abundance of edge habitat is projected on the Olympic Peninsula, so that by 2067, interior habitat will increase to provide 80% and 77% of *K'* in the OESF and Straits, respectively, and

61% in SWWA. Edge habitat is projected to provide a greater proportion of *K'* in SWWA by 2067, with 39% of the substantially greater habitat capability resulting largely from the increased abundance of high-edge habitat projected to develop in riparian forests. A complete summary of results discussed above can be found in the G-1 tables in Appendix G.

5.2 Projected Rate of Habitat Development on DNR-Managed Lands

The increase in habitat capability projected on DNR-managed lands in all three analysis units was relative to each unit's habitat abundance and land management objectives in concert with those of other landowners (Figure 5-3). Section 5.3 compares the projected outcomes of No Management and Habitat Management. Projected effects of Habitat Management are illustrated in Figure 5-4, showing the trend of increasing overall habitat capability, as well as the increasing abundance (see Table 5-1) and role in population support provided by presumed higher quality habitat.

The initial negative trends in *K'* for SWWA and the Straits (Figure 5-3) are the outcomes projected from timber harvests in areas not proposed to be designated to contribute to conservation, and would be managed according to DNR's broader policies under the Policy for Sustainable Forests (DNR 2006b) and the HCP (DNR 1997a). Although some potential marbled murrelet habitat is also projected to be harvested in the OESF under this approach, the context of DNR-managed lands and objectives specific to the OESF are such that habitat development was projected to be the dominant process over all time steps reported from the analyses (Figure 5-4). By 2067, *K'* on DNR-managed lands is projected to double in SWWA and the OESF, and increase by 22% in the Straits (Table 5-2). Most of those increases are projected to occur as the amount and quality of marbled murrelet habitat improves in response to management practices (Figure 5-4) both within MMMAs and elsewhere. A complete summary of results discussed above can be found in the G-1 tables in Appendix G.

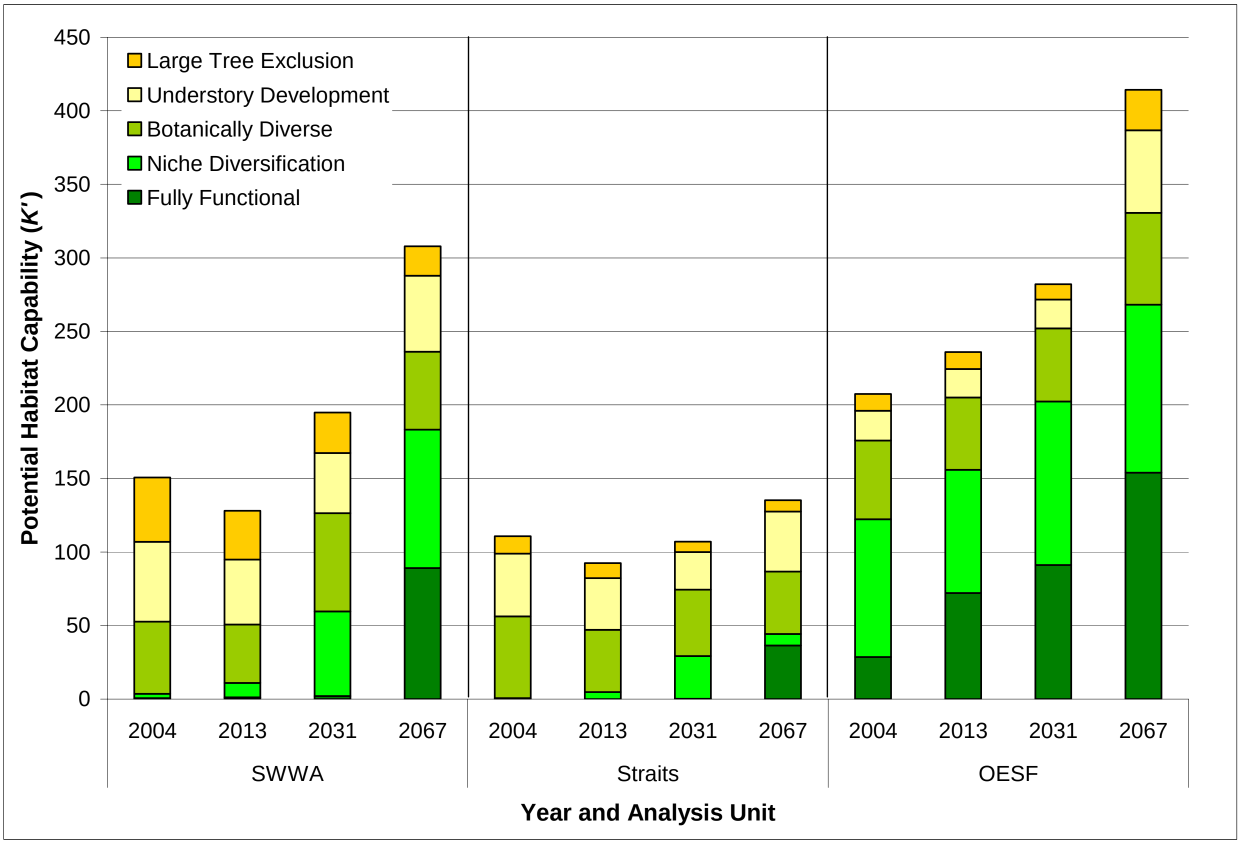
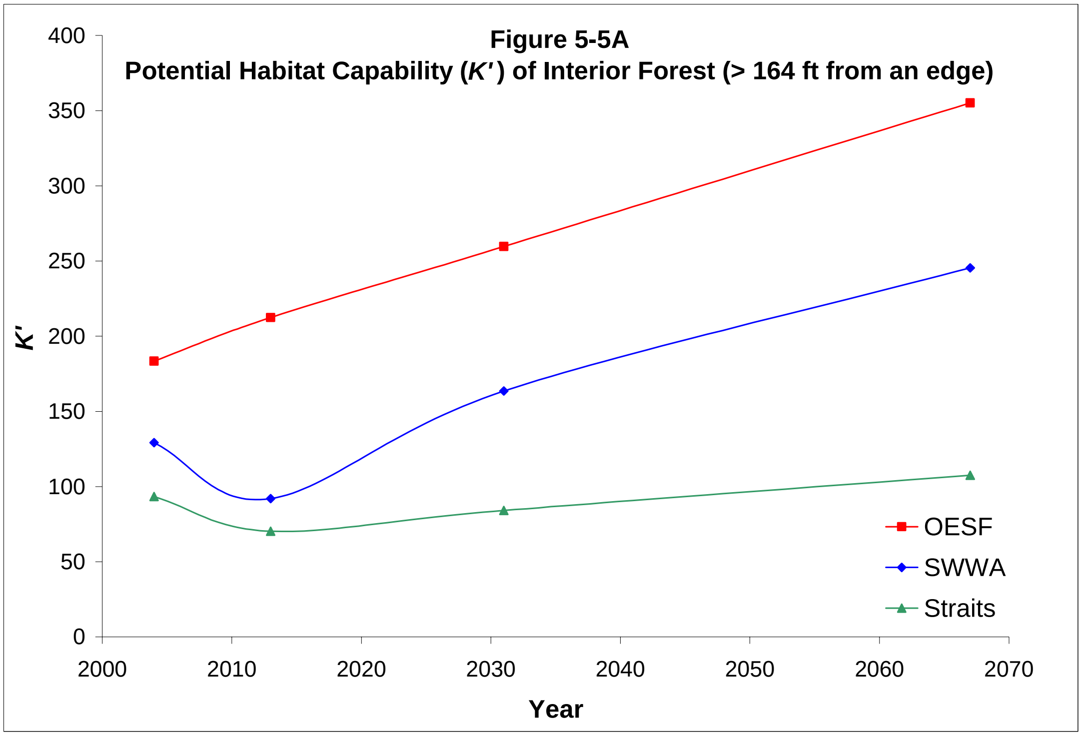


Figure 5-4. The Current and Projected Future Capability of DNR-Managed Forests, Classified by Stand Development Stage (Brodie et al. 2004), to Support Marbled Murrelet Populations (*K'*) in the SWWA, Straits, and OESF Analysis Units (under the Habitat Management Scenario).

Management in MMMAs and otherwise on DNR-managed lands was projected to result in long-term increases in the overall habitat capability of interior forest habitat, especially in SWWA and the OESF, because of the focus on marbled murrelet conservation and other conservation objectives in these analysis units (Figure 5-5A). The proportion of habitat capability occurring in this potentially more secure landscape context (i.e., interior forest) remained fairly constant over time (Figure 5-5B). The temporary decreases in interior habitat due to increased edge in the Straits and SWWA are the projected outcome of timber harvests in areas not recommended to be designated for conservation emphasis as noted in the previous paragraph.



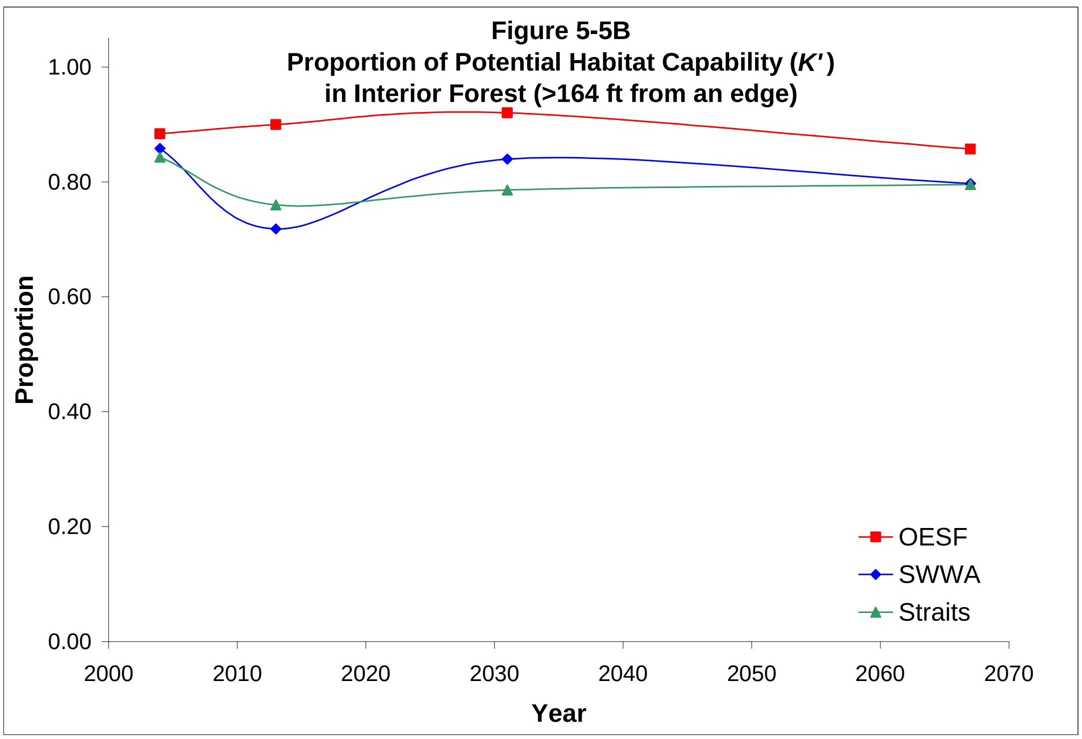


Figure 5-5. The Current and Projected Future Capability of DNR-Managed Interior Forest Habitat (More than 164 Feet [50 Meters] from Edges) to Support Marbled Murrelet Populations (*K′*) in the SWWA, Straits, and OESF Analysis Units (under the Habitat Management Scenario) (Figure 5-5A). The Proportion of Total *K′* Provided by DNR-Managed Interior Forest Habitat in the SWWA, Straits, and OESF Analysis Units (under the Habitat Management Scenario) (Figure 5-5B).

5.3 A Comparison of the No Management and Habitat Management Scenarios

Both the No Management and Habitat Management scenarios reflect the habitat objectives and geography of the Science Team's recommended approach to long-term marbled murrelet conservation. They differed only in their simulated management approaches, one portraying a passive and the other an active application of silviculture within the MMMAs designated in SWWA and the OESF. Projected management and its outcomes did not differ between those scenarios across the remainder of DNR-managed lands in those analysis units. That is, 66,000 of 324,000 acres (27,000 of 131,000 hectares) in SWWA and 50,000 of 271,000 acres (20,000 of 110,000 hectares) in the OESF were designated as MMMAs. These lands were the basis for the comparisons reported here against the background of implementing DNR policies and mandates over the rest of DNR-managed forests in those analysis units.

Projections of the scenarios demonstrated very little difference in their probable outcomes for marbled murrelet populations (Figure 5-6). The most pronounced difference is for SWWA in

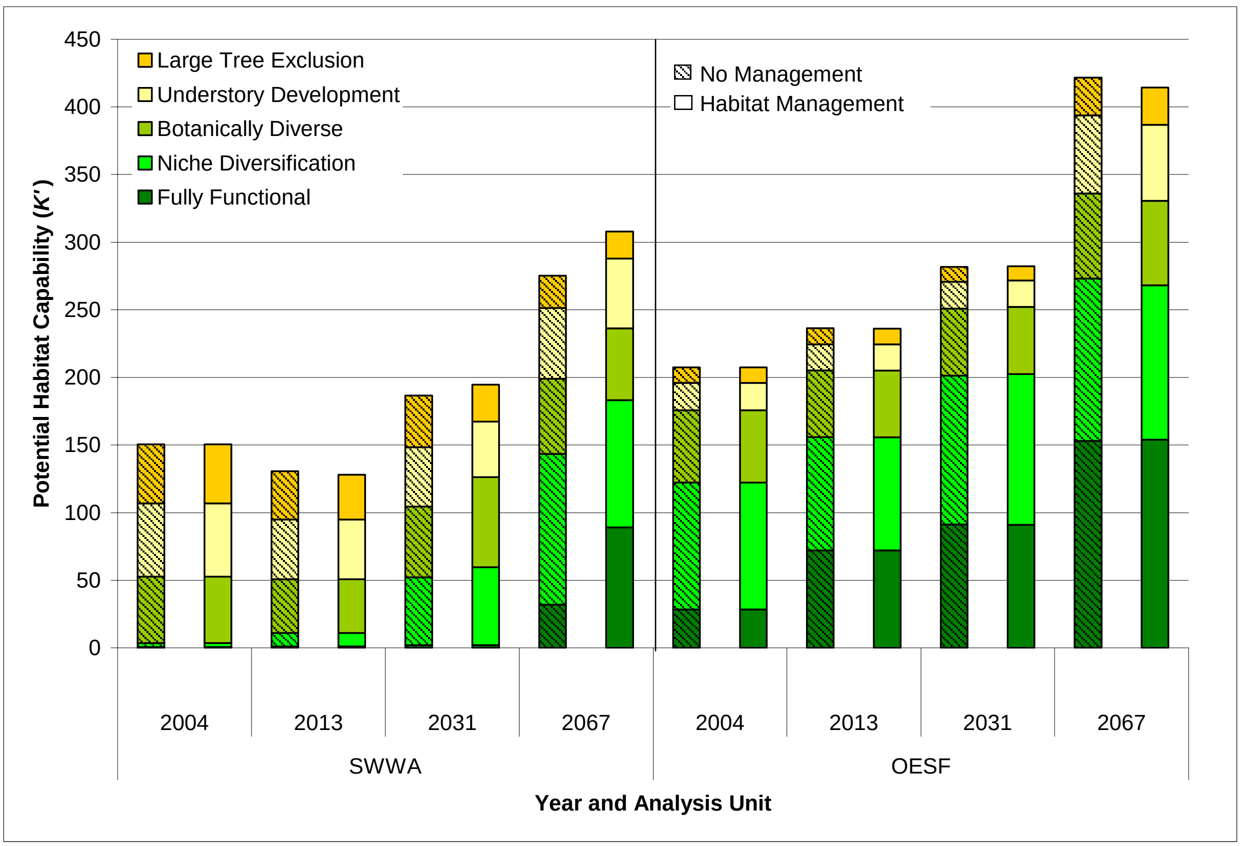


Figure 5-6. The Current and Projected Future Capability of DNR-Managed Forests to Support Marbled Murrelet Populations (*K'*) in the SWWA and OESF Analysis Units for the No Management and Habitat Management Scenarios.

2067, when *K'* is projected to be 308 under Habitat Management compared to 275 under No Management. Within the MMMAs, the differences between No Management and Habitat Management were more pronounced. Projections for *K'* in 2067 were 130 and 158 respectively, or 22% greater with Habitat Management. In the OESF, the No Management scenario projected a slightly greater *K'* in 2067, 422 versus 414 for Habitat Management. This is a confounding projected outcome, and seems unlikely in view of management applied specifically for the purpose of accelerated habitat development under the Habitat Management scenario, and habitat gains projected in SWWA. This phenomenon requires further investigation to explore the causes of this result in order to inform future modeling efforts. Habitat Management projected somewhat greater edge effects than No Management, with 80% versus 81% of *K'* from interior habitat in SWWA, and 86% versus 90% in the OESF. A complete summary of results discussed above can be found in the G-1 and G-2 tables in Appendix G.

5.4 A Comparison of Marbled Murrelet Habitat on DNR-Managed Lands within and outside Marbled Murrelet Management Areas

The role of MMMAs in supporting marbled murrelet populations is a function of the amount and quality of habitat existing or projected to exist within them. Their relative roles within the SWWA and OESF Analysis Units differ because the Science Team proposes designation of a larger percentage of the existing habitat in SWWA as MMMAs. The development of high-quality nesting habitat throughout entire MMMAs was designated as the primary objective for 66,000 acres (27,000 hectares) in SWWA (20% of the total DNR-managed land area). In OESF, 50,000 acres (20,000 hectares) (18% of the total DNR-managed land area) were designated as MMMAs with the primary objective being the development of high-quality nesting habitat in at least half of the area included in the designation (resulting in approximately 25,000 acres [10,000 hectares] or 9% of the OESF managed for high-quality nesting habitat). Currently, both SWWA and OESF areas designated as MMMAs provide a small portion of the habitat's total capability on DNR-managed lands: 17% and 18%, respectively (Figure 5-7). Active silviculture (as exemplified by the Habitat Management scenario) to achieve the Science Team's objectives for these areas is projected to increase their capability to support marbled murrelets, such that by 2067, MMMAs in SWWA are projected to provide 51% of *K'* (which will have more than doubled since 2004) for DNR-managed lands in SWWA (Figure 5-7). In the OESF, habitat

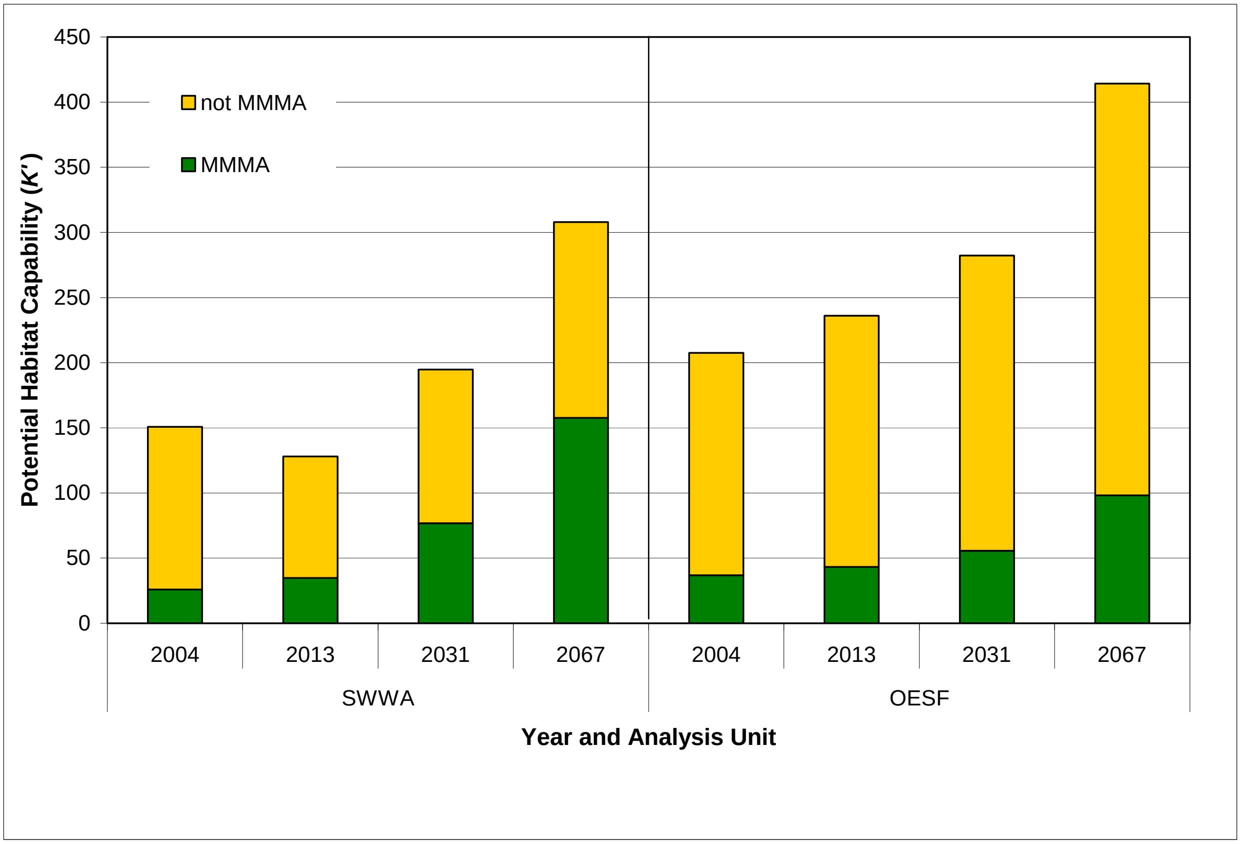


Figure 5-7. The Current and Projected Future Capability of DNR-Managed Forests to Support Marbled Murrelet Populations (*K'*) within and outside MMMAs in the SWWA and OESF Analysis Units (under the Habitat Management Scenario).

capability in the MMMAs is projected to increase nearly threefold by 2067 (37 to 98), comprising 24% of the overall *K'* on DNR-managed lands within the analysis unit (Figure 5-7).

The focus on retaining and/or developing high-quality marbled murrelet habitat within MMMAs was projected to increase habitat quality and increase habitat abundance, which led to the substantial increases in the projected values of *K'* between 2004 and 2067. In SWWA, the proportion of *K'* provided by higher quality habitat, including Botanically Diverse, Niche Diversification and Fully Functional stand development stages (SDS) (see Appendix B for definitions), was 42% in MMMAs and 33% on other DNR-managed lands in 2004 (Figure 5-8). Projected increases in habitat quality and abundance resulted in the majority of *K'* being provided by those higher quality stages by 2067, particularly in the MMMAs where 91% of the habitat capability was projected to be found in higher quality habitat. Overall management objectives in the OESF were more similar within and outside MMMAs, thus the striking changes projected for SWWA were not seen there. Habitat development was projected to increase the abundance of habitat in MMMAs, but the higher quality habitat provided similar proportions of *K'* in 2004 (86%) and 2067 (89%) (Figure 5-8). Edge effects were integrated with the influence of stand structure (SDS categories) in estimating future habitat capability, however the effects of management to intentionally reduce edge effects in MMMAs was evident in the projected increases in *K'* provided from interior forests. In SWWA, *K'* of interior forests in MMMAs increased 618% compared to its 2004 level, while it remained unchanged on state forests outside those areas. In the OESF MMMAs, *K'* of interior forests increased by 148% compared to an increase of 81% on other DNR-managed forests in the area. A complete summary of results discussed above can be found in the G-1 tables in Appendix G.

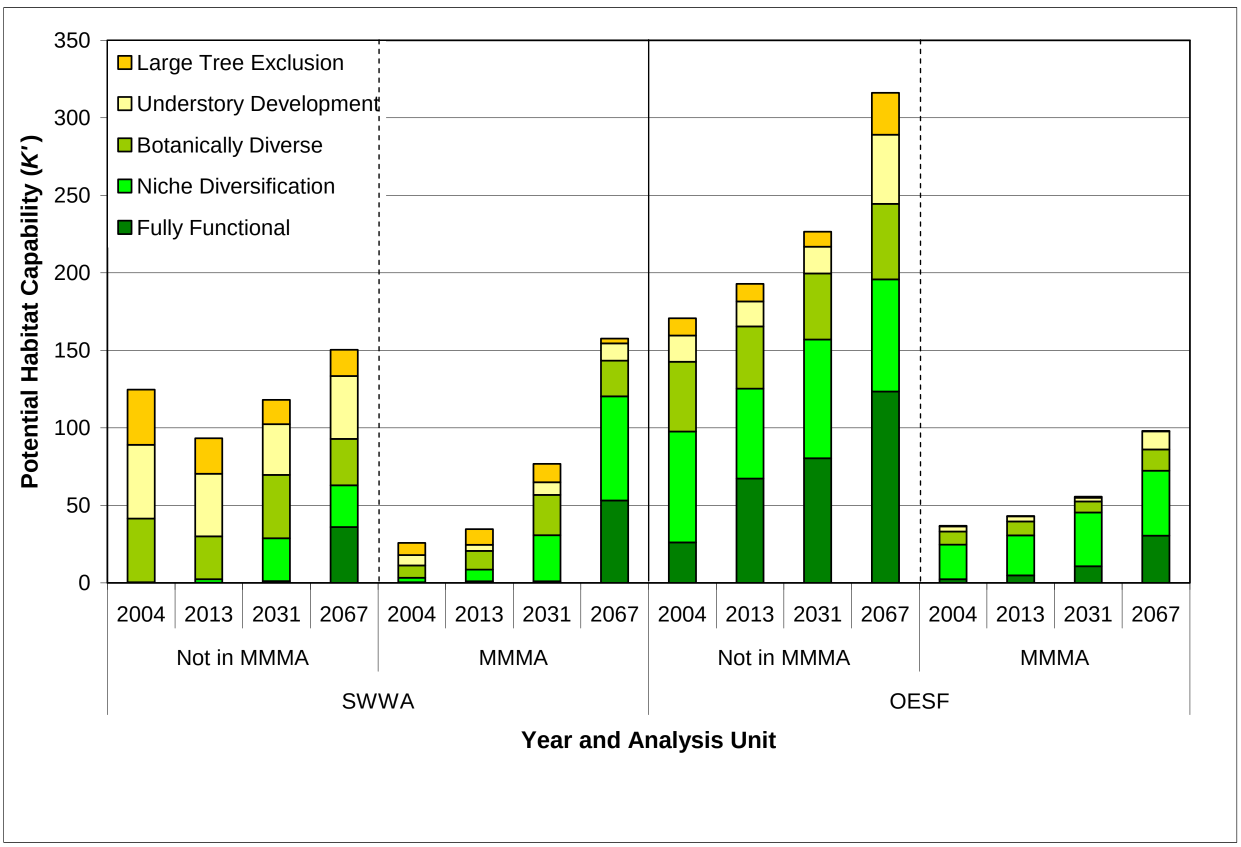


Figure 5-8. The Current and Projected Future Capability of DNR-Managed Forests, Classified by Stand Development Stage (Brodie et al. 2004, Appendix B), to Support Marbled Murrelet Populations (*K'*) within and outside MMMAs in the SWWA and OESF Analysis Units (under the Habitat Management Scenario).

5.5 Summary and Discussion

Chapter 4.0 provides a discussion of the hypotheses and assumptions that are the basis for the analyses reported here. A brief review of those hypotheses and assumptions, as well as the uncertainty around them can help the reader interpret the results of those analyses from both a quantitative and qualitative perspective. Additionally, a sensitivity analysis was conducted on the potential habitat capability (*K'*) model, describing how the uncertainty in estimation or classification of the factors listed below may contribute to habitat capability (Appendix H). Below is a summary of how knowledge and hypotheses regarding marbled murrelet biology and forest ecology were translated into specific assumptions concerning how forest habitat supports marbled murrelet populations and how forest succession, with and without active silvicultural intervention, influences the development of marbled murrelet habitat.

1. **Habitat area—**The assumption that 170 acres (69 hectares) of suitable forest habitat provides sufficient opportunities to support one nesting marbled murrelet is substantiated by inland studies using radar to estimate marbled murrelet numbers and radiotelemetry to assess inland behavior (Burger 2002, Raphael et al. 2002a, Peery et al. 2004, Bloxton and Raphael 2007), as well as by estimates of marbled murrelet numbers on adjacent marine foraging areas (Miller et al. 2006). However, it is likely there is a fine-grained variability in this relationship that is overlooked by the simple assumption used in these analyses.
2. **Stand characteristics—**The abundance of potential nesting platforms and the presence of complex canopy structure are well known as essential elements of marbled murrelet nesting habitat (Grenier and Nelson 1995, Hamer and Nelson 1995). The assumed relationship of habitat value with stand structure and composition as within Table 4-4 was derived from empirical studies of marbled murrelet behavior in DNR-managed stands (Prenzlow Escene 1999), but the generalization that used SDS categories as surrogates for those structural elements has not been validated with field studies. It is likely that Table 4-4 depicts general trends in potential habitat value (Prenzlow Escene et al. 2006), but the precise numerical estimates should be considered as working hypotheses. Additionally, recent studies have located marbled murrelet nests in what appear to be unsuitable land cover categories (Hamer and Nelson 1995, Bradley and Cooke 2001, M. Raphael pers. comm.), though these nests were generally in old forests, rather than heavily managed forest landscapes. These discoveries probably reflect the inability of coarse-grained, i.e., stand-level, classifications to

identify the specific, rare structural elements used as nest substrates by those birds (McShane et al. 2004).

3. **Forest succession—**The dynamics of succession in forest stands, with and without silvicultural intervention, have been well studied (Shugart 2003). Forest growth models can be sufficiently predictive (Vanclay and Skovsgaard 1997); therefore, they are widely used for effectively developing and implementing plans to manage forest properties for multiple objectives (Guisan and Zimmermann 2000). Projections for DNR-managed stands were based on data from high-resolution inventories of the forests (DNR Forest Resource Inventory System [FRIS]) and well-supported forest growth models (DNR 2004b). However, as the predictions from those models become increasingly specific (i.e., for individual stands as opposed to averages taken across multiple stands), they can become increasingly uncertain (Heuvelink 1998).

4. **Edge effects—**Negative edge effects have been observed at marbled murrelet nests, and the rates of high and low nest success used to model edge effects were developed from field studies (Manley and Nelson 1999, Nelson and Hamer 1995b). However, research on actual and simulated marbled murrelet nests demonstrates that edge effects are probably the result of several complex, interacting phenomena that are not adequately represented by the simple model employed in these analyses (Nelson and Hamer 1995b, Raphael et al. 2002b). Projections of the amounts of edge are fairly robust because they are based on the current landscape data on other ownerships (Interagency Vegetation Mapping Project) and projections of growth and harvest on DNR-managed lands (DNR 2004a), but there is substantial uncertainty as to the generality of the model that predicts their suitability as habitat. Some of this uncertainty may be resolved by ongoing and future research (see chapter 6.0).

5. **Distance from marine foraging areas—**Research on marbled murrelet behavior suggests there is a threshold distance between nesting and foraging areas beyond which the value of nesting habitat is markedly diminished (Hull et al. 2001). However, the assumption used in these analyses is merely an “educated guess” that reasonably conforms to observed patterns. It remains to be refined by ongoing research.

Thus, results of these analyses are best considered broadly. Smaller differences (e.g., on the order of 10%) are probably more meaningful when they are based on analyses across large areas, such as entire analysis units. Likewise, differences of that order in current or projected future conditions are likely to be less meaningful when measured across smaller analysis areas (e.g., individual SDS categories within MMMAs). Although there is uncertainty in the modeling assumptions, the fact that they were applied equally in the analyses allows the results to be directly compared. The best use of these results may be as relative comparisons:

- What are the relative roles of the analysis units and the landowners within them in regional marbled murrelet conservation?
- What broad trends are expected in marbled murrelet habitat within each analysis unit?
- Will DNR policies and the Science Team's recommendations meet their goals for marbled murrelet conservation?
- Is active silvicultural intervention an appropriate tactic for achieving marbled murrelet conservation goals?
- Are MMMAs an appropriate strategy for achieving marbled murrelet conservation goals?

The presentations of results earlier in this chapter were made with these types of comparisons in mind, although the text, tables, and figures allow the reader to evaluate projections at finer scales, if so desired. Table 5-3 summarizes current and projected future conditions relative to the Science Team's biological goals for marbled murrelet conservation on DNR-managed lands. In short, DNR's broader policies, in concert with the specific approach to marbled murrelet conservation suggested by the Science Team and current policies of federal and other landowners, will result in improved inland habitat conditions, which are likely to support those biological goals. However, the portion of the marbled murrelet population nesting in SWWA will likely remain less secure than that portion using the Olympic Peninsula because of the lack of habitat on federal lands in SWWA.

The Science Team's conservation emphasis in SWWA is an effort to meet their translation of biological goals for the marbled murrelet (page 5-1). The geography and extent of DNR-managed lands as well as the relatively few acres of federally managed forests limit those efforts. Even with those limitations, the strategy was projected to make substantial progress toward those goals, with DNR-managed lands providing a disproportionately large share (41%) of future

Table 5-3. Summary of the Current and Projected Future Condition of Marbled Murrelet Habitat in the SWWA, OESF, and Straits Analysis Units Relative to the Science Team's Biological Goals for Marbled Murrelet Conservation. This Summary Includes State, Federal, and Non-Federal Lands.

	SWWA		OESF		Straits	
	2004	**2067**	**2004**	**2067**	**2004**	**2067**
Population Size (Measured by Habitat Capability)	Small ($K' \approx 386$)	Moderate (95% increase)	Large ($K' \approx$ 1,335)	Large (28% increase)	Large ($K' \approx$ 1,200)	Large (16% increase)
Population Stability	Much habitat in high-edge situation, potential threat to stability	73% increase in K' from interior habitat but still high proportion of edge	Much habitat in interior forests, potentially supporting more stable population	61% increase in K' from interior habitat, improved potential for stable population	Much habitat in interior forests, potentially supporting more stable population	52% increase in K' from interior habitat, improved potential for stable population
Distribution	SWWA is a gap in broad distribution of habitat, few habitat concentrations within SWWA	Improved habitat distribution within SWWA and for rangewide population	Good, but ecological gap in distribution, little habitat in low elevation forest communities	Improved ecological distribution, K' increased 166% in MMMAs	Good	Good
Resilience	Probably low	Improved but less than Olympic Peninsula areas	Probably fairly high	Further improved	Probably fairly high	Further improved

habitat capability because of increased amounts and quality of habitat on state forests. About half of the future habitat capability on those DNR-managed lands will occur in the 20% of state forests designated as MMMAs. Forest growth modeling suggested that appropriate active management does not appear to affect the future development of habitat and may improve its effectiveness.

In the OESF and the Straits Analysis Units, the Science Team suggests relatively lower levels of focal management for marbled murrelet conservation because of the context of DNR-managed lands in a landscape dominated by federal forest reserves, and because the existing OESF northern spotted owl conservation strategy greatly supports marbled murrelet habitat. Considering DNR-managed lands as a whole, the Straits and OESF Analysis Units contribute to the broader trend of projected improvement in habitat capability. This is particularly true in the

OESF, where high-quality marbled murrelet habitat is a relatively larger proportion of the DNR-managed land base and where intentional management for marbled murrelet habitat restoration is part of the Science Team's recommended conservation approach. MMMAs in the OESF were likely to achieve the designated objective of increasing habitat capability in low elevation forest communities. The total habitat capability in MMMAs was projected to increase by 166% (Table 5-3) from active silviculture that included management for multiple objectives.

The management scenario analysis results indicate that there are a variety of ways to achieve equivalent levels of marbled murrelet habitat conservation. Each scenario has its own set of unique hypotheses and assumptions. Thoughtful evaluation of the most biologically relevant hypotheses and a minimal set of necessary assumptions required to enact the selected conservation strategy will ensure its success.

This page intentionally left blank.

6.0 CONCEPTS IN ADAPTIVE MANAGEMENT

6.1 Introduction

This chapter presents the foundations of an adaptive management plan that could be developed and applied once a Marbled Murrelet Long-Term Conservation Strategy (LTCS) is adopted. Adaptive management will allow the Department of Natural Resources (DNR) to monitor and adjust management practices in response to changing circumstances or improved knowledge in order to better achieve marbled murrelet conservation. This chapter frames potential topics for adaptive management, and outlines several questions central to marbled murrelet conservation in managed forests. Future policies, budgets, status of the species, and the composition of the adopted LTCS will influence the eventual application of these adaptive management strategies.

The broadly accepted definition of "adaptive management" used by natural resources sciences is "…the systematic acquisition and application of reliable information to improve natural resources management over time" (Wilhere 2002, p. 20). This definition is similar to that for Habitat Conservation Plans (HCP) which is described as "…a method for examining alternative strategies for meeting measurable biological goals and objectives, and ... adjusting future conservation management actions according to what is learned" (USFWS and NMFS 2000, p. 35245). Although the U.S. Fish and Wildlife Service (USFWS) and the National Marine Fisheries Service (NMFS) (together referred to as the Services) meant to define adaptive management broadly, in order to allow a variety of approaches to satisfy the ESA provisions, they too require a systematic approach and reliable information to incorporate adaptive management into HCPs. Thus, a brief review of the scientific principles of adaptive management and the Services' standard for its application to HCPs is appropriate.

Passive and active adaptive management were originally described as two approaches to finding solutions to ecological optimization problems (Walters and Hilborn 1978). Both are scientifically-rigorous approaches that:

1. Predict the behavior of ecological systems in response to management actions
2. Measure selected attributes of the managed systems

3. Evaluate performance of those attributes relative to desired outcomes, then revise predictions and management approaches appropriately
4. Reiterate the process to approach “optimal” solutions

At step three, the two approaches differ in the degree of rigor applied to inference that guides decision-making. Active adaptive management employs the principles of experimental design and statistical inference, while the passive approach does not. Those principles include replication and randomization of contrasting treatments, including controls, to establish cause-and-effect relationships between management actions and outcomes (Ford 2000). Thus, adaptive management programs begin with explicit objectives for management and a scientific model (i.e., a description of how nature works [Hilborn and Mangel 1997]) that guides management and includes explicit statements about predicted outcomes and sources of uncertainty that affect them. In active programs, management is implemented as designed experiments to test hypotheses about key uncertainties, with results from those experiments used to revise future management as well as the guiding model. Passive programs are implemented as though the model were correct, while expecting that monitoring will help resolve uncertainties and allow revision of the model and subsequent management. In general, implementation of active programs requires a greater commitment of human and financial resources relative to passive adaptive management.

The Services established a standard for adaptive management in HCP implementation allowing both active and passive approaches (USFWS and NMFS 2000). They defined essential characteristics of adaptive management in HCP implementation as:

1. Explicit biological goals and objectives to clarify the purpose and direction of the HCP
2. Identification of the parameters that potentially affect that goal (i.e., models that describe mechanistic relationships between management actions and biological goals)
3. Identification of key uncertainties in the model
4. Experimental strategies that address those uncertainties

5. A monitoring design that adequately detects strategy results
6. A defined feedback process ensuring effective changes in management

Biological goals and objectives can be either species- or habitat-based. Species-based goals are expressed in population terms while habitat-based goals express desired habitat amount and quality. The USFWS and NMFS allow a range of adaptive management approaches; from feedback exclusively based on HCP monitoring to integration of an HCP with a broad range of agency and academic research and monitoring.

6.2 Characteristics of DNR's Marbled Murrelet Long-Term Conservation Strategy

Threats to the viability of marbled murrelet populations likely result from their interactions with both the marine and terrestrial environment. DNR's LTCS is based on hypothesized mechanistic links between forest management and marbled murrelet ecology and, ultimately, demography. There are important uncertainties about many of these mechanisms, including the strength and consistency of marbled murrelet ecological and demographic responses, and even whether or not systems actually behave as hypothesized. These uncertainties carry over to projected outcomes of the LTCS and could result in the LTCS failing to perform as expected for marbled murrelet conservation. Thus, adaptive management offers potential improvements to performance of the strategy over time for conservation and policy objectives. Understanding the hierarchical relationship among demographic, ecological, and management mechanisms and the uncertainties around them can direct adaptive management of the LTCS. These relationships are outlined and discussed below in a format where the number assigned to each guiding hypothesis carries through the entire outline.

6.2a Hypothesized Risks about Marbled Murrelet Population Viability

1. The population is too small
2. The population is declining
3. A metapopulation structure exists in which some smaller local populations are at risk of extirpation, thus increasing the risk to the metapopulation

6.2b Hypothesized Demographic Mechanisms that Influence Risk

For a description of the Hypothesized Demographic Mechanisms that Influence Risk, please see the left column in Table 6-1.

6.2c Hypothesized Ecological Mechanisms that Influence Demographic Performance

Marbled murrelet ecology is complex and far from fully understood. Multiple hypotheses have been proposed, or are implicit in the "conventional wisdom," to explain observations or assumptions of marbled murrelet breeding biology. More complete discussions of the information and citations for these hypotheses are presented in chapter 2 and in recent reviews of marbled murrelet biology (Burger 2002, McShane et al. 2004). Some of the hypotheses reflect competing views, while some are complementary. The numbering and listing of hypotheses in Table 6-1 (middle column) builds on the hypothesized demographic mechanisms that influence risk enumerated in Table 6-1 (left column).

6.2d Models that Represent Hypotheses about Marbled Murrelet Ecology and Demography

Models are tools to evaluate hypotheses, as they enable predictions to be challenged with data gathered through monitoring (Hilborn and Mangel 1997). The forest management approaches of the LTCS will be based on these models, either implicitly or explicitly. Variation in model form as well as parameter values can reflect more specific alternative versions of a single hypothesis. Development of the general models presented below can, and should, be further expanded in a program of adaptive management. These models are described in more detail in chapter 4. The following general models (Table 6-1) build upon hypotheses of ecological mechanisms that influence demographic performance. The hypotheses that relate to each model are described in Table 6-1 and their relative numbering identifies each throughout this summary.

Table 6-1. Hypothesized Demographic and Ecological Mechanisms that Influence Risk and Demographic Performance, and Subsequent Models.

Hypothesized Demographic Mechanisms that Influence Risk	Hypothesized Ecological Mechanisms that Influence Demographic Performance	Models that Represent Hypotheses about Marbled Murrelet Ecology and Demography
1. Population size is limited by the availability of nest sites.	*Nest Sites:* 1a. Abundance and/or availability of nest sites increases within stands as stature and structural complexity increase. 1b. Abundance and/or availability of nest sites across landscapes is proportional to the area of stands that meet structural thresholds. 1c. Nest sites are more attractive in particular landscape contexts. 1d. Social facilitation (the presence of others encourages a particular behavior) increases the attractiveness of nest sites. 1e. Nesting is predicted by occupied behavior regardless of 1a, b, or c.	*Nest Sites – stand level:* 1a(1). The relationship of stand-level structural indices, tree sizes, platform abundance/occurrence, canopy complexity, etc. to indices of marbled murrelet use (i.e., predicted probability of occupancy and nesting rates) reflects "habitat quality." 1a(2). There is a gradient in stand-level habitat quality that can be approximated by classifying stands into groups based on the relationship of predicted marbled murrelet use to indices of forest structure. 1a(3). Managed forest stands (stands that have received silvicultural treatments to enhance nest site quality) attract marbled murrelets as predicted by models 1a (1 and 2). *Nest Sites – landscape level:* 1b(1). Landscape-level population carrying capacity for marbled murrelets can be predicted through calculating the area encompassed by suitably structured stands. 1b(2). Predictions of carrying capacity can be modified based on model 1a(2), where the contribution by lesser-quality stands is relative to their estimated quality. 1c(1). Landscape influences on attractiveness of stands of otherwise equivalent quality is a function of landscape composition and pattern.
2. The population is declining because productivity is limited by anthropogenic influences on the quality of nesting habitat.	*Nest Success:* 2a. Nest success is diminished by proximity to anthropogenic, high-contrast edges due to predator abundance and/or decreased nest concealment. 2b. Nest success is a function of complex interactions of landscape pattern and composition due to landscape influences on the diversity and abundance of predators. 2c. Nesting rates (i.e., nests per unit area per year)	*Nest Success – edge and landscape effects:* 2a(1). The gradient of edge effects on nest success is approximated by classifying edge distances and their predicted effects into three distance bins: <164, 164-492, and >492 feet from edge. 2b(1). A gradient of nest success is associated with landscape patchiness and compositional diversity. *Nesting Rates – influenced by nest success:* 2c(1). Nesting rates, as approximated by marbled murrelet activity indices, are a function of proximity to forest edge.

Hypothesized Demographic Mechanisms that Influence Risk	Hypothesized Ecological Mechanisms that Influence Demographic Performance	Models that Represent Hypotheses about Marbled Murrelet Ecology and Demography
	are correlated, following a time-lag, with nest success (see 2a and 2b) because unsuccessful nesters undertake fitness-dependent dispersal. 2d. Nesting rates and nest success are diminished by direct disturbance due to forest management activities, either additive or independent of hypotheses 2a-c.	2c(2). Nesting rates, as approximated by activity indices, are a function of landscape pattern and composition *Nest Success – disturbance effects:* 2d(1). Nesting rates and nest success are a function of the frequency and intensity of disturbances due to forest management activities.
3. Mechanisms 1 and 2 work within local populations; and small local populations face additional risk due to environmental and demographic stochasticity.	*Population Structure and Dispersal:* 3a. The abundance and quality of nest sites varies within and between sub-populations, as predicted by models 1 and 2, such that source and sink areas exist. 3b. Marbled murrelets are relatively philopatric and site-faithful; thus, habitat that is unused either because of local extirpation or because it developed *de novo* from successional processes is infrequently colonized. 3c. Marbled murrelets may have greater natal and breeding dispersal than suggested in 3a, including fitness-dependent dispersal from poor breeding sites; thus, unused habitat may be colonized at rates proportional to its overall quality as predicted under hypotheses 1 and 2. 3d. A metapopulation with source-sink structure exists.	*Population Structure - relationship to quantity and quality of nest sites:* 3a(1). Population consequences of various amounts and configurations of habitat can be predicted with demographic modeling, incorporating influences of nest site availability and nest success as predicted by models 1a-c and 2a-c. *Dispersal – relationship to site occupancy:* 3b,c(1). The frequency and extent of marbled murrelet natal and breeding dispersal, as reflected by apparent extirpation and colonization of sites, can be inferred from time-series observations of activity and nesting at sites that attract and retain marbled murrelets as a function of their overall quality as predicted by models 1a(1 and 2), 1c(1), and 2b(1 and 2), and their proximity to other sites with marbled murrelets. *Population consequences of habitat quantity/quality and dispersal* 3a,b,c,d(1). Population consequences of marbled murrelet dispersal behavior can be predicted with a metapopulation model and varying levels of dispersal among source and sink sub-populations..

6.3 Management Approaches

Conservation areas were delineated to address hypothesized habitat insufficiencies to the greatest extent possible (see chapter 3.0). Thus, this section takes a different form–brief descriptions of classification and management criteria for each class of conservation area, followed by a brief description of how habitat management in those areas is intended to address the principal hypotheses about mechanistic links to marbled murrelet population viability. The conservation areas are classified as follows: isolated occupied sites and undesignated habitat areas (both classifications apply to all analysis units), and Marbled Murrelet Management Areas (MMMAs) in Southwest Washington (SWWA) and the Olympic Experimental State Forest (OESF).

6.3a Isolated Occupied Sites

Occupied behavior was observed in these small areas (<~200 acres [<~81 hectares]) that are either in isolated DNR-managed parcels or are on DNR-managed land that lacks explicit objectives for marbled murrelet conservation. The sites encompass a range of structural conditions, from simple-structured second-growth to complex old-growth. The Science Team recommends an approach of passive management (i.e., no timber harvest and minimal disturbance) for all these areas because they may contribute to achieving the conservation objectives. Several hypotheses are particularly relevant to the role of these isolated occupied sites in achieving conservation: the relationship of nesting activity with site characteristics, hypotheses 1a, 1c-e; the relationship of nest success and nest-site fidelity with site characteristics, hypotheses 2a-d; and the role of dispersal behavior in the use of sites, hypothesis 3a. It is recommended that these hypotheses are tested prior to making any decisions about isolated occupied sites.

6.3b Undesignated Habitat Areas

According to HCP agreements for riparian conservation and other guiding elements of broader DNR policy, undesignated habitat areas (i.e., marbled murrelet habitat outside MMMAs and occupied sites) are recommended to occur throughout the analysis units. These lands encompass some existing areas of complex-structured forest and will be especially inclusive of extensive streamside and unstable slope areas where complex stands will be restored and maintained over time through both active and passive management (Bigley and Deisenhofer 2006). The landscape contexts of these undesignated habitat areas are recommended to vary according to management to meet multiple objectives for sustainable forestry, and in some areas they will be surrounded by stands under even-age management. These areas comprise a substantial proportion of the landbase in each analysis unit, for example the riparian areas alone comprise 43% in the OESF, 19% in the Straits, and more than 32% in SWWA (DNR 2004b). Although these areas are projected to substantially increase the abundance of potential nesting habitat, marbled murrelet productivity in these areas may be insufficient to meet objectives for supporting stable populations. Several hypotheses are particularly relevant to the role of these undesignated habitat areas in achieving conservation and other policy objectives: the relationship of nesting activity with site characteristics, hypotheses 1a-e; the relationship of nest success and nest-site fidelity with site characteristics, hypotheses 2a-d; and the role of dispersal behavior in colonization and use of habitat, hypothesis 3a-b.

6.3c Marbled Murrelet Management Areas in Southwest Washington

MMMAs in SWWA are relatively large areas (>1,000 acres [>405 hectares]) of contiguous DNR-managed lands. They contain occupied sites and some higher quality reclassified habitat not found to be occupied but the majority of their area is currently non-habitat. The Science Team recommends these MMMAs be actively managed to restore high quality nesting habitat and passively managed to maintain habitat within an analysis unit where contiguous blocks of high quality nesting habitat are scarce. The relationship of nesting behavior to habitat quality (hypotheses 1a-c), and relationships regarding landscape-level influences on nest success (hypotheses 2a-c) are central to the LTCS. Implementation of the LTCS will be constrained by land ownership patterns. For this component of the overall strategy to perform as desired, marbled murrelets must colonize restored habitat (as predicted by hypothesis 3b in the 3a/3b contrast).

6.3d Marbled Murrelet Management Areas in the OESF

Conservation in the OESF relies substantially on existing HCP strategies of landscape-level thresholds for “old-forest spotted owl habitat,” with structural properties similar to current estimates for high quality marbled murrelet nesting habitat. Existing HCP strategies for riparian conservation through management in streamside and unstable areas (i.e., the "undesignated habitat areas" in part described above) are additionally applied to MMMAs in the OESF. Where it is feasible, given soil and site characteristics, marbled murrelet habitat is recommended to be maintained or restored through active and passive management in these areas. An additional component of the LTCS in the OESF is management of high quality nesting habitat to enhance its security, and thus contribute to population goals. Also, discrete MMMAs were established in portions of the Sitka Spruce zone where restoration of high quality nesting habitat and management of its context in the landscape are designed to increase the amount and predicted security of this habitat. These discrete MMMAs are in an ecological type that is not well-represented on federal lands. Several hypotheses are particularly relevant to the role of these unique OESF areas in achieving conservation and other policy objectives: marbled murrelet responses to landscape-level abundance and attractiveness of nesting habitat, hypotheses 1b-c; the relationship of nest success and nest-site fidelity with site characteristics, hypotheses 2a-c; and source-sink relationships with habitat on federal land, hypothesis 3c.

6.4 Adaptive Management for the Long-Term Conservation Strategy

A practical program of adaptive management for DNR's marbled murrelet LTCS must be organized around several elements: management approaches and their predicted outcomes, uncertainties about predictions, the magnitude of consequences resulting from incorrect predictions, and the feasibility of resolving uncertainties with adaptive management. Examination of these elements will help identify portions of the strategy where resolution of uncertainties can result in sufficiently improved outcomes for biological and/or policy goals so the costs of gaining reliable knowledge can be justified. Then, adaptive management must follow guidelines published by the Services, as summarized in the introduction (USFWS and NMFS 2000), and comply with terms of the HCP Implementation Agreement (DNR 1997a).

6.4a Uncertainties in the Conservation Strategy and Potential Consequences

The models (in section 6.2d) allow objective predictions of the contributions of components of the LTCS briefly described above, as a class or as discrete geographic elements, to the size and stability of the regional marbled murrelet population. Important uncertainties exist at many steps leading to those predictions, but the magnitude of their consequences can be estimated by their predicted effects on marbled murrelet populations and the amount of land committed to a particular approach. In summary, the largest positive effects for marbled murrelet populations are predicted for habitat restoration in the SWWA MMMAs and the undesignated habitat areas, including those noted as part of the OESF approach (Tables G-4A through G-4L). Thus, overly optimistic predictions about habitat development in managed forests and marbled murrelet responses to that habitat would have the greatest consequences to a strategy failing to realize its biological goals. The largest negative effects on other policy goals (DNR 2006b), including generating revenue from timber harvest would derive from lands dedicated to relatively passive management approaches that fail to achieve the marbled murrelet biological goals. In this sense, limited nesting rates and nest success in isolated occupied sites and incorrect predictions about marbled murrelet responses to MMMAs in SWWA would have the greatest consequences. In either case, improving DNR's ability to manage for marbled murrelet conservation in a manner that achieves predictions would result in equivalent or better marbled murrelet conservation at less cost to the trust beneficiaries. This goal of "optimization" is explicit in academic discussions of adaptive management and implicit in the Services' definition.

Adaptive management to improve outcomes from these key management approaches then depends on the feasibility of resolving uncertainties around them. Uncertainties around the predictions of models 1a(1-3), regarding management approaches for restoring high quality nesting habitat at the stand level; models 1b(1,2), 1c(1), 2a(1), 2b(1), 2c(1,2), landscape influences on productivity; and model 3a,b(1), dispersal patterns, are important to achieving both biological and other policy goals. The predictions of model 3a,b,c(1) are important to conservation approaches in the OESF and Straits, which variously rely on a large contribution to population size and stability afforded by federal lands. These uncertainties are based upon the predictions of models describing relationships among marbled murrelet biology and forest characteristics, as well as management pathways, to achieve desired forest characteristics. A brief examination of the feasibility to resolve these uncertainties will assist in developing a program of adaptive management for implementing the LTCS.

6.4b Marbled Murrelet Studies at Varying Spatial Scales

Types and quantities of data needed, as well as the time and effort required to collect the data, are important to the practicability of resolving uncertainties around the LTCS. Thus, a brief review of techniques for investigating marbled murrelet ecology and the types of information they provide can help frame an adaptive management approach for the strategy. In order of decreasing spatial resolution, marbled murrelet studies are conducted at:

- *Nest Sites:* nest sites and their immediate vicinity, from the branch holding the nest to the nest tree to the surrounding 1-2 acres (0.4-0.8 hectares)
- *Nesting Neighborhoods:* nesting neighborhoods (Raphael et al. 2002), stands and/or the general vicinity of actual or presumed nest sites, from 10-1,000 acres (4-405 hectares)
- *Medium to Large Watersheds*: watersheds from several thousand to several hundred-thousand acres (or hectares)
- *Regional Scales*: similar to or larger than HCP planning units, from one to several million acres (or hectares)

In addition, silvicultural method studies provide information relevant to the LTCS. Silviculture studies on management techniques to restore or maintain marbled murrelet habitat can help guide different management approaches.

6.4c Nest Site Studies

Nest site studies depend on direct observation by audio-visual (a-v) observers, with studies of nesting behavior and outcomes often assisted by data recorders such as cameras or other monitors. Locating nests requires intensive field work. Old nests (up to about five years old) can be located by selective tree-climbing outside of nesting season, enabling studies of forest characteristics without regard to nest success. Active nests can be found through intense searches by ground-based observers, but following birds radio-tagged on the water to their nests has proven effective at providing a relatively unbiased sample of nests from which stronger inference about marbled murrelet biology can be made. An ongoing study of marbled murrelets on the Olympic Peninsula locates about 4 nests per year (Bloxton and Raphael 2006, 2007). If nests are apportioned in habitat according to its relative abundance, then 10 nests might be located on DNR-managed land (which contains 14% of the Olympic Peninsula's habitat) in seven years of effort. If managed-forest landscapes are less secure and/or attractive, marbled murrelets would nest in DNR-managed lands at lower rates, and even more effort would be required to accumulate a reasonable sample. However difficult, studies at actual nests are necessary to resolve uncertainties around nesting in managed-forest habitat, model 1a(3), and edge effects influences on nest success, models 2a(1) and 2b(1).

6.4d Nesting-Neighborhood or Stand-level Studies

Nesting-neighborhood studies monitor marbled murrelet responses with a-v observers and/or radar. Decisions as to the mode of observation depend on site-specific factors that limit radar and the nature of the study. Counts obtained with radar are less variable (Bigger et al. 2006), but a-v observers can collect more specific behavioral information potentially valuable for higher-resolution studies. Studies at this scale can improve the reliability of predictions that are central to the success of the LTCS, by testing predictions about habitat quality and restoration, models 1a(1-3); landscape-level influences on attractiveness of stands, models 1c(1) and 2c(1,2); and patterns of extirpation and recolonization at isolated sites, model 3a,b(1). Well-designed studies allow data collected in nesting-neighborhood studies to be applied to watershed or landscape-level investigations.

6.4e Watershed-Level Studies

Watershed-level studies rely on inland observations because marbled murrelets at sea cannot be reliably assigned to a particular watershed (Bloxton and Raphael 2006). Radar observations from strategic points in watersheds (3,500-400,000 acres [1,400-162,000 hectares]) have successfully estimated marbled murrelet numbers and their relationship with habitat characteristics (reviewed by Burger 2002, McShane et al. 2004). Reliable point-in-time estimates have been achieved with two to three years of monitoring. Trend studies would likely require intermittent monitoring over one to several decades. These types of studies are appropriate for landscape-level assessments in general, not just landscapes defined by watershed boundaries. Landform and other contingencies are very important to enabling these types of studies, particularly at the smaller spatial scales relevant to DNR's LTCS. They can increase certainty around predictions of models important to the LTCS regarding carrying capacity and attractiveness of landscapes, 1b(1,2) and 1c(1), regarding landscape-level consequences of fitness-dependent dispersal, 2c(1,2), and regarding extirpation and recolonization, 3a,b(1).

6.4f Regional-Level Studies

Regional-level studies, ongoing since 2000, are designed to estimate population size and trends by counting marbled murrelets at sea during the breeding season. These studies are conducted according to a sampling and analysis design allowing estimation of numbers and uncertainty (Madsen et al. 1999, Miller et al. 2006). DNR contributes funding toward this effort. These studies will provide reasonably certain estimates of population size and stability within two to 20 years depending on hypothesized rates of decline (Miller et al. 2006). Certainty in these estimates is particularly important to the OESF and Straits conservation approaches (i.e., evaluating the predictions of model 3a,b,c(1) regarding the role of federal lands in sustaining the marbled murrelet population).

6.4g Silvicultural Methods Studies

Silvicultural methods to restore and maintain marbled murrelet habitat are currently based on inference from studies designed to improve commodity production, retrospective studies of unmanaged stands, and work in progress directed at broader elements of forest biodiversity. Thus, even if models describing stand-level characteristics of marbled murrelet habitat are correct, reliable knowledge of means to achieve those characteristics will improve performance of the LTCS. Tree growth is a relatively slow process, so silvicultural studies often span decades. Silvicultural research and monitoring methods are well-established, and are explicitly acknowledged in the broader HCP agreement as "effectiveness monitoring" (DNR 1997a) to improve silvicultural performance at meeting habitat objectives.

Reliable information to improve performance of the LTCS can be gained less directly through inference gained in marbled murrelet studies from elsewhere in their range, experimental studies of simulated marbled murrelet nests, and observational and/or experimental studies of related phenomena with other bird species. Similarly, knowledge about silviculture can be generalized from other studies. An effective program of adaptive management will seek out and utilize multiple types of information to improve the reliability of information that is the basis for management decisions. Furthermore, the monitoring itself should be adaptive, changing direction and focus as information accumulates and management needs change (Carey et al. 2003).

6.5 Potential Topics for Adaptive Management

It is appropriate to propose "potential topics" for adaptive management at this point, as DNR, USFWS, and possibly other stakeholders must consider a broad range of factors that may influence the range of alternatives to explore and potentially pursue, including economics, policies, and regulations, as well as risk to marbled murrelet conservation (USFWS and NMFS 2000). An adaptive management strategy should:

1. Identify uncertainties
2. Develop alternative (i.e., experimental) approaches, and determine which of them to implement
3. Design a monitoring program for those approaches
4. Define how feedback from monitoring will result in effective changes in HCP implementation (USFWS and NMFS 2000)

Alternative or experimental approaches are appropriate for active adaptive management; passive methods are also permitted, and these would monitor outcomes from single management approaches and adapt appropriately. Uncertainties, alternative hypotheses, and monitoring methods are outlined and discussed as they relate to the management approaches summarized above. Several of those that may be appropriate for adaptive management are presented as examples in the following sections.

6.5a Adaptive Management of Isolated Occupied Sites

Conservation measures at discrete occupied sites are predicted to allow those sites to contribute to population size and stability by providing for successful nesting.

1. *Uncertainties:* Predictions regarding the relationship between habitat area and marbled murrelet numbers, negative fragmentation and edge effects, and fitness-dependent dispersal cast uncertainty on the ability of these sites to contribute measurably to biological goals. These sites appear to contribute relatively less to regional marbled murrelet populations in the OESF and Straits, but relatively more in SWWA.

2. *Alternatives*: A passive approach is proposed for these sites, consisting of two parts: (1) broad population monitoring for the OESF and Straits Planning Units and the Olympic Peninsula portion of SWWA (Humptulips), and (2) focused marbled murrelet monitoring for the SWWA Planning Unit. Individual sites within those planning units would be assigned to one of the following three classes based on their predicted abilities (below) to meet biological goals:

    1) Least likely;

    2) Moderately likely; or

    3) More likely.

    Classification criteria would include stand characteristics and landscape context, and identify sites that appeared least and most likely to support biological goals and an intermediate class.

3. *Monitoring*: Population size and trend estimates from at sea monitoring (Miller et al. 2006) within Conservation Zones 1 and 2 (see chapter 2.6h) would provide the basis for the management decisions regarding Olympic Peninsula sites. Monitoring marbled murrelet activity and behavior according to a statistically robust design at SWWA sites, stratified by the three classes above, would provide the basis for management decisions in this planning unit. Radar and/or a-v observations would be used to estimate whether sites were contributory to the biological goals.

4. *Feedback*: Monitoring results would initiate changes in management. If populations in Conservation Zones 1 and/or 2 were found to be stable or increasing, the "least likely" class could be released for timber harvest and the "moderately likely" class could be evaluated for release. In SWWA, sufficiently precise estimates of the annual proportion of sites in the least likely and moderately likely classes would provide criteria for deciding whether or not to release these sites to harvest. Such monitoring and analysis details, as well as decision thresholds, should be determined at a future date in coordination with the appropriate regulatory agencies.

6.5b Adaptive Management of Southwest Washington Marbled Murrelet Management Areas and Undesignated Habitat Areas

Substantial conservation benefits are predicted to result from MMMAs and undesignated habitat in the strategy due primarily to increased abundance of habitat from restoration efforts and, in places, because of explicit management efforts to decrease fragmentation effects. Three groups of hypotheses and their derivative models are important to these predictions:

- Habitat restoration and maintenance in managed forests
- Fragmentation and edge effects on productivity
- Colonization of restored habitat

Management approaches and contextual differences among planning units are such that it is convenient to partition this topic into these three groups.

Habitat Restoration and Maintenance

Management to restore and maintain habitat is predicted to increase nesting opportunities and thus contribute to goals for population size and stability.

1. *Uncertainties*: Current habitat models likely do not provide a full description of stand characteristics important to marbled murrelets and are based on observations from stands that regenerated and developed without silvicultural intervention. They may not present wholly appropriate targets for restoration

silviculture. Additionally, silvicultural treatments to achieve targets in a timely and financially efficient manner are not fully known. Finally, there is uncertainty about the timing and magnitude of marbled murrelet responses to restored habitat.

2. *Alternatives*: Passive and active approaches are appropriate to resolve these uncertainties. At present, habitat models can be refined with further analysis of existing and new data. Designed silvicultural experiments should be conducted to test approaches for achieving current, and possibly future, habitat targets. This active approach should encompass a broad range of silvicultural treatments as well as target conditions to encompass uncertainty in habitat models as well as restoration techniques. Observing marbled murrelet responses to silviculture would be mainly passive, but opportunities for a limited active approach to these uncertainties exist in the OESF (i.e., designed silvicultural experiments in areas used by marbled murrelets).

3. *Monitoring*: Predictions of habitat models should be tested by monitoring marbled murrelet responses. These observational studies could be designed to explore potential regional and/or site-level differences in habitat characteristics. A series of silvicultural experiments in young stands without habitat capability should monitor the rate and abundance at which characteristics of marbled murrelet habitat develop. These experiments should be implemented in a design that is robust to regional and site-level differences in silvics. Silvicultural experiments in unoccupied older stands that are approaching a threshold level of habitat quality should be conducted more cautiously. The OESF has stands of this type in a context of relatively abundant, higher quality habitat in conservation status on federal and DNR-managed lands. Experiments could be conducted in a sample of these stands in an active approach that measured marbled murrelet and stand responses. Marbled murrelet responses in these experiments, and to other managed stands that approach threshold levels of habitat quality, can be monitored with radar and/or a-v observers. Planned integration can allow some of these efforts to provide information around multiple questions.

4. *Feedback*: Habitat models can be refined in an iterative fashion through feedback from monitoring, thus improving silvicultural targets. Likewise, conclusions from silvicultural experiments would guide more effective, efficient management for habitat restoration in young stands. Findings from experiments in older, lower-quality habitat in the OESF could help direct management in all planning units regarding enhancement techniques for lower-quality habitat and management to maintain habitat quality while achieving other objectives. The most important feedback will result from monitoring marbled murrelet responses to restored habitat, which is likely to require two to four decades for sufficient restoration to estimate responses. Management changes prompted by this feedback are likely to depend substantially on then-current marbled murrelet population status and other issues.

<u>Fragmentation and Edge Effects</u>

The pattern of state trust ownership and multiple-use objectives for trust lands requires that all MMMAs are subject to the potentially negative effects of fragmentation and edge on the stability of marbled murrelet populations.

1. *Uncertainty:* The strength and consistency of edge and broad landscape-level influences, and their potential interaction effects on marbled murrelet nest success and nesting rates, is uncertain. Within the three analysis units (see Figure 3-1), the many geographically discrete designated and undesignated MMMAs exist in a broad range of edge and landscape contexts. Thus, predicted contributions of those areas toward the biological goals are also uncertain.

2. *Alternatives*: An active approach to resolving uncertainties is possible, even without experimental modifications of the landscape context around MMMAs, because the wide range that currently exists will allow measurement of marbled murrelet responses to substantial contrasts. Planned habitat restoration will provide further contrasts at some sites. Model predictions can identify sites with contrasting edge and/or landscape effects.

3. *Monitoring*: Two marbled murrelet responses are important to the biological goals: nesting rates and nest success. Due to the difficulty in locating nests nesting

rates may be best inferred by monitoring marbled murrelet activity and behavior with a-v and/or radar observations. These studies can be conducted in designed experiments at sites sampled from across the range of landscape conditions, using model predictions to identify contrasts. Given the existing uncertainty, experiments might identify four groups using a 2 x 2 matrix of predicted high and low negative edge and landscape effects, and then monitor and compare marbled murrelet responses among them. Extensive areas of habitat restoration and/or OESF management areas managed to minimize fragmentation could allow before and after comparisons at the same sites. Nest success in response to these influences must be inferred from direct observations at actual or simulated marbled murrelet nests. Experiments with simulated marbled murrelet nests could be conducted with a design as described above. Finding a sufficient number of marbled murrelet nests will likely be very challenging, requiring intensive efforts, so opportunistic observations could be compiled over time and reviewed against model predictions in a passive approach.

4. *Feedback*: It is possible that conclusions from monitoring would suggest that different habitat configurations or contexts would be more effective at meeting biological goals. DNR should explore and implement management alternatives and incorporate that feedback to the extent practicable. It is also possible that conclusions may suggest that discrete geographic components of the LTCS contribute little toward the biological goals. This potential finding is part of the reason the Services noted the interaction of "...economics, policies and regulations..." in identifying alternative management approaches in response to monitoring (USFWS and NMFS 2000). Greater certainty around projected outcomes for marbled murrelet conservation may allow DNR and USFWS to revise the LTCS to a more effective, efficient configuration.

Colonization of Restored Habitat

Conservation benefits projected to result from implementing this component of the LTCS depend on marbled murrelets recolonizing areas of restored habitat that are currently remote from substantial marbled murrelet inland activity (e.g., the Elochoman MMMA in SWWA).

1. *Uncertainty*: It is nearly certain that marbled murrelets are capable of colonizing newly developed habitat, given sufficient time and numbers of marbled murrelets. However, it is possible that this may not occur as predicted within the duration of the HCP at levels that are necessary to meet biological goals.

2. *Alternatives*: A substantial range of contexts relative to predicted habitat quality and current levels of marbled murrelet inland activity exists among the basic configuration of MMMAs. The contrasts in this range provide opportunities for a passive approach to evaluate marbled murrelet responses to various contexts.

3. *Monitoring*: Model predictions can identify areas likely to have higher or lower probabilities of recolonization. Periodic monitoring of marbled murrelet activity at a sample of these areas could help determine whether or not predicted levels of marbled murrelet use after habitat restoration are achieved.

4. *Feedback*: It is possible that conclusions may suggest that discrete geographic components of the LTCS contribute little toward biological goals. In this case, with feedback from other adaptive management components, it may appear that different habitat configurations would be more effective at meeting biological goals. DNR should explore and implement management alternatives to incorporate that feedback. Feedback on this component of the strategy likely awaits many decades of habitat restoration, accompanied by a well designed marbled murrelet monitoring program. Management changes prompted by any such feedback are likely to depend substantially on then-current marbled murrelet population status and other issues.

7.0 LITERATURE CITED

Ackerman, J. T., J. Adams, J. Y. Takekawa, H. R. Carter, D. L. Whitworth, S. H. Newman, R. T. Golightly, and D. L. Orthmeyer. 2004. Effects of Radiotransmitters on the Reproductive Performance of Cassin's Auklets. *Wildlife Society Bulletin* 32:1229-1241.

Agee, J.K. 1993. *Fire Ecology of the Pacific Northwest Forests*. Island Press. Washington, D.C.

Agler, B. A., S. J. Kendall, and D. B. Irons. 1998. Abundance and Distribution of Marbled and Kittlitz's Murrelets in Southcentral and Southeast Alaska. *The Condor* 100:254–265.

Ainley, D. G., S. G. Allen and L. B. Spear. 1995. Offshore occurrence patterns of Marbled Murrelets in central California. Pages 361–369 in C. J. Ralph, G. L. Hunt, Jr., M. G. Raphael, and J. F. Piatt, (Tech. eds.) *Ecology and Conservation of the Marbled Murrelet.* General Technical Report PSW-GTR-152. U.S. Forest Service, Pacific Southwest Research Station, Albany, CA.

American Ornithologists' Union. 1957. *Check-List of North American Birds.* Fifth Edition. Baltimore, MD.

American Ornithologists' Union. 1997. Forty-first Supplement to the American Ornithologists' Union Check-list of North American Birds. *The Auk* 114:542-552.

Baldwin, J. 2001 (November 21). *Investigating the Possibility of Changes in Status at a Site.* Unpublished report. Available: <http://www.pacificseabirdgroup.org>.

————. 2002 (July 16). *Assessing the 2-Year Protocol for Marbled Murrelets.* Unpublished report. Available: <http://www.pacificseabirdgroup.org>.

Beattie, W. and A. Seiders. 2003. *Indian Gillnet and Purse Seine Fisheries Declines in Washington State 1993-2001*. Unpublished report. Northwest Indian Fisheries Commission. Prepared for Bureau of Indian Affairs and U. S. Fish and Wildlife Service, Olympia, WA.

Beauchamp, W. D., F. Cooke, C. Lougheed, L. W. Lougheed, C. J. Ralph, and S. Courtney. 1999. Seasonal Movements of Marbled Murrelets: Evidence from Banded Birds. *The Condor* 101:671–674.

Beissinger, S. R. 1995. Population Trends of the Marbled Murrelet Projected from Demographic Analyses. Pages 385–393 in C. J. Ralph, G. L. Hunt, M. G. Raphael, and J. F. Piatt (Tech. eds.), *Ecology and Conservation of the Marbled Murrelet.* General Technical Report PSW-GTR-152. U.S. Forest Service, Pacific Southwest Research Station, Albany, CA.

Beissinger, S. R., and N. Nur. 1997. Population Trends of the Marbled Murrelet Projected from Demographic Analysis. Appendix B (pages B1–B35) in U.S. Fish and Wildlife Service, *Recovery Plan for the Threatened Marbled Murrelet* (Brachyramphus marmoratus) *in Washington, Oregon and California.* U. S. Fish and Wildlife Service, Portland, OR.

Beissinger, S. R., and M. Z. Peery. 2007. Reconstructing the Historic Demography of an Endangered Seabird. *Ecological Applications* 16:1516–1528.

Bellward, G. D., R. J. Norstrom, P. E. Whitehead, J. E. Elliott, S. M. Bandiera, C. Dworschak, T. Chang, S. Forbes, B. Cadario, L. E. Hart, and K.M. Cheng. 1990. Comparison of Polychlorinated Dibenzodioxin Levels with Hepatic Mixed-Function Oxidase Induction in Great Blue Herons. *Journal of Toxicological Environmental Health* 30:33–52.

Bergvall, J. A., and Y. D. Sharma. 1976. *A Profile of Washington State Uplands*. Washington State Department of Natural Resources, Volume W. 4, Olympia, WA.

Bigger, D., M.Z. Peery, J. Baldwin, S. Chinnici, and S. P. Courtney. 2006a. Power to Detect Trends in Marbled Murrelet Breeding Populations using Audio-Visual and Radar Surveys. *Journal of Wildlife Management* 70:493–504.

Bigger, D., M. Z. Peery, S. Chinnici, and S. P. Courtney. 2006b. Efficacy of Audiovisual and Radar Surveys for Studying Marbled Murrelets in Inland Habitats. *Journal of Wildlife Management* 70:504-515.

Bigley, R. E., and F. U. Deisenhofer. 2006. *Implementation Procedures for the Habitat Conservation Plan Riparian Forest Restoration Strategy.* Washington State Department of Natural Resources, Scientific Support Section, Olympia, WA.

Binford, L. C., B. G. Elliot, and S. W. Singer. 1975. Discovery of a Nest and the Downy Young of the Marbled Murrelet. *Wilson Bulletin* 87:303–319.

Bloxton, T. D., and M. G. Raphael. 2006. *Breeding Ecology of the Marbled Murrelet in Washington State. Annual Report, 2005 Field Season.* Available from M. G. Raphael at

U.S. Forest Service, Pacific Northwest Research Station, 3625 93rd Ave. SW, Olympia, WA 98512-9193.

————. 2007. *Breeding Ecology of the Marbled Murrelet in Washington State. Annual Report, 2006 Field Season.* Available from M. G. Raphael at U.S. Forest Service, Pacific Northwest Research Station, 3625 93rd Ave. SW, Olympia, WA 98512-9193.

Boulanger, J. G., K. Martin, G. Kaiser, and A. E. Derocher. 1999. Evaluation Uncertainty in Estimating Population Trends of Marbled Murrelets. Pages 55–63 in A. W. Diamond and A. W. Nettleship (eds.), *Biology and Conservation of Forest Birds.* Society of Canadian Ornithologists, Fredericton, NB, Canada.

Bradley, R.W. 2002. *Breeding Ecology of Radio-Marked Marbled Murrelets (*Brachyramphus marmoratus*) in Desolation Sound, British Columbia.* M.S. dissertation. Simon Fraser University, Department of Biological Sciences, Burnaby, BC, Canada.

Bradley, R. W., and F. Cooke. 2001. Cliff and Deciduous Tree Nests of Marbled Murrelets in Southwestern British Columbia. *Northwestern Naturalist* 82:52–57.

Bradley, R. W., F. Cooke, L. W. Lougheed, and W. S. Boyd. 2004. Inferring Breeding Success through Radiotelemetry in the Marbled Murrelet. *Journal of Wildlife Management* 68:318–331.

Bradley, R. W., and J. M. Marzluff. 2003. Rodents as Nest Predators: Influences on Predatory Behavior and Consequences to Nesting Birds. *The Auk* 120:1180–1187.

Bradley, R. W., L. A. McFarlane-Tranquilla, B. A. Vanderkist, and F. Cooke. 2002. Sex Differences in Nest Variation Rate of Chick Rearing Marbled Murrelets. *The Condor* 104:180–185.

Brodie, A. W., W. Jaross, B. Lu, and D. Lindley. 2004. Modeling Forest Stand Development Stages for Strategic Modeling of Forested State Trust Lands in Western Washington. Technical Note No. 2, Appendix B, in Washington State Department of Natural Resources. *Final Environmental Impact Statement on Alternatives for Sustainable Forest Management of State Trust Lands in Western Washington and for Determining the Sustainable Harvest Level.* Washington State Department of Natural Resources, Olympia, WA.

Budy, P., and H. Schaller. 2007. Evaluating Tributary Restoration Potential for Pacific Salmon Recovery. *Ecological Applications* 17:1068–1086.

Burger, A. E. 1995. Marine Distribution, Abundance, and Habitats of Marbled Murrelets in British Columbia. Pages 295–312 in C. J. Ralph, G. L. Hunt, Jr., M. G. Raphael, and J. F. Piatt (tech. eds.), *Ecology and Conservation of the Marbled Murrelet.* General Technical Report PSW-GTR-152. U. S. Forest Service, Pacific Southwest Research Station. Albany, CA.

Burger, A. E. 1997. Behavior and Numbers of Marbled Murrelets Measured with Radar. *Journal of Field Ornithology* 68:208-223.

————. 2001. Using Radar to Estimate Populations and Assess Habitat Associations of Marbled Murrelets. *Journal of Wildlife Management* 65:696–715.

————. 2002. *Conservation Assessment of Marbled Murrelets in British Columbia: A Review of the Biology, Populations, Habitat Associations, and Conservation.* Technical Report Series No. 387, Canadian Wildlife Service, Pacific and Yukon Region, Delta, BC. Available: <http://www.sfu.ca/biology/wildberg/bertram/mamurt/PartA.pdf>.

Burger, A. E., and D. M. Fry. 1993. Effects of Oil Pollution on Seabirds in the Northeast Pacific. Pages 254-263 in K. Vermeer, K.T. Briggs, K.H. Morgan, and D. Siegel-Causey, (tech. eds.), *The Status, Ecology, and Conservation of Marine Birds of the North Pacific*. Canadian Wildlife Service Special Publication, Ottawa, ON.

Burger, A. E., T. A. Chatwin, S. A. Cullen, N. P. Holmes, I. A. Manley, M. H. Mather, B. K. Schroeder, J. D. Steventon, J. E. Duncan, P. Arcese, and E. Selak. 2004. Application of Radar Surveys in the Management of Nesting Habitat of Marbled Murrelets *Brachyramphus marmoratus*. *Marine Ornithology* 32:1-11.

Burger, A. E. and R. E. Page. 2007. The Need for Biological Realism in Habitat Modeling: A Reinterpretation of Zharikov et al. (2006). *Landscape Ecology* (Online First) 10.1007/s10980-007-9114-6

Burkett, E. E. 1995. Marbled Murrelet Food Habits and Prey Ecology. Pages 223–246 in C. J. Ralph, G. L. Hunt, Jr., M. G. Raphael, and J. F. Piatt (tech. eds.), *Ecology and*

Conservation of the Marbled Murrelet. General Technical Report PSW-GTR-152. U.S. Forest Service, Pacific Southwest Research Station, Albany, CA.

Burkett, E. E. H. R. Carter, J. Y. Takekawa, S. Newman, R. T. Golightly, and J. L. Lanser. 1999. Marbled Murrelet Radio Telemetry in Central California in 1997 and 1998: A Reduced Effort Noted in an El Nino Year. *Pacific Seabirds* 26:32.

Burnham, K. P., and D. R. Anderson. 2002. *Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach.* Springer-Verlag, New York.

Cam, E., L. Lougheed, R. Bradley, and F. Cooke. 2003. Demographic Assessment of a Marbled Murrelet Population from Capture-Mark-Recapture and Radiotelemetry Data. *Conservation Biology* 17:1118–1126.

Campbell, R. W., M. A. Paul, M. S. Rodway, and H. R. Carter. 1977. Tree-nesting Peregrine Falcons in British Columbia. *The Condor* 79:500-501.

Canadian Marbled Murrelet Recovery Team. 2003. Marbled Murrelet Conservation Assessment 2003, Part B: Marbled Murrelet Recovery Team Advisory Document on Conservation and Management. Canadian Marbled Murrelet Recovery Team Working Document No. 1.

Carey, A. B., S. P. Courtney, J. F. Franklin, J. M. Marzluff, M. G. Raphael, J. C. Tappanier, and D. A. Thornburgh. 2003. *Managing Second-Growth Forests in the Redwood Region to Enhance Marbled Murrelet Habitat.* Unpublished report of the Scientific Panel on Restoration of Marbled Murrelet Habitat. Sustainable Ecosystems Institute, Portland, OR.

Carey, A. B., C. Elliot, B. R. Lippke, J. Sessions, C. J. Chambers, C. D. Oliver, J. F. Franklin, and M. J. Raphael. 1996. A Pragmatic, Ecological Approach to Small-Landscape Management. Washington Forest Landscape Management Project Report No. 2. Washington State Department of Natural Resources, Olympia, WA.

Carter, H. R. 1984. *At-Sea Biology of the Marbled Murrelet in Barkley Sound, British Columbia.* M.S. dissertation. University of Manitoba, Winnipeg, MB, Canada.

————. 2003. Oil and California's Seabirds: An Overview. *Marine Ornithology* 31:3–9.

Carter, H.R., and R.A. Erickson. 1988. Population Status and Conservation Problems of the Marbled Murrelet in California, 1892-1987. Unpublished report, California Department of Fish and Game, Sacramento, California.

Carter, H. R., and R.A. Erickson. 1992. Status and Conservation of the Marbled Murrelet in California. In: H. R. Carter and M. L. Morrison (eds.), Status and Conservation of the Marbled Murrelet in North America. *Proceedings of the Western Foundation of Vertebrate Zoology* 5:92–108.

Carter, H. R., and K. J. Kuletz. 1995. Mortality of Marbled Murrelets due to Oil Pollution in North America. Pages 161–169 in C. J. Ralph, G. L. Hunt, M. G. Raphael, and J. F. Piatt (tech. eds.), *Ecology and Conservation of the Marbled Murrelet.* General Technical Report PSW-GTR-152. U.S. Forest Service, Pacific Southwest Research Station, Albany, CA.

Carter, H. R., and S. G. Sealy. 1984. Marbled Murrelet (*Brachyramphus marmoratus*) Mortality Due to Gill-Net Fishing in Barkley Sound, British Columbia. Pages 212–220 in D. N. Nettleship, G. A. Sanger, and P. F. Springer (eds.), *Marine Birds: Their Feeding Ecology and Commercial Fisheries Relationships.* Canadian Wildlife Service Special Publication. Ottawa, ON.

————. 1986. Year-round Use of Coastal Lakes by Marbled Murrelets. *The Condor* 88:473-477.

Carter, H. R. and S. G. Sealy. 1987a. Fish-Holding Behavior of Marbled Murrelets. *Wilson Bulletin* 99: 289–291.

————. 1987b. Inland Records of Downy Young and Fledgling Marbled Murrelets in North America. *The Murrelet* 68:58–63.

————. 1990. Daily Foraging Behavior of Marbled Murrelets. *Studies in Avian Biology* 14:93–102.

Carter, H. R., and J. L. Stein. 1995. Molts and Plumages in the Annual Cycle of the Marbled Murrelet. Pages 99–109 in C. J. Ralph, G. L. Hunt, M. G. Raphael, and J. F. Piatt (tech. eds.), *Ecology and Conservation of the Marbled Murrelet*. General

Technical Report PSW-GTR-152. U.S. Forest Service, Pacific Southwest Research Station, Albany, CA.

Carter, H. R., M. L. C. McAllister, and M. E. Isleib. 1995. Mortality of Marbled Murrelets Due to Gill-Net Fishing in North America. Pages 271–283 in C. J. Ralph, G. L. Hunt, Jr., M. G. Raphael, and J. F. Piatt (tech. eds.), *Ecology and Conservation of the Marbled Murrelet*. General Technical Report PSW-GTR-152. U.S. Forest Service, Pacific Southwest Research Station, Albany, CA.

Chatterjee, S., and A. S. Hadi. 1988. *Sensitivity Analysis in Linear Regression*. John Wiley, New York.

Chen, J., J. F. Franklin, and T. A. Spies. 1990. Microclimate Pattern and Basic Biological Responses at the Clearcut Edge of Old-Growth Douglas-fir Stands. *Northwest Environmental Journal* 6:424–425.

————. 1993. Contrasting Microclimates among Clearcut, Edge, and Interior of Old-Growth Douglas-fir Forest. *Agricultural and Forest Meteorology* 63:219–237.

————. 1995. Growing-Season Microclimatic Gradients from Clearcut Edges into Old-Growth Douglas-fir Forests. *Ecological Applications* 5:74–86.

Colodey, A. G., and P. G. Wells. 1992. Effects of Pulp and Paper Mill Effluents on Estuarine and Marine Ecosystems in Canada: A Review. *Journal of Aquatic Ecosystem Stress and Recovery* 1:201–226.

Congdon, B. C., J. F. Piatt, K. Martin, and V. L. Friesen. 2000. Mechanisms of Population Differentiation in Marbled Murrelets: Historical versus Contemporary Processes. *Evolution* 54:974–986.

Cooper, B. A., M. G. Raphael, and M. Z. Peery. 2006. Trends in Radar-Based Counts of Marbled Murrelets on the Olympic Peninsula, Washington, 1996-2004. *The Condor* 108:936–947.

Crookston, N. L., and A. R. Stage. 1999. *Percent Canopy Cover and Stand Structure Statistics from the Forest Vegetation Simulator.* General Technical Report RMRS-GTR-24. U.S. Forest Service, Rocky Mountain Research Station, Ogden, UT.

Cross, J. C., and J. M. Comnick. 2006. Identifying Northern Spotted Owl Habitat in the Olympic Experimental State Forest: Applying Fuzzy Set Theory to Reduce Type II Errors. Final Report to U.S. Forest Service, Pacific Northwest Research Station, Portland, OR.

Curtis, R. O., and D.D. Marshall. 2000. Why Quadratic Mean Diameter? *Western Journal of Applied Forestry* 15:137–139.

Daniels, J. M. 2004. *Assessing Socioeconomic Resiliency in Washington Counties.* General Technical Report PNW-GTR-607. U.S. Forest Service, Pacific Northwest Research Station, Portland, OR.

DeGange, A. R. 1996. *A Conservation Assessment for the Marbled Murrelet in Southeast Alaska.* General Technical Report PNW-GTR-388. U.S. Forest Service, Pacific Northwest Research Station, Portland, OR.

Den Boer, P. J. 1981. On the Survival of Populations in a Heterogeneous and Variable Environment. *Oecologia* 50:39–53.

De Santo, T. L, and S. K. Nelson. 1995. Comparative Reproductive Ecology of the Auks (Family Alcidae) with Emphasis on the Marbled Murrelet. Pages 33–47 in C. J. Ralph, G. L. Hunt, Jr., M. G. Raphael, and J. F. Piatt (tech. eds.), *Ecology and Conservation of the Marbled Murrelet*. General Technical Report PSW-GTR-152. U.S. Forest Service, Pacific Southwest Research Station, Albany, CA.

Divoky, G. J., and M. Horton. 1995. Breeding and Natal Dispersal, Nest Habitat Loss and Implications for Marbled Murrelet Populations. Pages 83–87 in C. J. Ralph, G. L. Hunt, Jr., M. G. Raphael, and J. F. Piatt (tech. eds.), *Ecology and Conservation of the Marbled Murrelet.* General Technical Report PSW-GTR-152. U.S. Forest Service, Pacific Southwest Research Station, Albany, CA.

DNR. *See* Washington State Department of Natural Resources.

Duke, S. 1997. *An Inventory-Based Procedure for Estimating the Abundance of Marbled Murrelet Platforms.* Unpublished report. Weyerhaeuser, Tacoma, WA.

Eisenhawer, A. E., and T. E. Reimchen. 1990. Inland Flight Patterns of Marbled Murrelets, *Brachyramphus marmoratus,* on the Queen Charlotte Islands, B.C. *Canadian Field Naturalist* 104:439–444.

Elliott, J. E., R. W. Butler, R. J. Nortstrom, and P. E. Whitehead. 1989. Environmental Contaminants and Reproductive Success of Great Blue Heron (*Ardea herodias*) in British Columbia, 1986–1989. *Environmental Pollution* 59:91–114.

Ethier, T. J. 1999. *Breeding Ecology and Habitat of Northern Goshawks* (*Accipiter gentiles* laingi) *on Vancouver Island: A Hierarchical Approach.* M.S. dissertation. University of Victoria, Victoria, BC, Canada.

Evans Mack, D., W. P. Ritchie, S. K. Nelson, E. Kuo-Harrison, P. Harrison, and T. E. Hamer. 2000. *Methods for Surveying Marbled Murrelets in Forests: An Update to the Protocol for Land Management and Research.* Pacific Seabird Group Marbled Murrelet Technical Committee, McKinleyville, CA.

Evans Mack, D., W. P. Ritchie, S. K. Nelson, E. Kuo-Harrison, P. Harrison, and T. E. Hamer. 2003. *Methods for Surveying Marbled Murrelets in Forests: A Revised Protocol for Land Management and Research.* Pacific Seabird Group Marbled Murrelet Technical Committee, McKinleyville, CA.

Everett, R. L., P. F. Hessburg, and T. R. Lillybridge. 1994. Emphasis Areas as an Alternative to Buffer Zones and Reserved Areas in the Conservation of Biodiversity and Ecosystem Processes. *Journal of Sustainable Forestry* 2:283–292.

Everett, R. L., and J. F. Lehmkuhl. 1999. Restoring Biodiversity on Public Forest Lands through Disturbance and Patch Management Irrespective of Land-Use Allocation. Pages 87–105 in R. K. Baydack, H. Campa III, and J. B. Haufler (eds.), *Practical Approaches to the Conservation of Biological Diversity.* Island Press, Washington, DC.

Flaherty, E. A., S. A. Dubay, J. Bradley, J. Marzluff, and G. D. Hayward. 2000. The Northern Flying Squirrel (*Glaucomys sabrinus*) as a Potential Predator of Marbled Murrelet (*Brachyramphus marmoratus*) Eggs. *Northwest Science* 74:335–339.

Ford, D. E. 2000. *Scientific Method for Ecological Research*. Cambridge University Press, Cambridge, U.K.

Ford, R. G., G. K. Himes Boor, B. E. Sharp, and J. L. Casey. 2002. *Estimates of Bird Impacts Resulting from the M/V Kure/Humboldt Bay Oil Spill of November 5, 1997.* Final report prepared for California Department of Fish and Game, Office of Spill Prevention and Response.

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

Franklin, J. F., T. A. Spies, R. Van Pelt, A. B. Carey, D. A. Thorngurgh, D. R. Berg, D. B. Lindenmayer, M. E. Harmon, W. S. Keeton, D. C. Shaw, K. Bible, and J. Chen. 2002. Disturbance and Structural Development of Natural Forest Ecosystems with Silvicultural Implications, Using Douglas-Fir Forests as an Example. *Forest Ecology and Management* 155:399–423.

Friesen, V. L., A. J. Baker, and J. F. Piatt. 1996a. *A Genetic Study to Aid in the Restoration of Murres, Guillemots and Murrelets to the Gulf of Alaska.* Restoration project 00169 final report. Exxon Valdez Trustee Council, Anchorage, AK.

————. 1996b. Phylogenetic Relationships within the Alcidae (Charadriiformes: Aves) Inferred from Total Molecular Evidence. *Molecular Biology and Evolution* 13:359–367.

Friesen, V. L., T. P. Birt, J. F. Piatt, R. T. Golightly, S. H. Newman, P. N. Hébert, B. C. Congdon, and G. Gissing. 2005. Population Genetic Structure and Conservation of Marbled Murrelets (*Brachyramphus marmoratus*). *Conservation Genetics* 6:607–614.

Friesen, V. L., B. C. Congdon, H. E. Walsh, and T. P. Birt. 1997. Intron Variation in Marbled Murrelets Detected Using Analyses of Single-Stranded Conformational Polymorphisms. *Molecular Ecology* 6:1047–1058.

Fry, D. M. 1995. Pollution and Fishing Threats to Marbled Murrelets. Pages 257–260 in C. J. Ralph, G. L. Hunt, Jr., M. G. Raphael, and J. F. Piatt (eds.), *Ecology and Conservation of the Marbled Murrelet*. General Technical Report PSW-GTR-152. U.S. Forest Service, Pacific Southwest Research Station, Albany, CA.

Gaston, A. J., and I. L. Jones. 1998. *The Auks: Alcidae.* Oxford University Press, New York, NY.

Greene, S. E., P. A. Harcombe, M. E. Harmon, and G. Spycher. 1992. Patterns of Growth, Mortality, and Biomass Change in a Coastal *Picea sitchensis-Tsuga heterophylla* Forest. *Journal of Vegetation Science* 3:697–706.

Green, K. S., S. Bernath, L. Lackey, M. Brunengo, and S. Smith. 1993. Analyzing the Cumulative Effects of Forest Practices: Where Do We Start? *Geo Info Systems* 3:31–41.

Grenier, J. J., and S. K. Nelson 1995. Marbled Murrelet Habitat Associations in Oregon. Pages 191-204 in Ralph, C. J., G. L. Hunt Jr., M. G. Raphael, and J. F. Piatt (tech. eds), *Ecology and Conservation of the Marbled Murrelet.* General Technical Report PSW-GTR-152. U.S. Forest Service, Pacific Southwest Research Station, Albany, CA.

Guisan, A., and N. E. Zimmermann. 2000. Predictive Habitat Distribution Models in Ecology. *Ecological Modeling* 135:147–186.

Haas, C. A. 1998. Effects of Prior Nesting Success on Site Fidelity and Breeding Dispersal: An Experimental Approach. *The Auk* 115:929–936.

Hamer, T. E., and E. B. Cummins. 1991. *Relationships between Forest Characteristics and the Use of Inland Sites by Marbled Murrelets in Northern Washington.* Washington Department of Wildlife, Non-game Program, Olympia, WA.

Hamer, T. E., and D. J. Meekins. 1999. *Marbled Murrelet Nest Site Selection in Relation to Habitat Characteristics in Western Washington.* Unpublished report. Hamer Environmental, L.P., Mount Vernon, WA.

Hamer, T. E., and S. K. Nelson. 1995. Characteristics of Marbled Murrelet Nest Trees and Nesting Stands. Pages 69–82 in C. J. Ralph, G. L. Hunt Jr., M.G. Raphael, and J. F. Piatt (tech. eds.), *Ecology and Conservation of the Marbled Murrelet.* General Technical Report PSW-GTR-152. U.S. Forest Service, Pacific Southwest Research Station, Albany, CA.

Hamer, T. E., S. K. Nelson, and T. I. Mohagen. 2003. *Nesting Chronology of the Marbled Murrelet.* Unpublished report. U. S. Fish and Wildlife Service, Portland, OR.

Harris, M. P. 1983. Biology and Survival of the Immature Puffin *Fratercula arctica*. *Ibis* 125:109–114.

Harris, M. P., and S. Wanless. 1989. Fall Colony and Attendance and Breeding Success in the Common Murre. *The Condor* 91:139–146.

Harris, M.P., D.J. Halley, and S. Wanless. 1996a. Philopatry in the Common Guillemot *Uria aalge*. *Bird Study* 43:134-137.

Harris, M.P., S.Wanless, and T.R. Barton. 1996b. Site Use and Fidelity in the Common Guillemot *Uria aalge*. *Ibis* 138:399-404.

Harris, M.P., M. Frederiksen, and S. Wanless. 2007. Within- and Between-year Variation in the Juvenile Survival of Common Guillemots *Uria aalge*. *Ibis* 149:472–481.

Harrison, P. 2007. Natural Resources Scientist. Washington Department of Natural Resources, Olympia, WA. March 30, 2007—e-mail to Erin Colclazier, Research Biologist, Hamer Environmental, L.P., Mount Vernon, WA.

Harrison, P., S. Horton, D. Prenzlow Escene. 2003. Reports from DNR Inland Marbled Murrelet Surveys. Unpublished report. Washington State Department of Natural Resources, Olympia, WA.

Hawksworth, F. G. 1977. *The 6-Class Dwarf Mistletoe Rating System.* General Technical Report RM-48. U.S. Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Hebert, P. N., H. R. Carter, R. T. Golightly, and D. L. Orthmeyer. 2003. Radio-telemetry Evidence of Re-nesting in the Same Season by the Marbled Murrelet. *Waterbirds* 26:261–265.

Hebert, P. N., and R. T. Golightly. 2003. *Breeding Biology, and Human-Caused Disturbance to Nesting of Marbled Murrelets* (*Brachyramphus marmoratus*) *in Northern California: Progress Report 2002.* Humboldt State University, Department of Wildlife, and U.S. Geological Survey, Western Ecological Research Center, Arcata and Sacramento, CA.

Henkel, L. A., and J. T. Harvey. 2006. Potential Prey Resources for Marbled Murrelets in Central California. *California Fish and Game* 92:191–206.

Heuvelink. G. B. M. 1998. Uncertainty Analysis in Environmental Modelling Under a Change of Spatial Scale. *Nutrient Cycling in Agroecosystems* 50:255–264.

Hilborn, R., and M. Mangel. 1997. *The Ecological Detective: Confronting Models with Data.* Princeton University Press, Princeton, NJ.

Hobson, K. A. 1990. Stable Isotope Analysis of Marbled Murrelets: Evidence for Freshwater Feeding and Determination of Trophic Level. *The Condor* 92:897–903.

Holling, C. S. 1973. Resilience and Stability of Ecological Systems. *Annual Review of Ecology and Systematics* 4:1–23.

Holmberg, P., B. Aulds, G. McFadden, and W. Jaross. 2005. *Thinning Forest Stands, Westside: An Inter-Active Self-Study and Reference Pamphlet.* Internal document. Washington State Department of Natural Resources, Olympia, WA.

Hooper, T. D. 2001. *Research and Inventory of Marbled Murrelets* (Brachyramphus marmoratus) *in British Columbia: 1991–1999.* Unpublished report. Canadian Wildlife Service, Pacific and Yukon Region, Delta, BC, Canada.

Horton, S. 2008. Temporal Variability of Marbled Murrelet Activity in Old-Growth Forests. Pages 1-35 in Ph.D. dissertation. University of Washington, College of Forest Resources, Seattle, WA.

Hudson, P. J. 1985. Population Parameters for the Atlantic Alcidae. Pages 233–261 in D. N. Nettleship and T. R. Birkhead (eds.), *The Atlantic Alcidae.* Academic Press, London, England.

Huff, M., P. Jodice, J. Baldwin, S. Miller, R. Young, K. Ostrom, C. J. Ralph, M. Raphael, C. Strong, and C. Thompson. 2003. *Draft Marbled Murrelet Effectiveness Monitoring Northwest Forest Plan. 2002 Annual Summary Report.* Northwest Forest Plan Interagency Regional Monitoring Program.

Hull, C. L., G. W. Kaiser, C. Lougheed, L. Lougheed, S. Boyd, and F. Cooke. 2001. Intraspecific Variation in Commuting Distance of Marbled Murrelets (*Brachyramphus marmoratus*): Ecological and Energetic Consequences of Nesting Further Inland. *The Auk* 118:1036–1046.

Hunt, G.L. Jr.1995a. Monospecific and Mixed Species Foraging Associations of Marbled Murrelets. Pages 255-256 in Ralph, C. J., G. L. Hunt Jr., M. G. Raphael, and J. F. Piatt (tech. eds), *Ecology and Conservation of the Marbled Murrelet.* General Technical Report PSW-GTR-152. U.S. Forest Service, Pacific Southwest Research Station, Albany, CA.

Hunt, G. L. Jr. 1995b. Oceanographic Processes and Marine Productivity in Waters Offshore of Marbled Murrelet Breeding Habitat. Pages 219-222. in C. J. Ralph, J. G. L. Hunt, M. G. Raphael, and J. F. Piatt (tech. eds.), *Ecology and Conservation of the Marbled Murrelet*. General Technical Report PSW-152. U. S. Forest Service, Pacific Southwest Research Station, Albany, CA.

Irons, D. B. 1992. *Aspects of Foraging Behavior and Reproductive Biology of the Black-Legged Kittiwake.* Ph.D. dissertation. University of California, Irvine, CA.

Iverson, G. C., G. D. Hayward, K. Titus, E. DeGayner, R. E. Lowell, D. C. Crocker-Bedford, P. F. Schempf, and J. Lindell. 1996. Conservation Assessment for the Northern Goshawk in Southeast Alaska. General Technical Report PNW-GTR-387. U. S. Forest Service, Pacific Northwest Research Station, Portland, OR.

Jaross, W., and W. Read. 2006. *Wind Hazard Assessment in the Willapa Region of Southwestern Washington.* Unpublished document. Washington State Department of Natural Resources, Olympia, WA.

Jodice, P. G. R., and M. W. Collopy. 1999. Diving and Foraging Patterns of Marbled Murrelets (*Brachyramphus marmoratus*): Testing Predictions from Optimal-Breathing Models. *Canadian Journal of Zoology* 77:1409–1418.

Jones, P.H. 1992. Marbled Murrelet Flight Behaviour at a Presumed Nesting Area in the Caren Range, near Sechelt, British Columbia. *British Columbia Birds* 2:14-18.

————. 1994. Canada's Second Marbled Murrelet Chick Sighting, Caren Range, B.C. *Discovery* 23:99.

————. 2001. *The Marbled Murrelets of the Caren Range and Middlepoint Bight.* Western Canada Wilderness Committee, Vancouver, BC, Canada.

Kokko, H., M. P. Harris, and S. Wanless. 2004. Competition for Breeding Sites and Site-Dependent Population Regulation in a highly Colonial Seabird, the Common Guillemot *Uria aalge*. *Journal of Animal Ecology* 73:367–376.

Konyukhov, N. B., and A. S. Kitaysky. 1995. The Asian Race of the Marbled Murrelet. Pages 23–29 in C. J. Ralph, G. L. Hunt, M. G. Raphael, and J. F. Piatt (tech. eds.), *Ecology and*

Conservation of the Marbled Murrelet. General Technical Report PSW-GTR-152. U. S. Forest Service, Pacific Southwest Research Station, Albany, CA.

Kremsater, L., and F. L. Bunnel. 1999. Edge Effects: Theory, Evidence and Implication to Management of Western North American Forests. In J. A. Rochelle, L. Lehman, and J. Wisniewski (eds.), *Forest Fragmentation: Wildlife and Management Implications.* Brill, Leiden, The Netherlands.

Kuletz, K. J. 1996. Marbled Murrelet Abundance and Breeding Activity at Naked Island, Prince William Sound, and Kachemak Bay, Alaska, Before and After the Exxon Valdez Oil Spill. *American Fisheries Society Symposium* 18:770–784.

Kuletz, K. J. 2005. *Foraging Behavior and Productivity of a Non-colonial Seabird, the Marbled Murrelet (Brachyramphus marmoratus), Relative to Prey and Behavior*. Ph.D. dissertation. University of Victoria, Victoria, B.C., Canada.

Kuletz, K. J., and S. J. Kendall. 1998. A Productivity Index for Marbled Murrelets in Alaska Based on Surveys at Sea. *Journal of Wildlife Management* 62: 446–460.

Lance, M. M., and S. F. Pearson. 2005. 2005 At-Sea Marbled Murrelet Population Monitoring. Washington Department of Fish and Wildlife, Olympia, WA. Available: <http://wdfw.wa.gov/wlm/research/papers/murrelet/2005_at_sea_monitoring.pdf>.

Lank, D. B., N. Parker, E. A. Krebs, and L. McFarlane-Tranquilla. 2003. *Geographic Distribution, Habitat Selection, and Population Dynamics with Respect to Nesting Habitat Characteristics of Marbled Murrelets* (Brachyramphus marmoratus). Simon Fraser University, Center of Wildlife Ecology, Vancouver, BC, Canada.

Lindenmayer, D. B., and J. F. Franklin. 2002. *Conserving Forest Biodiversity: A Comprehensive Multiscaled Approach.* Island Press, Washington, DC.

Lougheed, L. W., W. D. Beauchamp, I. A. Manley, A. E. Derocher, G. W. Kaiser, and F. Cooke. 1998. *Demography and Ecology of Marbled Murrelets in Desolation Sound, British Columbia (1995).* CWS/NSERC Wildlife Ecology Chair Technical Report No. 001. Simon Fraser University, Burnaby, BC, Canada.

Lougheed, C. L., L. W. Lougheed, F. Cooke, and S. Boyd. 2002. Local Survival of Adult and Juvenile Marbled Murrelets and Their Importance for Estimating Reproductive Success. *The Condor* 104:309–318.

Luginbuhl, J. M. 2003. Patch and Landscape Factors Affecting Marbled Murrelet Nest Predation in Coastal Oregon. Unpublished report. University of Washington, College of Forest Resources, Seattle, WA.

Luginbuhl, J. M., J. M. Marzluff, J. E. Bradley, M. G. Raphael, and D. E. Varland. 2001. Corvid Survey Techniques and the Relationship between Corvid Relative Abundance and Nest Predation. *Journal of Field Ornithology* 72:556–572.

Madsen, S., D. Evans, T. Hamer, P. Henson, S. Miller, S. K. Nelson, D. Roby, and M. Stapanian. 1999. *Marbled Murrelet Effectiveness Monitoring Plan for the Northwest Forest Plan.* General Technical Report PNW-GTR-439. U.S. Forest Service, Pacific Northwest Research Station, Portland, OR.

Mahon T. E., G.W. Kaiser, and A. E. Burger. 1992. The Role of Marbled Murrelets in Mixed-Species Feeding Flocks in British Columbia. *The Wilson Bulletin* 104:738-743.

Malt, J., and D. Lank. 2007. Temporal Dynamics of Edge Effects on Nest Predation Risk for the Marbled Murrelet. *Biological Conservation* 140:160–173.

Manley, I. A. 1999. *Behaviors and Habitat Selection of Marbled Murrelets Nesting on the Sunshine Coast.* Simon Fraser University, Department of Biological Sciences, Burnaby, BC, Canada.

————. 2000. *Radar Surveys of Marbled Murrelets on the Northwest Coast of Vancouver Island, British Columbia.* Unpublished report. British Columbia Ministry of Environment, Lands and Parks, Nanaimo, BC, Canada.

————. 2003. *Characteristics of Marbled Murrelet Nest Sites in Desolation Sound and Clayoquot Sound, BC.* Unpublished report. Simon Fraser University, Burnaby, BC, Canada.

Manley, I. A., and S. Cullen. 2003. *Marbled Murrelet Occurrence in the Squamish and Chilliwack Forest Districts: Results of Reconnaissance Radar Surveys in 2002.*

Unpublished report. British Columbia Ministry of Water, Land and Air Protection, Victoria, BC.

Manley, I. A., and S. K. Nelson. 1999. Habitat Characteristics Associated with Nesting Success and Predation at Marbled Murrelet Nests. *Pacific Seabirds* 26:40.

Marks, D. K., and K. J. Kuletz. 2001. Use of Treeless and Forested Habitat by Marbled Murrelets in South-Central Alaska. *Waterbirds* 24:161–168.

Marks, D. K., and N. L. Naslund. 1994. Sharp-Shinned Hawk Preys on a Marbled Murrelet Nestling in Old-Growth Forest. *Wilson Bulletin* 106:565–567.

Marshall, D. B. 1988. *Status of the Marbled Murrelet in North America: With Special Emphasis on Populations in California, Oregon, and Washington.* U.S. Fish and Wildlife Service, Portland, OR.

Marzluff, J. M., and M. Restani. 1999. *The Effects of Forest Fragmentation on Rates of Avian Nest Predation and Parasitism.* Unpublished report. University of Washington, College of Forest Resources, Seattle, Washington.

Marzluff, J. M., J. B. Boone, and G. W. Cox. 1994. Historical Changes in Populations and Perceptions of Native Pest Bird Species in the West. *Studies in Avian Biology* 15:202–220.

Marzluff, J. M., J. M. Luginuhl, J. E. Bradley, E. Neatherlin, M. G. Raphael, D. M. Evans, D. E. Varland, L. S. Young, S. P. Horton, and S. P. Courtney. 1999. *The Influence of Stand Structure, Proximity to Human Activity, and Forest Fragmentation on the Risk of Predation to Nests of Marbled Murrelets on the Olympic Peninsula.* Unpublished report. Sustainable Ecosystems Institute and University of Washington College of Forest Resources, Seattle, WA.

Marzluff, J. M., M. G. Raphael, and R. Sallabanks. 2000. Understanding the Effects of Forest Management on Avian Species. *Wildlife Society Bulletin* 28:1132–1143.

Mathews, N. J. C., and A. E. Burger. 1998. Diving Depth of a Marbled Murrelet. *Northwestern Naturalist* 79:70–71.

McFarlane Tranquilla, L., R. Bradley, N. Parker, D. Lank, and F. Cooke. 2003. Replacement Laying in Marbled Murrelets (*Brachyramphus marmoratus*). *Marine Ornithology* 31:75–81.

McFarlane Tranquilla, L., N. R. Parker, R. W. Bradley, D. B. Lank, E. A. Krebs, L. Lougheed, and C. Lougheed. 2005. Breeding Chronology of Marbled Murrelets Varies Between Coastal and Inshore Sites in Southern British Columbia. *Journal of Field Ornithology* 76:357–367.

McFarlane Tranquilla, L., T. D. Williams, and F. Cooke. 2004. Using Physiology to Examine Interannual Variation in Breeding Chronology of Marbled Murrelets in Desolation Sound, B.C. *The Auk* 120:512-521.

McShane, C. T., T. Hamer, H. Carter, G. Swartzman, V. Friesen, D. Ainley, R. Tressler, K. Nelson, A. Burger, L. Spear, T. Mohagen, R. Martin, L. Henkel, K. Prindle, C. Strong, and J. Keany. 2004. *Evaluation Report for the 5-Year Status Review of the Marbled Murrelet in Washington, Oregon and California*. Unpublished report. EDAW, Inc. Seattle, WA. Prepared for the U.S. Fish and Wildlife Service, Region 1. Portland, OR.

Meyer, C. B., S. L. Miller, and C. J. Ralph. 2002. Multi-scale Landscape and Seascape Patterns Associated with Marbled Murrelet Nesting Areas on the US West Coast. *Landscape Ecology* 17:95–115.

————. 2004. Logistic Regression Accuracy Across Different Spatial and Temporal Scales for a Wide-Ranging Species, the Marbled Murrelet. Pages 94-106 in S. Huzurbazar (ed.) *Resource Selection Methods and Applications*. Omnipress, Madison, Wisconsin.

Miller, S. L., C. J. Ralph, M. G. Raphael, C. Strong, C. W. Thompson, J. Baldwin, M. H. Huff, and G. A. Falxa. 2006. At-Sea Monitoring of Marbled Murrelet Population Status and Trend in the Northwest Forest Plan Area. Pages 31–60 in M. H. Huff, S. L. Miller, S. K. Nelson, and J. Baldwin (tech. coords.), *Northwest Forest Plan—the First 10 Years (1994–2003): Status and Trends of Populations and Nesting Habitat for the Marbled Murrelet.* General Technical Report PNW-GTR-650. U. S. Forest Service, Pacific Northwest Research Station, Portland, OR.

Mitchell, S. J. 2000. *Stand Density Management Diagram. Forest Health: Preliminary Interpretations for Wind Damage.* Forest Practices Branch Information Booklet. British Columbia Ministry of Forests, Victoria, BC, Canada.

Mlodinow, S. G. 1997. The Long-Billed Murrelet (*Brachyramphus perdix*) in North America. *Birding* 29:460–475.

Morris, W. F., and D. F. Doak. 2002. *Quantitative Conservation Biology: Theory and Practice of Population Viability Analysis.* Sinauer Associates, Sunderland, MA.

Naslund, N. L. 1993. *Breeding Biology and Seasonal Activity Patterns of Marbled Murrelets* (*Brachyramphus marmoratus*) *Nesting in an Old-Growth Forest.* M.S. dissertation. University of California, Santa Cruz, CA.

Naslund, N. L., K. J. Kuletz, M. B. Cody, and D. K. Marks. 1995. Tree and Habitat Characteristics and Reproductive Success at Marbled Murrelet Tree Nests in Alaska. *Northwestern Naturalist* 76:12–25.

National Geographic Society. 1987. *Field Guide to Birds of North America*. National Geographic Society, Washington D.C.

Nechaev, V. A. 1986. New Information on the Seabirds of Sakhalin Island. Pages 71–81 in N. M. Lituinenko (ed.), *Seabirds of the Far East.* Akademiya Nauk SSSR. Vladivostok, USSR. (In Russian; English translation by D. Siegel-Causey.)

Neel, J., C. Hart, D. Lynch, S. Chan, and J. Harris. 1997. *Oil Spills in Washington State: A Historical Analysis.* Washington Department of Ecology. Olympia, WA. Available: <http://www.ecy.wa.gov/pubs/97252.pdf>.

Nelson, S. K. 1997. Marbled Murrelet (*Brachyramphus marmoratus*). Pages 1–32 in A. Poole and G. Gill, (eds.) *Birds of North America,* No. 276 Academy of Natural Sciences, Philadelphia, and American Ornithologists' Union, Washington, DC.

Nelson, S. K., M. H. Huff, S. L. Miller, M. G. Raphael. 2006. Marbled Murrelet Biology: Habitat Relations and Populations. Pages 9–32 in M. H. Huff, M. G. Raphael, S. L. Miller, S. K. Nelson, and J. Baldwin (tech. coords.), *Northwest Forest Plan—The First 10 years (1994-2003): Status and Trends of Populations and Nesting Habitat for the Marbled*

Murrelet. General Technical Report PNW-GTR-650. U. S. Forest Service, Pacific Northwest Research Station, Portland, OR.

Nelson, S. K., and T. E. Hamer. 1995a. Nesting Biology and Behavior of the Marbled Murrelet. Pages 57-67 in C. J. Ralph, J. G. L. Hunt, M. G. Raphael, and J. F. Piatt (tech. eds.), *Ecology and Conservation of the Marbled Murrelet*. General Technical Report PSW-152. U. S. Forest Service, Pacific Southwest Research Station, Albany, CA.

Nelson, S. K., and T. E. Hamer. 1995b. Nest Success and the Effects of Predation on Marbled Murrelets. Pages 89–98 in C. J. Ralph, J. G. L. Hunt, M. G. Raphael, and J. F. Piatt (tech. eds.), *Ecology and Conservation of the Marbled Murrelet*. General Technical Report PSW-152, U.S. Forest Service, Pacific Southwest Research Station, Albany, CA.

Nelson, S.K., T. E. Hamer, A. K. Wilson and D. J. Meekins. 2002. Characteristics of Marbled Murrelet Nest Trees and Nest Sites in the Pacific Northwest. Abstract. Third North American Ornithological Conference (World Meeting Number 000 64 222), New Orleans, LA.

Nelson, S. K., M. L. C. McAllister, M. A. Stern, D. H. Varoujean, and J. M. Scott. 1992. The Marbled Murrelet in Oregon, 1899–1987. Pages 61–91 in H. R. Carter (editor), Status, Distribution and Management of the Marbled Murrelet. Proceedings of the Western Foundation Vertebrate Zoology.

Nelson, S. K., and R. W. Peck. 1995. Behavior of Marbled Murrelets at Nine Nest Sites in Oregon. *Northwestern Naturalist* 76:43–53.

Nelson, S. K., and A. K. Wilson. 2002. *Marbled Murrelet Habitat Characteristics on State Lands in Western Oregon.* Unpublished report to the Oregon Department of Forestry, Salem, OR. Final report, Oregon Cooperative Fish and Wildlife Research Unit, Oregon State University, Department of Fisheries and Wildlife, Corvallis, OR.

Newton, I. 2001. Causes and Consequences of Breeding Dispersal in the Sparrowhawk (*Accipiter nisus)*. *Ardea* 89:143–154.

Norris, D.R., P. Arcese, D. Preikshot, D.F., Bertram, and T.K. Kyser. 2007. Diet Reconstruction and Historic Population Dynamics in a Threatened Seabird. *Journal of Applied Ecology* 44: 875-884.

Nur, N., and W. J. Sydeman. 1999. Survival, Breeding Probability and Reproductive Success in Relation to Population Dynamics of Brandt's Cormorants *Phalacrocorax penicillatus. Bird Study* 46:92–103.

Oakley, K. L., and K. J. Kuletz. 1994. *Population, Reproduction, and Foraging of Pigeon Guillemots at Naked Island, Alaska, Before and After the Exxon Valdez Oil Spill.* Exxon Valdez Oil Spill State/Federal Natural Resources Damage Assessment Final Reports: Bird Study No. 9. Unpublished report. U. S. Fish and Wildlife Service, Anchorage, AK.

Oakley, K. L., T. L. Wade, and K. J. Kuletz. 1994. *Aliphatic and Polycyclic Aromatic Hydrocarbons in Livers of Marbled Murrelets in Prince William Sound, Alaska, after the Exxon Valdez Oil Spill.* Exxon Valdez Oil Spill State/Federal Natural Resources Damage Assessment Final Reports: Bird Study 6. Unpublished manuscript supplied by authors. U. S. Fish and Wildlife Service, Anchorage, AK.

Odum, E. P., and G. W. Barrett. 2005. *Fundamentals of Ecology.* Fifth edition. Thomson Brooks/Cole, Belmont, CA.

Ohlendorf, H. M., R. W. Risebrough, and K. Vermeer. 1978. *Exposure of Marine Birds to Environmental Pollutants.* Wildlife Research Report 9. U. S. Fish and Wildlife Service, Washington, DC.

Parker, N., E. Cam, D. B. Lank, and F. Cooke. 2003. Post-Fledgling Survival of Marbled Murrelets *Brachyramphus marmoratus* Estimated with Radio-Marked Juveniles in Desolation Sound, British Columbia. *Marine Ornithology* 31:207–212.

Paton, P. W. C. 1995. Marbled Murrelet Inland Patterns of Activity: Defining Detections and Behavior. Pages 113–116 in C. J. Ralph, G. L. Hunt, M. G. Raphael, and J. F. Piatt (tech. eds.), *Ecology and Conservation of the Marbled Murrelet.* General Technical Report PSW-GTR-152. U.S. Forest Service, Pacific Southwest Research Station, Albany, CA.

Peery, M. Z. 2004. Ecology and Conservation of the Marbled Murrelet (*Brachyramphus marmoratus)* in Central California. Ph.D. dissertation. University of California, Environmental Science, Policy, and Management, Berkeley, CA.

Peery, M. Z., B. H. Becker, and S. R. Beissinger. 2007. Age Ratios as Estimators of Productivity: Testing Assumptions on a Threatened Seabird, the Marbled Murrelet (*Brachyramphus marmoratus*). *The Auk* 124:224–240.

Peery, M. Z., B. H. Becker, and S. R. Beissinger. 2006a. Combining Demographic and Count-Based Approaches to Identify Source-Sink Dynamics: An Example Using a Threatened Seabird. *Ecological Applications* 16:1516–1528.

Peery, M. Z., S. R. Beissinger, E. Burkett, and S. H. Newman. 2006b. Local Survival Rates of Marbled Murrelets: Roles of Oceanographic Conditions, Sex, and Radio-Tagging. *Journal of Wildlife Management* 70:78-88.

Peery, M. Z., S. R. Beissinger, S. H. Newman, B. H. Becker, E. Burkett, and T. D. Williams. 2004a. Applying the Declining Population Paradigm: Diagnosing Causes of Poor Reproduction in the Marbled Murrelet. *Conservation Biology* 18:1088–1098.

————. 2004b. Individual and Temporal Variation in Inland Flight Behavior of Marbled Murrelets: Implications for Population Monitoring. *The Condor* 106:344–353.

Peery, M. Z., L. A. Henkel, S. H. Newman, B. H. Becker, J. T. Harvey, C. Thompson, and S. R. Beissinger. *In press*. Effects of Rapid Flight-Feather Molt on Post-Breeding Dispersal in a Threatened Seabird. *The Auk*.

Pennycuick, C. J. 1987. Flight of Seabirds. Pages 43–62 in J. P. Croxall (ed.), *Seabirds: Feeding Ecology and Role in Marine Ecosystems.* Cambridge University Press, Cambridge, England.

Piatt, J. F., and R. G. Ford. 1993. Distribution and Abundance of Marbled Murrelets in Alaska. *The Condor* 95:662–669.

Piatt, J. F., K. J. Kuletz, A. E. Burger, S. A. Hatch, T. P. Birt, M. L. Arimitsu, G. S. Drew, A. M. A. Harding, and K. S. Bixler. 2007. *Status Review of the Marbled Murrelet* (Brachyramphus marmoratus) *in Alaska and British Columbia.* U. S. Geological Survey Open-File Report 2006-1387.

Piatt, J. F., and N. L. Naslund. 1995. Abundance, Distribution, and Population Status of Marbled Murrelets in Alaska. Pages 285–294 in C. J. Ralph, G. L. Hunt, M. G. Raphael, and J. F. Piatt (Tech. eds.), *Ecology and Conservation of the Marbled Murrelet.* General Technical

Report PSW-GTR-152. U.S. Forest Service, Pacific Southwest Research Station. Albany, CA.

Pimm, S. 1976. Estimation of Duration of Bird Molt. *The Condor* 78:550.

Prenzlow Escene, D. 1999. Marbled Murrelet Forest Habitat Relationship Studies. Unpublished report. Washington State Department of Natural Resources. Olympia, WA.

Prenzlow Escene, D. 2002. *Final Recommendations from the Steering Committee for the Marbled Murrelet Inland Survey Protocol Statistical Analyses.* Unpublished report. Pacific Seabird Group. Available: <http://www.pacificseabirdgroup.org>.

Prenzlow Escene, D., S. Horton, W. S. Jaross, and J. Baldwin. 2006. *Predicting Carrying Capacity (K) for Marbled Murrelets in the Coastal Lowlands of Southwest Washington*. Poster presented at the Thirty-third Annual Meeting of the Pacific Seabird Group, 15-19 February 2006, Girdwood, Alaska. Available from: D. Prenzlow Escene, Washington Department of Natural Resources, PO Box 47016, Olympia, WA, 98504-7016; danielle.escene@dnr.wa.gov.

Pulliam, H.R. 1988. Sources, Sinks and Population Regulation. *American Naturalist* 132:652–661.

Ralph, C. J., S. K. Nelson, M. M. Shaughnessy, and S. L. Miller. 1993. *Methods for Surveying Marbled Murrelets in Forests.* Technical Paper No. 1. Pacific Seabird Group, Marbled Murrelet Technical Committee.

Ralph, C. J., S. K. Nelson, M. M. Shaughnessy, S. L. Miller, and T. E. Hamer. 1994. *Methods for Surveying for Marbled Murrelets in Forests—A Protocol for Land Management and Research.* Technical Paper No. 1, revision. Pacific Seabird Group, Marbled Murrelet Technical Committee. Available from U. S. Forest Service, Redwood Sciences Laboratory, 1700 Bayview Dr., Arcata, CA.

Ralph, C. J., G. L. Hunt Jr., M. G. Raphael, and J. F. Piatt (tech. eds). 1995a. *Ecology and Conservation of the Marbled Murrelet.* General Technical Report PSW-GTR-152. U. S. Forest Service, Pacific Southwest Research Station, Albany, CA.

Ralph, C.J., G.L. Hunt Jr., M.G. Raphael, and J.F. Piatt 1995b. Ecology and Conservation of the Marbled Murrelet in North America: an Overview. Pages 3-22 in Ralph, C. J., G. L. Hunt

Jr., M. G. Raphael, and J. F. Piatt (tech. eds), *Ecology and Conservation of the Marbled Murrelet.* General Technical Report PSW-GTR-152. U. S. Forest Service, Pacific Southwest Research Station, Albany, CA.

Ralph, C. J., S. K. Nelson, S. L. Miller, and T. E. Hamer. 1995c. Pacific Seabird Group, Marbled Murrelet Technical Committee, Inland Survey Protocol Subcommittee. March 8, 1995—letter to marbled murrelet surveyors and managers providing additions to the 1994 inland survey protocol. Available from U. S. Forest Service, Redwood Sciences Laboratory, 1700 Bayview Dr., Arcata, CA.

————. 1996. Pacific Seabird Group, Marbled Murrelet Technical Committee, Inland Survey Protocol Subcommittee. April 24, 1996—letter to marbled murrelet surveyors and managers providing clarification and updates for the 1994 protocol and 1995 protocol letter. Available from U. S. Forest Service, Redwood Sciences Laboratory, 1700 Bayview Dr., Arcata, CA.

————. 1997. Pacific Seabird Group, Marbled Murrelet Technical Committee, Inland Survey Protocol Subcommittee. April 24, 1997—letter to marbled murrelet surveyors and managers providing clarification and updates for the 1994 protocol and subsequent protocol letters. Available from U. S. Forest Service, Redwood Sciences Laboratory, 1700 Bayview Dr., Arcata, CA.

————. 1998. Pacific Seabird Group, Marbled Murrelet Technical Committee, Inland Survey Protocol Subcommittee. March 11, 1998—letter to marbled murrelet surveyors and managers providing clarification and updates for the 1994 protocol and subsequent protocol letters. Available from U. S. Forest Service, Redwood Sciences Laboratory, 1700 Bayview Dr., Arcata, CA.

Raphael, M. G. 2006. Conservation of the Marbled Murrelet under the Northwest Forest Plan. *Conservation Biology* 20:297–305.

Raphael, M. G., D. Evans Mack, and B. A. Cooper. 2002a. Landscape-Scale Relationships between Abundance of Marbled Murrelets and Distribution of Nesting Habitat. *The Condor* 104:331–342.

Raphael, M. G., D. Evans Mack, J. M. Marzluff, and J. M. Luginbuhl. 2002b. Effects of Forest Fragmentation on Populations of the Marbled Murrelet. *Studies in Avian Biology* 25:221–235.

Raphael, M. G., B. M. Galleher, M. H. Huff, S. L. Miller, S. K. Nelson, and R. Young. 2006. Spatially Explicit Estimates of Potential Nesting Habitat for the Marbled Murrelet. Chapter 5 in M. H. Huff, S. L. Miller, S. K. Nelson, and J. Baldwin (tech. coords.), *Northwest Forest Plan—The First 10 Years (1994–2003): Status and Trends of Populations and Nesting Habitat for the Marbled Murrelet*. General Technical Report PNW-GTR-650. U. S. Forest Service, Pacific Northwest Research Station, Portland, OR.

Raphael, Martin G. Chief Research Wildlife Ecologist. U.S. Forest Service, Pacific Northwest Research Station, Portland, OR. July 25, 2005—PowerPoint presentation in e-mail to Scott Horton, Olympic Region Wildlife Biologist, Washington State Department of Natural Resources, Forks, WA.

Reimer, D., W. Jaross, and M. Bowering. 2004. *Growth and Yield, and Regime Analysis Supporting DNR Sustainable Harvest Calculations.* Washington State Department of Natural Resources internal reports. Olympia, WA.

Remsoft, Inc. 2005. *Woodstock 3.28 User Guide.* Fredericton, NB, Canada.

Ripple, W. J., S. K. Nelson, and E. M. Glenn. 2003. Forest Landscape Patterns around Marbled Murrelet Nest Sites in the Oregon Coast Range. *Northwestern Naturalist* 84:80–89.

Rodway, M. S., H. M. Regehr, and J.-P. L. Savard. 1993. Activity Patterns of Marbled Murrelets in Old-Growth Forest in the Queen Charlotte Islands, British Columbia. *The Condor* 95: 831-848.

Rodway, M. S., H. R. Carter, S. G. Sealy, and R. W. Campbell. 1992. Status of the Marbled Murrelet in British Columbia. In: H. R. Carter and M. L. Morrison (eds.), Status and Conservation of the Marbled Murrelet in North America. *Proceedings of the Western Foundation of Vertebrate Zoology* 5:17–47.

Sanger, G. A. 1987. Winter Diets of Common Murres and Marbled Murrelets in Kachemak Bay, Alaska. *The Condor* 89:426–430.

Schroeder, B. K., M. H. Mather, and T. A. Chatwin. 1999. *Reconnaissance Inventory of Marbled Murrelets on the Central Coast of British Columbia 1998.* Unpublished report. British Columbia Ministry of Environment, Lands, and Parks, Nanaimo, BC.

Sealy, S. G. 1974. Breeding Phenology and Clutch Size in the Marbled Murrelet. *The Auk* 91:10–23.

————. 1975. Feeding Ecology of Ancient and Marbled Murrelets near Langara Island, British Columbia. *Canadian Journal of Zoology* 53:418–433.

Sealy, S. G., H. R. Carter, W. D. Shurford, K. D. Powers, and C. A. Chase III. 1991. Long-Distance Vagrancy of the Asiatic Marbled Murrelet in North America 1979–1989. *Western Birds* 22:145–155.

Shugart, H. H. 2003. A Theory of Forest Dynamics: the Ecological Implications of Forest Succession Models. The Blackburn Press, Caldwell, New Jersey.

Singer, S. W., N. L. Naslund, S. A. Singer, and C. J. Ralph. 1991. Discovery and Observations of Two Tree Nests of the Marbled Murrelet. *The Condor* 93:330–339.

Singer, S. W., D. L. Suddjian, and S. A. Singer. 1995. Fledging Behavior, Flight Patterns, and Forest Characteristics at Marbled Murrelet Tree Nests in California. *Northwestern Naturalist* 76:54–62.

Speckman, S. G. 1996. *Marbled Murrelet Distribution and Abundance in Relation to the Marine Environment*. M. S. dissertation. University of Alaska, Fairbanks, AK.

Speckman, S. G., J. F. Piatt, and A. M. Springer. 2003. Deciphering the Social Structure of Marbled Murrelets from Behavioral Observations at Sea. *Waterbirds* 26:266-274.

Speich, S. M., and T. R. Wahl. 1995. Marbled Murrelet Populations of Washington— Marine Habitat Preferences and Variability of Occurrence. Pages 313–326 in C. J. Ralph, G. L. Hunt, M. G. Raphael, and J. F. Piatt (tech. eds.), *Ecology and Conservation of the Marbled Murrelet*. General Technical Report PSW-GTR-152. U. S. Forest Service, Pacific Southwest Research Station, Albany, CA.

Steventon, J. D. and N. L. Holmes. 2002. A Radar Based Inventory of Marbled Murrelets (*Brachyramphus marmoratus*): Northern Mainland Coast of British Columbia.

Unpublished report. Smithers, British Columbia: Ministry of Forests, Prince Rupert Region.

Strachan, G., M. McAllister, and C. J. Ralph. 1995. Marbled Murrelet At-Sea and Foraging Behavior. Pages 247–254 in C. J. Ralph, G. L. Hunt, M. G. Raphael, and J. F. Piatt (eds.), *Ecology and Conservation of the Marbled Murrelet.* General Technical Report PSW-GTR-152. U. S. Forest Service, Pacific Southwest Research Station, Albany, CA.

Strong, C. S., B. S. Keitt, W. R. McIver, C. J. Palmer, and I. Gaffney. 1995. Distribution and Population Estimates of Marbled Murrelets At-Sea in Oregon during the Summers of 1992 and 1993. Pages 339–352 in C. J. Ralph, G. L. Hunt, Jr., M. G. Raphael, and J. F. Piatt (tech. eds.), *Ecology and Conservation of the Marbled Murrelet.* General Technical Report PSW-GTR-152. U. S. Forest Service, Southwest Research Station, Albany, CA.

Suddjian, D. B. 2003. Ten Years of Monitoring Marbled Murrelets at the South Fork of Butano Creek, San Mateo County, California, 1992-2001. Big Creek Lumber Company, Davenport, CA.

Swartzman, G., H. Carter, S. Nelson, P. Morrison, and K. L. Sallee. 1997. *LIMBS (Landscape-Level Individual Murrelet Based Simulation): A Model for Examining the Effects of Different Forest Management Scenarios on Marbled Murrelets in Northern California.* Unpublished report. Sierra Club and Environmental Protection Information Center, Garberville, California.

Thompson, C. W. 1997. *Distribution and Abundance of Marbled Murrelets and Common Murres on the Outer Coast of Washington.* Unpublished report to the Tenyo Maru Trustee Council. Washington Department of Fish and Wildlife, Olympia, WA.

Thompson, C. W. 1999. *Distribution and Abundance of Marbled Murrelets and Common Murres on the Outer Coast of Washington*. Washington Department of Fish and Wildlife, Olympia, WA. Available: <http://wdfw.wa.gov/wlm/research/papers/murrelet>.

USDA and USDI. *See* U.S. Department of Agriculture and U.S. Department of the Interior.

U.S. Department of Agriculture and U.S. Department of the Interior. 1994. *Record of Decision for Amendments to Forest Service and Bureau of Land Management Planning Documents within the Range of the Northern Spotted Owl; Standards and Guidelines for*

Management of Habitat for Late-Successional and Old-Growth Forest Related Species within the Range of the Northern Spotted Owl. Region 10. U. S. Forest Service and Bureau of Land Management, U.S. Government Printing Office, Washington, DC.

U.S. Fish and Wildlife Service. 1997. *Recovery Plan for the Threatened Marbled Murrelet* (*Brachyramphus marmoratus*) *in Washington, Oregon, and California.* Portland, OR.

U.S. Fish and Wildlife Service and National Marine Fisheries Service. 2000. Notice of Availability of a Final Addendum to the Handbook for Habitat Conservation Planning and Incidental Take Permitting Process. *Federal Register* 65:35242–35257. Available: <http://www.epa.gov/fedrgstr/EPA-IMPACT/2000/June/Day-01/i13553.htm>.

USFWS. *See* U.S. Fish and Wildlife Service.

USFWS and NMFS. *See* U.S. Fish and Wildlife Service and National Marine Fisheries Service.

Vanclay, J. K., and J. P. Skovsgaard. 1997. Evaluating Forest Growth Models. *Ecological Modeling* 98:1–12.

Van Pelt, R. 2007. *Identifying Mature and Old Forests in Western Washington*. Washington State Department of Natural Resources, Olympia, WA.

Varoujean, W. A., and D. H. Williams. 1995. Abundance and Distribution of Marbled Murrelets in Oregon and Washington Based on Aerial Surveys. Pages 327–337 in C. J. Ralph, G. L. Hunt, Jr., M. G. Raphael, and J. F. Piatt (tech. eds.), *Ecology and Conservation of the Marbled Murrelet.* General Technical Report PSW-GTR-152. U.S. Forest Service, Southwest Research Station. Albany, CA.

Vermeer, K., and R. W. Butler (eds.). 1989. *The Ecology and Status of Marine and Shoreline Birds in the Strait of Georgia, British Columbia.* Special Publication, Canadian Wildlife Service, Ottawa, ON, Canada.

Vermeer, K., S. G. Sealy, and G. A. Sanger. 1987. Feeding Ecology of Alcidae in the Eastern North Pacific Ocean. Pages 189–227 in Croxall, J. P. (ed.) *Seabirds: feeding biology and role in marine ecosystems.* Cambridge University Press, Cambridge, UK.

Vigallon, S. M, and J. M. Marzluff. 2005. Is Nest Predation by Steller's Jays (*Cyanocitta stelleri*) Incidental or the Result of a Specialized Search Strategy? *The Auk* 122:36–49.

Walters, C. J., and R. Hilborn. 1978. Ecological Optimization and Adaptive Management. *Annual Reviews of Ecology and Systematics* 9:157–188.

Washington State Department of Natural Resources. 1992. *Forest Resource Plan.* Olympia, WA.

————. 1995. *Standard Methodology for Conducting Watershed Analysis.* Version 3.0. Washington Forest Practices Board, Seattle, WA.

————. 1997a. *Final Habitat Conservation Plan.* Olympia, WA.

————. 1997b. *Permanent Marbled Murrelet Rules.* Washington Forest Practices Board, Seattle, WA.

————. 2002a. *Washington Timber Harvest Summary Report 1965–2002.* Olympia, WA. Available: <http://www.dnr.wa.gov/htdocs/obe/timberharvest/timhar6501.xls>.

————. 2002b. *Forest Resource Inventory System: Field Procedures*. Olympia, WA.

————. 2004a. *Timber Harvest Summary 2002.* Office of Budget and Economics. Available: <http://dnr.wa.gov/htdocs/obe/timberharvest/timhar6501.xls>. Accessed June 28, 2007.

————. 2004b. *Final Environmental Impact Statement on Alternatives for Sustainable Forest Management of State Trust Lands in Western Washington and for Determining the Sustainable Harvest Level.* Olympia, WA.

————. 2006a. *Washington State Forest Practices Board Manual.* Draft. Olympia, WA.

————. 2006b. *Policy for Sustainable Forests.* Olympia, WA.

Washington State Forest Practices Board. 2001. WAC 222-16-010. Forest Practices Rules [Effective 10/27/2007] General Definitions p. 16-5.

————. 2002. WAC 222-30-021. Western Washington Riparian Management Zones [Effective 7/1/2005] (1), (I), (ii) Harvest options pp. 30-9-11.

————. 2005. WAC 222-12-090. Forest Practices Board Manual [Effective 7/1/2005] (14 and 15).

Weaver, J. L., P. C. Paquet, and L. F. Ruggiero. 1996. Resilience and Conservation of Large Carnivores in the Rocky Mountains. *Conservation Biology* 10:964–976.

Whitehead, P. 1989. Toxic Chemicals in Great Blue Heron (*Ardea herodius*) Eggs in the Strait of Georgia. Pages 177–183 in K. Vermeer and R. W. Butler (eds.), *The Ecology and Status of Marine and Shoreline Birds in the Strait of Georgia, British Columbia*. Special Publication. Canadian Wildlife Service, Ottawa, ON.

Whitworth, D. L., S. K. Nelson, S. H. Newman, G. B. Van Vliet, and W. P. Smith. 2000. Foraging Distances of Radio-Marked Marbled Murrelets from Inland Areas in Southeast Alaska. *The Condor* 102:452–456.

Whitworth, D. L., J. Y. Takekawa, H. R. Carter, and W. R. McIver. 1997. A Night-Lighting Technique for At-Sea Capture of Xantus' Murrelets. *Colonial Waterbirds* 20:525–531.

Wilhere, G. F. 2002. Adaptive Management in Habitat Conservation Plans. *Conservation Biology* 16:20–29.

Woodall, C. W., C. H. Perry, and P. D. Miles. 2006. The Relative Density of Forests in the United States. *Forest Ecology and Management* 226:368–372.

Yen, P. P. W., F. Huettmann, and F. Cooke. 2004. A Large-Scale Model for the At-Sea Distribution and Abundance of Marbled Murrelets (*Brachyramphus marmoratus*) during the Breeding Season in Coastal British Columbia, Canada. *Ecological Modeling* 171:395–413.

Zharikov, Y., D. B. Lank, F. Huettmann, R. W. Bradley, N. Parker, P. P-W. Yen, L. A. McFarlane-Tranquilla, and F. Cooke. 2006. Habitat Selection and Breeding Success in a Forest-Nesting Alcid, the Marbled Murrelet, in Two Landscapes with Different Degrees of Forest Fragmentation. *Landscape Ecology* 21:107–120.

APPENDIX A

DNR MARBLED MURRELET SUMMIT MEETING ATTENDEES

OCTOBER 21, 2003

Janet Anthony (WDFW)
Martha Bean (facilitator)
Richard Bigley (DNR)
Brian Cooper (ABR Inc.)
Eric Cummins (WDFW)
Florian Deisenhofer (DNR)
Lisa Egtvedt (DNR)
Kim Flotlin (USFWS)
John Grettenberger (USFWS)
Shelley Hall (ONP)
Tom Hamer (Hamer Environmental L.P.)
Peter Harrison (DNR)
Scott Horton (DNR)
Simon Kihia (DNR)
Peter McBride (DNR)
Kim Nelson (OSU)
Teodora Minkova (DNR)
Noelle Nordstrom (WDFW)
Mark Ostwald (USFWS)
Marty Raphael (PNWRS)
Bill Ritchie (WDFW)
Paula Swedeen (WDFW)
Chris Thompson (WDFW)
Todd Welker (DNR)

Later arrivals: Danielle Prenzlow Escene (DNR), Craig Hansen (USFWS)

OCTOBER 22, 2003

Janet Anthony (WDFW)
Martha Bean (facilitator)
Richard Bigley (DNR)
Andy Carey (PNWRS)
Brian Cooper (ABR Inc.)
Eric Cummins (WDFW)
Florian Deisenhofer (DNR)
Lisa Egtvedt (DNR)
Kim Flotlin (USFWS)
John Grettenberger (USFWS)
Shelley Hall (ONP)
Tom Hamer (Hamer Environmental L.P.)
Craig Hansen (USFWS)
Peter Harrison (DNR)
Scott Horton (DNR)
Simon Kihia (DNR)
Dov Lank (Simon Fraser U.)
Diana Linch (USFWS)
Peter McBride (DNR)
Kim Nelson (OSU)
Teodora Minkova (DNR)
Mark Ostwald (USFWS)
Marty Raphael (PNWRS)
Tami Riepe (DNR)
Bill Ritchie (WDFW)
Chris Thompson (WDFW)
Todd Welker (DNR)

Morning only: John Baarspul (DNR), Jodi Barnes (DNR)

Later arrivals: Joe Buchanan (WDFW), Danielle Prenzlow Escene (DNR)

This page intentionally left blank.

APPENDIX B

FOREST STAND CLASSIFICATION CROSSWALK

Stand development stages are defined based on Brodie et al. (2004), and are crosswalked with two seral stage classification systems used in this document (Table B-1). There were two groupings of seral stages: one for the scorecard utilized to evaluate lands in southwest Washington (detailed in section 3.2a of chapter 3.0) and the other for projecting potential habitat capability predominantly on non-DNR-managed lands as part of the management scenarios analysis (from Green et al. 1993; detailed in section 4.5 of chapter 4.0). See Van Pelt's (2007) chapter (pp. 27-47) and appendix (p. 103) on stand development for illustrations and further descriptions of forest stands at different stages of development.

Table B-1. Definition and Description of Stand Development Stages (SDS), Crosswalked to Two Seral Stage Classification Systems.

Seral Stages (Science Team Scorecard)	Seral Stages (Green et al.)	Stand Development Stage (Brodie et al.)	Description
Early	Cleared Forest	Ecosystem Initiation	Death or removal of mature forest overstory trees by wildfire, windstorm, insects, disease, or timber harvest leads to reestablishment of a young forest ecosystem. This open-canopy forest is dominated by herbs, forbs, and small trees.
	Early	Sapling Exclusion	The pioneer of competitive exclusion is the Sapling Exclusion stage. It has a dense canopy from the ground up. Shrubs and branches of regenerated trees begin to intertwine.
Pole	Mid	Pole Exclusion	Closed canopies feature taller, intermediate-sized trees. Understory forest floor plants are absent. Mortality of suppressed trees is evident.
Mid	Late	Large Tree Exclusion	Even larger, closely spaced trees of similar heights compete, perpetuating mortality and suppression of forest floor plants. There are not enough large openings to allow light for forest floor plants to grow. Mortality of larger trees is evident.
		Understory Development	As overstory trees die, fall down, or are harvested, the competitive exclusion of overstory trees fades and canopy gaps become larger. Light penetrates the canopy gaps and an understory of trees, forbs, ferns, and shrubs develops. There is little diversification of plant communities.
		Botanically Diverse	Multiple canopies of trees and communities of forest floor plants are evident. Large and small trees have a variety of diameters and heights. Decayed and fallen trees are rare.
Late		Niche Diversification	Coarse woody debris, cavity trees, tree litter, soil organic matter, and diversity of forest floor plant communities are evident, as well as the wildlife that use this type of habitat. Multiple canopies of trees are present. Large and small trees have a variety of diameters and heights.
		Fully Functional	The most complex of the forest structures, the Fully Functional forest has large-scale habitat elements such as rotting fallen trees or “nurse logs,” onto which trees and other vegetation grow. The added complexity enables the increased interactions that provide for the life requirements of diverse vertebrates, invertebrates, fungi, and plants.

APPENDIX C

MANAGEMENT SCENARIO ANALYSIS ASSUMPTIONS AND METHODS

C.1 Analysis Assumptions for Southwest Washington

In southwest Washington (SWWA), the Science Team recommends that DNR:

1. Designate areas (Marbled Murrelet Management Areas or MMMAs) within DNR-managed lands (see section 3.2d in chapter 3.0) within which DNR will:
    a. Manage with the goal of achieving high-quality nesting habitat over the entire area
    b. Not manage stands once high-quality nesting habitat is achieved
    c. Defer from harvest all currently known occupied sites
    d. Accelerate the development of non-functioning habitat with the goal of achieving high-quality nesting habitat
2. Outside the designated areas (MMMAs):
    a. Release all reclassified habitat from a deferral status (these areas were surveyed and found not occupied)

Specific assumptions employed in management scenarios to analyze SWWA recommendations:

- Replace existing deferrals (pre-year 2007 modeling assumptions) with Science Team recommended deferrals (as described above) and defer from harvest.
- Apply decadal targets across a minimum of 90% of all naturally regenerated conifer-dominated stands in each designated area to achieve and maintain suitable habitat or better. Apply the target to all harvest types.
- Apply a 10% maximum seven-period constraint (see below) to each designated deferral by stand for all harvest types to account for incidental impacts and natural disturbances such as salvage from endemic blowdown, silvicultural experiments, riparian and northern spotted owl restoration activities, structure regeneration, landings, road access, crossings, rights-of-way, and yarding corridors. This means that as a "modeling assumption," no more than 10% of the site cumulatively over the course of seven decades can be affected. This also means that once this occurs, the site is locked out from additional harvest for the remainder of the seven decades.

The Science Team's recommendations are reflected in the overarching objective of this analysis, to maximize marbled murrelet potential habitat capability subject to harvest restrictions. As this target is being achieved over the course of the simulation, a limited range of harvest activities may occur in non-habitat. In this context, non-habitat refers to areas within the MMMAs that do not meet the structural requirements of suitable habitat. Simulation may also account for regeneration within deferred areas. Yield-based definitions of stages of stand development, and thus P_{stage}, are based on modeled averages for species, site class, and silvicultural treatments and may not reflect in-field, site-specific observations. Within-year seasonal restrictions are strictly operational considerations, and therefore do not affect annual or decadal scenario analysis.

C.2 Analysis Assumptions for Olympic Experimental State Forest

In the Olympic Experimental State Forest (OESF), the Science Team recommends that DNR:

1. Designate areas (MMMAs) within DNR-managed lands (see section 3.3d in chapter 3.0)
2. Defer harvest in specific areas within the designated areas (MMMAs), including:
    a. Designated stands of old forest
    b. All surveyed habitat
    c. All occupied habitat
3. Achieve pole-sized or better structure over two-thirds of the area of a 328-foot (100-meter) buffer around designated occupied and older forest sites.[1]
4. Establish an additional restoration target within the Dickodochtedor landscape planning unit (LPU) (Table 3-12 in chapter 3.0) for high-quality nesting habitat in 50% of each area; the deferrals outlined under point one are included in this 50%.
5. Direct management toward restoring high-quality nesting habitat in riparian and unstable slope areas, which comprise more than 50% of the area within the Goodman Creek and Kalaloch LPUs (Table 3-12).
6. Achieve at least pole-sized structure over two-thirds of all (in the Queets LPU [Table 3-8]) or the remainder of designated areas (in the Dickodochtedor, Goodman Creek, and Kalaloch LPUs [Table 3-12]) not already designated in points one through four above.

[1] Final recommendations determined by the Science Team resulted in a change from the two-thirds forested buffer area to a 100% forested buffer area around all known occupied sites in the OESF. This change will be reflected in future modeling exercises.

Specific assumptions employed in management scenarios to analyze OESF recommendations:

- Replace existing deferrals (pre-year 2007 modeling assumptions) with Science Team recommended deferrals (as described above) and defer from harvest.
- Apply targets to achieve a 66.67% minimum of the designated area in each landscape as described above, and a 100% target to each designated 328-foot (100-meter) buffer to achieve and maintain a 6 inch (15 centimeter) QMD minimum for all dominant live trees more than 2 inches (more than 5 centimeters) at all times. Apply the target to all harvest types. Pole size structure will be assumed to be more than 5 inches (more than 13 centimeters) QMD for all dominant live trees.
- Apply targets to achieve a 50% minimum of the designated area in each landscape as described above to achieve and maintain high-quality habitat. The target will be applied to all harvest types. High-quality habitat is assumed to result from either natural stand development or a series of treatments.
- Apply a 10% maximum seven-period constraint (see below for explanation) to each designated deferral by stand for all harvest types to account for incidental impacts and natural disturbances such as salvage from endemic blowdown, silvicultural experiments, riparian and northern spotted owl restoration activities, structure regeneration, landings, road access, crossings, right-of-ways, and yarding corridors. This means that as a “modeling assumption,” no more than 10% of the site cumulatively over the course of seven decades can be affected. This also means that once this occurs, the site is locked out from additional harvest for the remainder of the seven decades.

As these targets are achieved over the course of the simulation, the full range of simulated harvest activities becomes available. Simulation may also account for regeneration within deferred areas. Yield-based definitions of stand development and potential habitat capability are based on modeled averages for species, site class, and silvicultural treatments and may not reflect in-field site-specific observations. Within-year seasonal restrictions are strictly operational considerations, and therefore do not affect annual or decadal scenario analysis.

This page intentionally left blank.

APPENDIX D
SCIENCE TEAM RECOMMENDATIONS:
ROADS, YARDING AND SALVAGE IN OCCUPIED SITES

D.1 Road and Yarding Corridor Access

Ideally, occupied sites should not be disturbed. The Science Team recognizes, within limits, the need for DNR to access the land base for habitat restoration activities with roads and yarding corridors. Before considering road access through an occupied site, all alternative access routes should be thoroughly explored and impacts as to the effects of modifying occupied patch size should also be examined. If access through an occupied site is necessary, special attention should be given to maintain the integrity of the occupied site and to minimize the effects of human activities. The Science Team recommends that all efforts be made to minimize:

- Loss of core areas of high-quality nesting habitat.
- Loss of platform trees with special priority given to the protection of multi-platform trees.
- Disturbance during critical nesting season (1 April through 31 August) including observing daily peak activity periods for marbled murrelets (one hour before sunrise to two hours after; one hour before sunset to one hour after) (Washington Forest Practices Rules 2001 [WAC 222-16-010]).
- Frequency of road use (i.e., mainline road vs. gated or temporary road).

D.2 Salvage

Salvage is defined as removing downed trees, particularly in the case of catastrophic natural events such as windthrow and fire. When salvage is being considered within Marbled Murrelet Management Areas, the primary consideration should be the maintenance of high-quality nesting habitat followed by the restoration of remaining habitat within the stand.

The Science Team Recommends that salvage be given the following considerations:

- Priority should be given to maintaining all standing trees.
- When removing salvage trees, consider options (legacies) for the development of a replacement buffer.

- If harvest of standing trees is necessary, limit loss of platform trees with special priority given to multi-platform trees.
- Salvage should occur outside of the critical nesting season.
- When salvaging within an occupied site, salvage should not have a negative effect on functional habitat.

The Science Team further recommends that the above guidelines be followed for proposed salvage within isolated occupied sites outside of MMMAs in the OESF, and for all occupied sites within the Straits Analysis Unit. In addition, DNR should maintain the integrity (and therefore the function) of buffers around occupied sites during salvage operations and if necessary, develop a replacement buffer to the extent that a buffer no longer exists due to windthrow or other factors.Once a long-term conservation strategy is adopted by DNR, it is recommended that the implementation document provides additional details, methods, and justification for habitat loss and salvage within occupied sites.

APPENDIX E
SCIENCE TEAM RECOMMENDATIONS:
PERFORMANCE CRITERIA FOR BUFFERS AROUND OCCUPIED SITES

Establishment of forest buffers is the primary management action directed at reducing edge-related predation and environmental effects such as windthrow and microclimate changes within a stand (Luginbuhl 2003). Current regulation requires that buffers on high-quality marbled murrelet nesting habitat be an average of 300 feet (91 meters) wide in Washington (Washington State Forest Practices Board 2002). There are no data on the effectiveness of these buffers. Occupied habitat in California also receives a 300-foot (91-meter) buffer.

The Science Team recommends buffering all occupied sites with the application of a 328-foot (100-meter) buffer area. The purpose of the buffer is to:

- Maintain the stand structure in the condition that provides high-quality nesting habitat for marbled murrelets (McShane et al. 2004).
- Reduce potential for blowdown (Jaross and Read 2006).
- Maintain microclimates within the occupied stand (Chen et al. 1993, 1995, Kremsater and Bunnell 1999, McShane et al. 2004).
- Reduce the impacts of hard edges, which have been linked to increased nest predation (Nelson et al. 2002).

Ideally, buffers should be designed to absorb and mediate wind disturbance to minimize postharvest blowdown so that adjacent marbled murrelet habitat is not compromised. The buffers should be configured so that if some blowdown occurs within the buffer area, the integrity of the buffer is not compromised and the buffer still provides protection to the marbled murrelet habitat of concern.

The buffer should protect the stand from dramatic changes in sunlight, humidity, and wind penetration within the stand after harvest. There is very little data on the tolerance of marbled murrelet chicks to radiation and thermal stress that can result near forest edges. Kremsater and Bunnell (1999) reported that microclimate effects can extend up to two to three tree heights (328 to 492 feet [100 to 150 meters]) into the forest.

This page intentionally left blank.

APPENDIX F

EVALUATION OF SURVEY EFFORT FOR DNR SURVEYS

This section presents a retrospective evaluation of how variable survey efforts may have affected the outcome of DNR surveys conducted prior to the release of the 2003 Pacific Seabird Group (PSG) marbled murrelet inland survey protocol (Evans Mack et al. 2003). We evaluate surveys conducted in the SWWA, OESF, and Straits Analysis Units, from 1994 through 2003. During that time, DNR followed the guidelines of earlier PSG protocols released between 1994 and 2001 (Ralph et al. 1994, 1995c, 1996, 1997, 1998, Evans Mack et al. 2003). The Science Team did not use the evaluation presented here to assist them in the development of the LTCS recommendations. However, an explanation of how the guidelines from earlier PSG protocols may have affected the classification of sites provides additional confidence that the Science Team's recommendations are appropriate.

The most current PSG marbled murrelet inland survey protocol (Evans Mack et al. 2003) recommends that surveys be conducted for 2 consecutive years. An analysis of the 1989 to 1998 Washington/Oregon/California marbled murrelet database showed clearly that sites could be occupied in one year and not another (Baldwin 2001). The estimated proportion of occupied sites that changed status between two years ranged from 18% to 65% per year, with a weighted average of 39%.

The PSG inland survey protocol recommends a two-stage sampling technique for the number of survey visits required to detect occupancy. In two-stage sampling over a two-year time frame, sites are visited a set minimum number of times (s^*) in each of two years. In year one, if no detections are observed in the first s^* visits, visits may be terminated for that year. If presence behaviors are observed, a set number of additional visits are conducted for a total of s visits to determine occupancy. In year two, for the sites with presence behaviors but no occupancy behaviors observed in year one, a total of s year two visits are conducted for a two-year total of $2s$ visits to determine occupancy. For the sites with no detections in year one, a minimum of s^* visits are conducted in year two. If there are no detections observed in the first s^* visits to those sites, visits may be terminated for a two-year total of $2s^*$ visits. If presence behaviors are first observed during year two, additional visits are conducted for a total of s year-two visits to determine occupancy, and for a two-year total of $s* + s$ visits. Of course, in all instances described above, visits may be terminated once occupancy behaviors are observed.

To recommend a two-stage sampling effort, three detection probabilities were estimated using the three-state database mentioned above (Baldwin 2002). Given that a site is occupied in a year, the probability of observing no detections on a single visit during that year is 0.4244 (q_0). Given that a site is occupied in a year, the probability of observing presence-only behaviors on a single visit during that year is 0.3416 (q_1). Given that a site is occupied in a year, the probability of observing occupied behaviors on a single visit during that year is 0.2341 (q_2).

The PSG inland survey protocol (Evans Mack et al. 2003) recommends that the minimum number of visits, or *s**, be five, and the total number of visits if presence behaviors are detected, or *s*, be nine. This recommendation is based on:

- The estimates of q_0, q_1, and q_2, given above.
- The assumption of 0.40 for the proportion of sites that change status between years, of sites that are occupied in at least one of two years.
- An overall error rate of 5% or less for misclassification of occupied sites (i.e. less than 5% chance that a site will be classified as "not occupied" when it is actually occupied).
- The assumption that the set of sites to be surveyed is similar to the set of sites in the three-state database.

All of DNR’s marbled murrelet inland survey efforts employed two-stage sampling for a two-year time period, following the evolving PSG inland survey protocol valid at the time of the surveys (Ralph et al. 1994, 1995c, 1996, 1997, 1998). Based on the recommendations from these prior PSG inland survey protocols, DNR employed *s** and *s* values that were often less than five and nine, respectively. The *s** and *s* values were often the same for year one and year two, but some of the efforts had different *s** and *s* values between the two years of survey. Table F-1 outlines the various survey efforts by planning unit and years, the values of s* and *s* for the years of survey, and the associated error rate. The error rates listed below were calculated using the values of q_0, q_1, and q_2, given above, the assumption of 0.40 for the proportion of occupied sites that change status between years, and the assumption that DNR sites are similar to the set of sites in the three-state database. The formulas provided in the 2003 PSG inland survey protocol allow calculation of error rates only if *s** and *s* are the same for both years of survey; therefore, the error rates listed below were calculated using precursor formulas provided in *Final Recommendations from the Steering Committee for the Marbled Murrelet Inland Survey Protocol Statistical Analysis* (Prenzlow Escene 2002).

Table F-1. Evaluation of Survey Effort for DNR Surveys.

Survey Effort	Years	HCP Unit(s)	Year 1 *s**	Year 1 *s*	Year 2 *s**	Year 2 *s*	Error Rate	Number of Sites	Number of Sites Classified as Occupied	Estimated Number Misclassified as Not Occupied[1]
Habitat Relationship Studies	1994–1996	OESF, Straits	4	6	4	10	0.072	107	41	~3
Habitat Relationship Studies	1994–1996	S. Coast, Columbia	4	6	4	10	0.072	110	25	~2
Inventory Surveys	1996–2001	OESF	4	5	4	5	0.152	767	306	~55
Inventory Surveys	1998–2001	S. Coast, Columbia	4	5	4	5	0.152	305	82	~15
Inventory Surveys	2000–2001	Straits	4	5	4	5	0.152	110	28	~5
Inventory Surveys	2001–2002	Straits	4	5	4	8	0.102	157	30	~3
Inventory Surveys	2001–2002	S. Coast, Columbia	4	5	4	8	0.102	122	0	0
Inventory Surveys	2002–2003	Straits	4	8	5	9	0.056	21	1	0

[1] This column is defined as the number of sites that are classified as "not occupied" that, according to this retrospective evaluation, could actually be occupied. This column is calculated in two steps. First calculate the total number of occupied sites by dividing the number of sites classified as occupied by (one minus the error rate). Second, calculate the estimated number misclassified as simply the total number of occupied sites minus the number of sites classified as occupied.

What appears most alarming are the 55 inventory survey sites in the OESF predicted to be misclassified. It is important to note that all marbled murrelet inventory surveys in the OESF Planning Unit were conducted in old-growth forest types. The Science Team recommended that all forests where inventory surveys were conducted (since these were almost exclusively old-growth forest types) be deferred from harvest, regardless of their survey status. This recommendation completely mitigates the risk of misclassified occupied sites within the OESF not receiving protection.

The SWWA Analysis Unit encompasses the South Coast and Columbia Planning Units. In SWWA a total of 17 sites are predicted to be misclassified. Science Team recommendations in the SWWA Analysis Unit prescribe substantial habitat enhancement (on the order of 60,000 acres [24,000 hectares]), which mitigates the risk of misclassified occupied sites not being protected in SWWA.

APPENDIX G

COMPREHENSIVE SUMMARY OF RESULTS FROM THE MANAGEMENT SCENARIO ANALYSIS

I. SUMMARY OF ANALYSIS RESULTS

The tables below summarize the current and projected future habitat abundance (thousands of acres) and capability of forests to support marbled murrelet populations (*K′*) under the Habitat Management scenario (Tables G-1A through G-1L; see section II in chapter 4.0 for description) and No Management scenario (Tables G-2A through G-2L; see section II in chapter 4.0 for description) by:

- Analysis unit (SWWA, OESF, and Straits);
- Year (2004, 2013, 2031, and 2067);
- Landowner (DNR; Federal = National Park Service and U.S. Forest Service; and Other);
- DNR MMMA or DNR non-MMMA;
- Forest stage (stand development stages of LTS = Large Tree Exclusion, UDS = Understory Development, BDS = Botanically Diverse, NDS = Niche Diversification, and FFS = Fully Functional; and non-DNR forest stages of Existing Late-Seral and Projected Late-Seral);
- Closer than or farther than 40 miles (64 kilometers) from marbled murrelet-dense marine waters (see definition in section 3.2b); and
- Forest edge (less than 164 feet [less than 50 meters] from an edge) or interior (more than 164 feet [more than 50 meters] from an edge).

To simplify the presentation of projected habitat abundance under the two management scenarios, the following G-1 and G-2 tables in this appendix as well as tables and figures in the body of the text offer a simplified accounting by probability of occupancy (P_{stage}) values for each forest stand development stage (SDS). For these tables, each projected acre of habitat fits cleanly within one of the five reported SDS categories with an associated P_{stage} value. While each SDS and associated P_{stage} value is predominately composed of acres in the reported SDS category, each P_{stage} is also composed of some acres of other SDS categories and the existing and projected Interagency Vegetation Mapping Project (IVMP) Late-Seral forest stages. An explanation and summary of these reporting differences for the Habitat Management scenario and the No Management scenario is in section II of this appendix.

Table G-1A. SWWA 2004—Habitat Management Scenario. Current and Projected Future Habitat Abundance (Thousands of Acres) and Capability of Forests to Support Marbled Murrelet Populations (*K'*) (See Section II in Chapter 4.0 for Description of Habitat Management Scenario).

			< 40 Miles from Marbled Murrelet-Dense Marine Waters					> 40 Miles from Marbled Murrelet-Dense Marine Waters								
			Interior		Edge				Interior		Edge					
Land	Stage	*P* for Stage	Thousands of Acres	*K*	*P* for Edge	Thousands of Acres	*K*	*P* for > 40 mi.	Thousands of Acres	*K*	*P* for Edge	Thousands of Acres	*K*	*K* Int.	*K* Edge	*K'*
DNR MMMA	LTS	0.25	4.5	7	0.70	1.2	1	0.25	0.0	0	0.70	0.0	0	7	1	8
	UDS	0.36	2.7	6	0.70	0.7	1	0.25	0.0	0	0.70	0.0	0	6	1	7
	BDS	0.47	2.5	7	0.70	0.6	1	0.25	0.0	0	0.70	0.0	0	7	1	8
	NDS	0.62	0.7	2	0.70	0.1	0	0.25	0.0	0	0.70	0.0	0	2	0	3
	FFS	0.89	0.1	0	0.70	0.0	0	0.25	0.0	0	0.70	0.0	0	0	0	0
	Total		10.4	22		2.7	4		0.0	0		0.0	0	22	4	26
DNR Non-MMMA	LTS	0.25	15.7	23	0.70	3.2	3	0.25	21.2	8	0.70	5.3	1	31	5	36
	UDS	0.36	15.3	32	0.70	3.2	5	0.25	16.8	9	0.70	5.0	2	41	7	48
	BDS	0.47	10.0	28	0.70	2.3	4	0.25	10.7	7	0.70	3.5	2	35	6	41
	NDS	0.62	0.0	0	0.70	0.0	0	0.25	0.0	0	0.70	0.0	0	0	0	0
	FFS	0.89	0.0	0	0.70	0.0	0	0.25	0.0	0	0.70	0.0	0	0	0	0
	Total		41.0	83		8.7	13		48.7	24		13.8	5	107	18	125
DNR Total			**51.4**	**105**		**11.4**	**16**		**48.7**	**24**		**13.8**	**5**	**129**	**21**	**151**
Federal	Existing	0.68	0.5	2	0.70	0.0	0	0.25	0.0	0	0.70	0.0	0	2	0	2
Other	Existing	0.31	65.9	120	0.70	78.6	100	0.25	11.7	5	0.70	23.3	7	125	108	233
Total			117.7	227		90.0	117		60.4	29		37.2	12	257	129	386

Note: values for acres, *K*, and *K'* may not sum due to rounding.

Table G-1B. SWWA 2013—Habitat Management Scenario. Current and Projected Future Habitat Abundance (Thousands of Acres) and Capability of Forests to Support Marbled Murrelet Populations (*K'*) (See Section II in Chapter 4.0 for Description of Habitat Management Scenario).

			< 40 Miles from Marbled Murrelet-Dense Marine Waters					> 40 Miles from Marbled Murrelet-Dense Marine Waters								
			Interior		Edge				Interior		Edge					
Land	Stage	*P* for Stage	Thousands of Acres	*K*	*P* for Edge	Thousands of Acres	*K*	*P* for > 40 mi.	Thousands of Acres	*K*	*P* for Edge	Thousands of Acres	*K*	*K* Int.	*K* Edge	*K'*
DNR MMMA	LTS	0.25	5.6	8	0.70	1.8	2	0.25	0.0	0	0.70	0.0	0	8	2	10
	UDS	0.36	1.5	3	0.70	0.5	1	0.25	0.0	0	0.70	0.0	0	3	1	4
	BDS	0.47	3.9	11	0.70	0.7	1	0.25	0.0	0	0.70	0.0	0	11	1	12
	NDS	0.62	1.9	7	0.70	0.3	1	0.25	0.0	0	0.70	0.0	0	7	1	8
	FFS	0.89	0.2	1	0.70	0.0	0	0.25	0.0	0	0.70	0.0	0	1	0	1
	Total		13.0	30		3.4	5		0.0	0		0.0	0	30	5	35
DNR Non-MMMA	LTS	0.25	7.1	10	0.70	6.1	6	0.25	13.0	5	0.70	5.0	1	15	8	23
	UDS	0.36	8.6	18	0.70	7.3	11	0.25	17.5	9	0.70	6.0	2	28	13	41
	BDS	0.47	4.4	12	0.70	4.0	8	0.25	8.9	6	0.70	3.3	2	18	9	28
	NDS	0.62	0.2	1	0.70	0.4	1	0.25	0.5	0	0.70	0.2	0	1	1	2
	FFS	0.89	0.0	0	0.70	0.0	0	0.25	0.0	0	0.70	0.0	0	0	0	0
	Total		20.3	41		17.8	26		39.9	21		14.6	5	62	31	93
DNR Total			**33.3**	**71**		**21.2**	**31**		**39.9**	**21**		**14.6**	**5**	**92**	**36**	**128**
Federal	Existing	0.68	0.5	2	0.70	0.0	0	0.25	0.0	0	0.70	0.0	0	2	0	2
	Projected	0.20	0.4	0	0.70	0.0	0	0.25	0.0	0	0.70	0.0	0	0	0	1
	Total		**0.9**	**2**		**0.1**	**0**		**0.0**	**0**		**0.0**	**0**	**2**	**0**	**2**
Other	Existing	0.31	65.8	120	0.70	78.7	100	0.25	11.7	5	0.70	23.3	7	125	108	233
	Projected	0.13	51.7	40	0.70	59.6	32	0.25	2.5	0	0.70	8.0	1	40	33	73
	Total		**117.5**	**160**		**138.3**	**132**		**14.2**	**6**		**31.3**	**9**	**165**	**141**	**306**
Total			151.7	233		159.5	163		54.1	26		45.9	14	260	177	437

Note: values for acres, *K*, and *K'* may not sum due to rounding.

Table G-1C. SWWA 2031—Habitat Management Scenario. Current and Projected Future Habitat Abundance (Thousands of Acres) and Capability of Forests to Support Marbled Murrelet Populations (*K'*) (See Section II in Chapter 4.0 for Description of Habitat Management Scenario).

			< 40 Miles from Marbled Murrelet-Dense Marine Waters					> 40 Miles from Marbled Murrelet-Dense Marine Waters								
			Interior		Edge				Interior		Edge					
Land	Stage	*P* for Stage	Thousands of Acres	*K*	*P* for Edge	Thousands of Acres	*K*	*P* for > 40 mi.	Thousands of Acres	*K*	*P* for Edge	Thousands Of Acres	*K*	*K* Int.	*K* Edge	*K'*
DNR MMMA	LTS	0.25	7.3	11	0.70	1.0	1	0.25	0.0	0	0.70	0.0	0	11	1	12
	UDS	0.36	9.2	19	0.70	1.3	2	0.25	0.0	0	0.70	0.0	0	19	2	21
	BDS	0.47	6.5	18	0.70	0.9	2	0.25	0.0	0	0.70	0.0	0	18	2	20
	NDS	0.62	5.7	21	0.70	0.8	2	0.25	0.0	0	0.70	0.0	0	21	2	23
	FFS	0.89	0.2	1	0.70	0.0	0	0.25	0.0	0	0.70	0.0	0	1	0	1
	Total		28.9	70		4.0	7		0.0	0		0.0	0	70	7	77
DNR Non-MMMA	LTS	0.25	5.1	7	0.70	4.0	4	0.25	8.4	3	0.70	2.7	1	11	5	15
	UDS	0.36	8.5	18	0.70	5.4	8	0.25	12.7	7	0.70	6.0	2	25	10	35
	BDS	0.47	9.7	27	0.70	2.7	5	0.25	9.0	6	0.70	2.7	1	33	7	40
	NDS	0.62	5.2	19	0.70	0.7	2	0.25	5.7	5	0.70	1.3	1	24	3	27
	FFS	0.89	0.2	1	0.70	0.0	0	0.25	0.0	0	0.70	0.0	0	1	0	1
	Total		28.7	72		12.9	19		35.9	21		12.7	5	94	24	118
DNR Total			**57.6**	**142**		**16.9**	**26**		**35.9**	**21**		**12.7**	**5**	**164**	**31**	**195**
Federal	Existing	0.68	0.5	2	0.70	0.0	0	0.25	0.0	0	0.70	0.0	0	2	0	2
	Projected	0.20	0.8	1	0.70	0.1	0	0.25	0.0	0	0.70	0.0	0	1	0	1
	Total		**1.3**	**3**		**0.1**	**0**		**0.0**	**0**		**0.0**	**0**	**3**	**0**	**3**
Other	Existing	0.31	69.5	127	0.70	75.0	96	0.25	12.4	6	0.70	22.6	7	132	103	235
	Projected	0.13	87.5	67	0.70	143.0	77	0.25	6.6	1	0.70	33.7	5	68	81	149
	Total		**157.0**	**194**		**218.0**	**172**		**19.0**	**7**		**56.3**	**12**	**201**	**184**	**385**
Total			215.9	339		235.0	199		54.9	28		69.1	17	367	215	582

Note: values for acres, *K*, and *K'* may not sum due to rounding.

Table G-1D. SWWA 2067—Habitat Management Scenario. Current and Projected Future Habitat Abundance (Thousands of Acres) and Capability of Forests to Support Marbled Murrelet Populations (*K'*) (See Section II in Chapter 4.0 for Description of Habitat Management Scenario).

			< 40 Miles from Marbled Murrelet-Dense Marine Waters					> 40 Miles from Marbled Murrelet-Dense Marine Waters								
			Interior		Edge				Interior		Edge					
Land	Stage	*P* for Stage	Thousands of Acres	*K*	*P* for Edge	Thousands of Acres	*K*	*P* for > 40 mi.	Thousands of Acres	*K*	*P* for Edge	Thousands of Acres	*K*	*K* Int.	*K* Edge	*K'*
DNR MMMA	LTS	0.25	1.6	2	0.70	0.7	1	0.25	0.0	0	0.70	0.0	0	2	1	3
	UDS	0.36	3.6	8	0.70	2.3	3	0.25	0.0	0	0.70	0.0	0	8	3	11
	BDS	0.47	6.8	19	0.70	2.7	5	0.25	0.0	0	0.70	0.0	0	19	5	24
	NDS	0.62	16.9	62	0.70	2.8	7	0.25	0.0	0	0.70	0.0	0	62	7	69
	FFS	0.89	8.7	46	0.70	1.3	5	0.25	0.0	0	0.70	0.0	0	46	5	50
	Total		37.7	136		9.8	21		0.0	0		0.0	0	136	21	158
DNR Non-MMMA	LTS	0.25	6.3	9	0.70	4.1	4	0.25	9.3	3	0.70	3.8	1	13	5	18
	UDS	0.36	8.8	19	0.70	6.4	9	0.25	17.3	9	0.70	7.2	3	28	12	40
	BDS	0.47	5.7	16	0.70	3.7	7	0.25	8.6	6	0.70	2.7	1	22	8	30
	NDS	0.62	4.1	15	0.70	2.1	5	0.25	5.5	5	0.70	2.1	1	20	7	27
	FFS	0.89	3.9	21	0.70	2.1	8	0.25	5.1	7	0.70	0.9	1	27	9	36
	Total		28.8	79		18.4	34		45.7	30		16.7	7	109	41	150
DNR Total			**66.5**	**215**		**28.2**	**55**		**45.7**	**30**		**16.7**	**7**	**245**	**62**	**308**
Federal	Existing	0.68	0.5	2	0.70	0.0	0	0.25	0.0	0	0.70	0.0	0	2	0	2
	Projected	0.20	0.9	1	0.70	0.1	0	0.25	0.0	0	0.70	0.0	0	1	0	1
	Total		**1.4**	**3**		**0.1**	**0**		**0.0**	**0**		**0.0**	**0**	**3**	**0**	**3**
Other	Existing	0.31	69.5	127	0.70	75.0	96	0.25	12.4	6	0.70	22.6	7	132	103	235
	Projected	0.13	102.4	78	0.70	223.2	119	0.25	10.2	2	0.70	64.4	9	80	128	208
	Total		**171.8**	**205**		**298.2**	**215**		**22.6**	**8**		**87.0**	**16**	**213**	**231**	**444**
Total			239.7	423		326.5	271		68.3	38		103.7	23	461	294	754

Note: values for acres, *K*, and *K'* may not sum due to rounding.

Table G-1E. OESF 2004—Habitat Management Scenario. Current and Projected Future Habitat Abundance (Thousands of Acres) and Capability of Forests to Support Marbled Murrelet Populations (*K′*) (See Section II in Chapter 4.0 for Description of Habitat Management Scenario).

Land	Stage	*P* for Stage	Interior: Thousands of Acres	Interior: *K*	Edge: *P* for Edge	Edge: Thousands of Acres	Edge: *K*	*K'*
DNR MMMA	LTS	0.25	0.2	0	0.70	0.1	0	0
	UDS	0.36	1.3	3	0.70	0.3	0	3
	BDS	0.47	2.7	7	0.70	0.5	1	8
	NDS	0.62	5.4	20	0.70	1.0	3	22
	FFS	0.89	0.4	2	0.70	0.1	0	2
	Total		10.1	33		2.0	4	37
DNR Non-MMMA	LTS	0.25	6.4	9	0.70	1.5	2	11
	UDS	0.36	7.0	15	0.70	1.6	2	17
	BDS	0.47	14.0	39	0.70	3.2	6	45
	NDS	0.62	17.6	64	0.70	2.9	7	72
	FFS	0.89	4.6	24	0.70	0.6	2	26
	Total		49.5	151		9.8	20	171
DNR Total			**59.6**	**183**		**11.8**	**24**	**207**
Federal	Existing	0.68	203.2	813	0.70	79.3	222	1,035
Other	Existing	0.31	29.3	53	0.70	30.2	39	92
Total			292.1	1,050		121.3	285	1,335

Note: values for acres, *K*, and *K′* may not sum due to rounding.

Table G-1F. OESF 2013—Habitat Management Scenario. Current and Projected Future Habitat Abundance (Thousands of Acres) and Capability of Forests to Support Marbled Murrelet Populations (K') (See Section II in Chapter 4.0 for Description of Habitat Management Scenario).

Land	Stage	*P* for Stage	Interior Thousands of Acres	Interior *K*	Edge *P* for Edge	Edge Thousands of Acres	Edge *K*	*K'*
DNR MMMA	LTS	0.25	0.1	0	0.70	0.1	0	0
	UDS	0.36	1.3	3	0.70	0.3	0	3
	BDS	0.47	2.9	8	0.70	0.5	1	9
	NDS	0.62	6.6	24	0.70	0.7	2	26
	FFS	0.89	0.9	4	0.70	0.1	0	5
	Total		11.8	40		1.6	4	43
DNR Non-MMMA	LTS	0.25	6.3	9	0.70	1.9	2	11
	UDS	0.36	6.1	13	0.70	2.2	3	16
	BDS	0.47	12.3	34	0.70	3.2	6	40
	NDS	0.62	14.7	54	0.70	1.7	4	58
	FFS	0.89	12.0	63	0.70	1.2	4	67
	Total		51.4	173		10.2	20	193
DNR Total			**63.2**	**212**		**11.8**	**24**	**236**
Federal	Existing	0.68	203.3	813	0.70	79.3	222	1,035
	Projected	0.20	39.8	47	0.70	3.8	3	50
	Total		**243.1**	**860**		**83.1**	**225**	**1,085**
Other	Existing	0.31	29.3	53	0.70	30.2	39	92
	Projected	0.13	11.4	9	0.70	12.3	7	15
	Total		**40.7**	**62**		**42.5**	**45**	**107**
Total			347.0	1,134		137.5	294	1,428

Note: values for acres, *K*, and *K'* may not sum due to rounding.

Table G-1G. OESF 2031—Habitat Management Scenario. Current and Projected Future Habitat Abundance (Thousands of Acres) and Capability of Forests to Support Marbled Murrelet Populations (*K′*) (See Section II in Chapter 4.0 for Description of Habitat Management Scenario).

Land	Stage	*P* for Stage	Interior: Thousands of Acres	Interior: *K*	Edge: *P* for Edge	Edge: Thousands of Acres	Edge: *K*	*K'*
DNR MMMA	LTS	0.25	0.4	1	0.70	0.1	0	1
	UDS	0.36	1.0	2	0.70	0.3	0	3
	BDS	0.47	2.6	7	0.70	0.4	1	8
	NDS	0.62	8.6	31	0.70	0.8	2	34
	FFS	0.89	2.0	10	0.70	0.1	0	11
	Total		14.6	52		1.8	4	56
DNR Non-MMMA	LTS	0.25	5.3	8	0.70	1.7	2	9
	UDS	0.36	7.0	15	0.70	1.9	3	18
	BDS	0.47	13.4	37	0.70	2.9	6	43
	NDS	0.62	19.6	72	0.70	1.9	5	76
	FFS	0.89	14.7	77	0.70	1.0	4	80
	Total		60.0	208		9.3	19	226
DNR Total			**74.6**	**260**		**11.1**	**23**	**282**
Federal	Existing	0.68	206.8	827	0.70	75.7	212	1,039
	Projected	0.20	82.3	97	0.70	1.6	1	98
	Total		**289.1**	**924**		**77.3**	**213**	**1,137**
Other	Existing	0.31	30.4	56	0.70	29.1	37	93
	Projected	0.13	23.1	18	0.70	46.4	25	42
	Total		**53.5**	**73**		**75.5**	**62**	**135**
Total			417.2	1,257		164.0	298	1,555

Note: values for acres, *K*, and *K′* may not sum due to rounding.

Table G-1H. OESF 2067—Habitat Management Scenario. Current and Projected Future Habitat Abundance (Thousands of Acres) and Capability of Forests to Support Marbled Murrelet Populations (*K′*) (See Section II in Chapter 4.0 for Description of Habitat Management Scenario).

			Interior		Edge			
Land	Stage	*P* for Stage	Thousands of Acres	*K*	*P* for Edge	Thousands of Acres	*K*	*K’*
DNR MMMA	LTS	0.25	0.1	0	0.70	0.2	0	0
	UDS	0.36	4.0	8	0.70	2.2	3	12
	BDS	0.47	3.7	10	0.70	1.8	4	14
	NDS	0.62	9.9	36	0.70	2.3	6	42
	FFS	0.89	5.1	27	0.70	1.0	4	31
	Total		22.8	82		7.5	16	98
DNR Non-MMMA	LTS	0.25	27.0	40	0.70	9.8	10	50
	UDS	0.36	8.9	19	0.70	3.7	6	24
	BDS	0.47	13.7	38	0.70	4.3	8	46
	NDS	0.62	17.6	64	0.70	3.2	8	72
	FFS	0.89	21.5	113	0.70	2.9	11	123
	Total		88.7	273		23.9	43	316
DNR Total			**111.5**	**355**		**31.4**	**59**	**414**
Federal	Existing	0.68	206.7	827	0.70	75.8	212	1,039
	Projected	0.20	96.1	113	0.70	2.2	2	115
	Total		**302.8**	**940**		**78.0**	**214**	**1,154**
Other	Existing	0.31	30.4	55	0.70	29.1	37	93
	Projected	0.13	26.0	20	0.70	62.1	33	53
	Total		**56.4**	**75**		**91.2**	**70**	**146**
Total			470.74	1,370		200.7	344	1,714

Note: values for acres, *K*, and *K′* may not sum due to rounding.

Table G-1I. Straits 2004—Habitat Management Scenario. Current and Projected Future Habitat Abundance (Thousands of Acres) and Capability of Forests to Support Marbled Murrelet Populations (*K'*) (See Section II in Chapter 4.0 for Description of Habitat Management Scenario).

			Interior		Edge			
Land	Stage	*P* for Stage	Thousands of Acres	*K*	*P* for Edge	Thousands of Acres	*K*	*K'*
DNR Non-MMMA	LTS	0.25	6.4	9	0.70	2.1	2	12
	UDS	0.36	17.7	38	0.70	3.6	5	43
	BDS	0.47	16.6	46	0.70	5.0	10	56
	NDS	0.62	0.1	1	0.70	0.0	0	1
	FFS	0.89	0.0	0	0.70	0.0	0	0
	Total		**40.8**	**93**		**10.8**	**17**	**111**
Federal	Existing	0.68	193.2	773	0.70	93.0	260	1,033
Other	Existing	0.31	13.9	25	0.70	24.1	31	56
Total			248.0	892		127.9	309	1,200

Note: values for acres, *K*, and *K'* may not sum due to rounding.

Table G-1J. Straits 2013—Habitat Management Scenario. Current and Projected Future Habitat Abundance (Thousands of Acres) and Capability of Forests to Support Marbled Murrelet Populations (*K'*) (See Section II in Chapter 4.0 for Description of Habitat Management Scenario).

			Interior		Edge			
Land	Stage	*P* for Stage	Thousands of Acres	*K*	*P* for Edge	Thousands of Acres	*K*	*K'*
DNR Non-MMMA	LTS	0.25	5.0	7	0.70	2.6	3	10
	UDS	0.36	13.1	28	0.70	5.1	8	35
	BDS	0.47	11.5	32	0.70	5.4	10	42
	NDS	0.62	0.9	3	0.70	0.6	1	5
	FFS	0.89	0.0	0	0.70	0.0	0	0
	Total		**30.5**	**70**		**13.7**	**22**	**92**
Federal	Existing	0.68	193.1	772	0.70	93.1	261	1,033
	Projected	0.20	50.9	60	0.70	4.4	4	64
	Total		**244.0**	**832**		**97.5**	**264**	**1,097**
Other	Existing	0.31	13.8	25	0.70	24.2	31	56
	Projected	0.13	1.3	1	0.70	2.7	1	2
	Total		**15.1**	**26**		**26.9**	**32**	**59**
Total			289.7	929		138.1	319	1,248

Note: values for acres, *K*, and *K'* may not sum due to rounding.

Table G-1K. Straits 2031—Habitat Management Scenario. Current and Projected Future Habitat Abundance (Thousands of Acres) and Capability of Forests to Support Marbled Murrelet Populations (*K'*) (See Section II in Chapter 4.0 for Description of Habitat Management Scenario).

Land	Stage	*P* for Stage	Interior Thousands of Acres	Interior *K*	Edge *P* for Edge	Edge Thousands of Acres	Edge *K*	*K'*
DNR Non-MMMA	LTS	0.25	3.4	5	0.70	1.8	2	7
	UDS	0.36	9.1	19	0.70	4.3	6	26
	BDS	0.47	13.5	37	0.70	4.0	8	45
	NDS	0.62	6.1	22	0.70	2.7	7	29
	FFS	0.89	0.0	0	0.70	0.0	0	0
	Total		**32.2**	**84**		**12.8**	**23**	**107**
Federal	Existing	0.68	199.4	798	0.70	86.8	243	1,041
	Projected	0.20	99.5	117	0.70	6.5	5	122
	Total		**299.0**	**915**		**93.4**	**248**	**1,163**
Other	Existing	0.31	14.2	26	0.70	23.8	30	56
	Projected	0.13	5.1	4	0.70	18.1	10	14
	Total		**19.3**	**30**		**41.9**	**40**	**70**
Total			350.4	1,029		148.1	311	1,340

Note: values for acres, *K*, and *K'* may not sum due to rounding.

Table G-1L. Straits 2067—Habitat Management Scenario. Current and Projected Future Habitat Abundance (Thousands of Acres) and Capability of Forests to Support Marbled Murrelet Populations (*K'*) (See Section II in Chapter 4.0 for Description of Habitat Management Scenario).

Land	Stage	*P* for Stage	Interior Thousands of Acres	Interior *K*	Edge *P* for Edge	Edge Thousands of Acres	Edge *K*	*K'*
DNR Non-MMMA	LTS	0.25	4.2	6	0.70	1.7	2	8
	UDS	0.36	15.0	32	0.70	6.0	9	41
	BDS	0.47	12.2	34	0.70	4.4	8	42
	NDS	0.62	1.7	6	0.70	0.6	2	8
	FFS	0.89	5.6	29	0.70	1.9	7	36
	Total		**38.8**	**108**		**14.6**	**28**	**135**
Federal	Existing	0.68	199.5	798	0.70	86.7	243	1,041
	Projected	0.20	117.4	138	0.70	8.4	7	145
	Total		**316.9**	**936**		**95.2**	**250**	**1,186**
Other	Existing	0.31	14.2	26	0.70	23.8	30	56
	Projected	0.13	6.5	5	0.70	28.1	15	20
	Total		**20.7**	**31**		**52.0**	**45**	**76**
Total			376.4	1,075		161.7	323	1,397

Note: values for acres, *K*, and *K'* may not sum due to rounding.

Table G-2A. SWWA 2004—No Management Scenario. Current and Projected Future Habitat Abundance (Thousands of Acres) and Capability of Forests to Support Marbled Murrelet Populations (*K*′) (See Section II in Chapter 4.0 for Description of No Management Scenario).

			< 40 Miles from Marbled Murrelet-Dense Marine Waters					> 40 Miles from Marbled Murrelet-Dense Marine Waters								
			Interior		Edge				Interior		Edge					
Land	Stage	*P* for Stage	Thousands of Acres	*K*	*P* for Edge	Thousands of Acres	*K*	*P* for > 40 mi.	Thousands of Acres	*K*	*P* for Edge	Thousands of Acres	*K*	*K* Int.	*K* Edge	*K*’
DNR MMMA	LTS	0.25	4.5	7	0.70	1.2	1	0.25	0.0	0	0.70	0.0	0	7	1	8
	UDS	0.36	2.7	6	0.70	0.7	1	0.25	0.0	0	0.70	0.0	0	6	1	7
	BDS	0.47	2.5	7	0.70	0.6	1	0.25	0.0	0	0.70	0.0	0	7	1	8
	NDS	0.62	0.7	2	0.70	0.1	0	0.25	0.0	0	0.70	0.0	0	2	0	3
	FFS	0.89	0.1	0	0.70	0.0	0	0.25	0.0	0	0.70	0.0	0	0	0	0
	Total		10.4	22		2.7	4		0.0	0		0.0	0	22	4	26
DNR Non-MMMA	LTS	0.25	15.7	23	0.70	3.2	3	0.25	21.2	8	0.70	5.3	1	31	5	36
	UDS	0.36	15.3	32	0.70	3.2	5	0.25	16.8	9	0.70	5.0	2	41	7	48
	BDS	0.47	10.0	28	0.70	2.3	4	0.25	10.7	7	0.70	3.5	2	35	6	41
	NDS	0.62	0.0	0	0.70	0.0	0	0.25	0.0	0	0.70	0.0	0	0	0	0
	FFS	0.89	0.0	0	0.70	0.0	0	0.25	0.0	0	0.70	0.0	0	0	0	0
	Total		41.0	83		8.7	13		48.7	24		13.8	5	107	18	125
DNR Total			**51.4**	**105**		**11.4**	**16**		**48.7**	**24**		**13.8**	**5**	**129**	**21**	**151**
Federal	Existing	0.68	0.5	2	0.70	0.0	0	0.25	0.0	0	0.70	0.0	0	2	0	2
Other	Existing	0.31	65.9	120	0.70	78.6	100	0.25	11.7	5	0.70	23.3	7	125	108	233
Total			117.7	227		90.0	117		60.4	29		37.2	12	257	129	386

Note: values for acres, *K*, and *K'* may not sum due to rounding.

Table G-2B. SWWA 2013—No Management Scenario. Current and Projected Future Habitat Abundance (Thousands of Acres) and Capability of Forests to Support Marbled Murrelet Populations (*K'*) (See Section II in Chapter 4.0 for Description of No Management Scenario).

			< 40 Miles from Marbled Murrelet-Dense Marine Waters					> 40 Miles from Marbled Murrelet-Dense Marine Waters								
			Interior		Edge				Interior		Edge					
Land	Stage	*P* for Stage	Thousands of Acres	*K*	*P* for Edge	Thousands of Acres	*K*	*P* for > 40 mi.	Thousands of Acres	*K*	*P* for Edge	Thousands of Acres	*K*	*K* Int.	*K* Edge	*K'*
DNR MMMA	LTS	0.25	7.2	11	0.70	1.7	2	0.25	0.0	0	0.70	0.0	0	11	2	12
	UDS	0.36	1.5	3	0.70	0.5	1	0.25	0.0	0	0.70	0.0	0	3	1	4
	BDS	0.47	3.9	11	0.70	0.7	1	0.25	0.0	0	0.70	0.0	0	11	1	12
	NDS	0.62	1.9	7	0.70	0.3	1	0.25	0.0	0	0.70	0.0	0	7	1	8
	FFS	0.89	0.2	1	0.70	0.0	0	0.25	0.0	0	0.70	0.0	0	1	0	1
	Total		14.6	32		3.2	5		0.0	0		0.0	0	32	5	37
DNR Non-MMMA	LTS	0.25	7.3	11	0.70	6.1	6	0.25	13.0	5	0.70	5.0	1	16	8	23
	UDS	0.36	8.6	18	0.70	7.3	11	0.25	17.5	9	0.70	6.0	2	28	13	41
	BDS	0.47	4.4	12	0.70	4.0	8	0.25	8.9	6	0.70	3.3	2	18	9	28
	NDS	0.62	0.2	1	0.70	0.4	1	0.25	0.5	0	0.70	0.2	0	1	1	2
	FFS	0.89	0.0	0	0.70	0.0	0	0.25	0.0	0	0.70	0.0	0	0	0	0
	Total		20.5	42		17.8	26		39.9	21		14.6	5	63	31	94
DNR Total			**35.1**	**74**		**21.0**	**30**		**39.9**	**21**		**14.6**	**5**	**95**	**36**	**131**
Federal	Existing	0.68	0.5	2	0.70	0.0	0	0.25	0.0	0	0.70	0.0	0	2	0	2
	Projected	0.20	0.4	0	0.70	0.0	0	0.25	0.0	0	0.70	0.0	0	0	0	1
	Total		**0.9**	**2**		**0.1**	**0**		**0.0**	**0**		**0.0**	**0**	**2**	**0**	**2**
Other	Existing	0.31	65.8	120	0.70	78.7	100	0.25	11.7	5	0.70	23.3	7	125	108	233
	Projected	0.13	51.7	40	0.70	59.6	32	0.25	2.5	0	0.70	8.0	1	40	33	73
	Total		**117.5**	**160**		**138.3**	**132**		**14.2**	**6**		**31.3**	**9**	**165**	**141**	**306**
Total			153.5	236		159.3	163		54.1	26		45.9	14	263	177	439

Note: values for acres, *K*, and *K'* may not sum due to rounding.

Table G-2C. SWWA 2031—No Management Scenario. Current and Projected Future Habitat Abundance (Thousands of Acres) and Capability of Forests to Support Marbled Murrelet Populations (*K'*) (See Section II in Chapter 4.0 for Description of No Management Scenario).

			< 40 Miles from Marbled Murrelet-Dense Marine Waters					> 40 Miles from Marbled Murrelet-Dense Marine Waters								
			Interior		Edge				Interior		Edge					
Land	Stage	*P* for Stage	Thousands of Acres	*K*	*P* for Edge	Thousands of Acres	*K*	*P* for > 40 mi.	Thousands of Acres	*K*	*P* for Edge	Thousands of Acres	*K*	*K* Int.	*K* Edge	*K'*
DNR MMMA	LTS	0.25	13.4	20	0.70	1.5	2	0.25	0.0	0	0.70	0.0	0	20	2	21
	UDS	0.36	4.5	9	0.70	0.8	1	0.25	0.0	0	0.70	0.0	0	9	1	11
	BDS	0.47	4.3	12	0.70	0.7	1	0.25	0.0	0	0.70	0.0	0	12	1	13
	NDS	0.62	5.8	21	0.70	0.8	2	0.25	0.0	0	0.70	0.0	0	21	2	23
	FFS	0.89	0.2	1	0.70	0.0	0	0.25	0.0	0	0.70	0.0	0	1	0	1
	Total		28.2	63		3.7	6		0.0	0		0.0	0	63	6	69
DNR Non-MMMA	LTS	0.25	5.8	8	0.70	4.1	4	0.25	8.5	3	0.70	2.8	1	12	5	17
	UDS	0.36	7.9	17	0.70	5.3	8	0.25	12.7	7	0.70	6.0	2	24	10	34
	BDS	0.47	9.5	26	0.70	2.7	5	0.25	9.0	6	0.70	2.7	1	32	7	39
	NDS	0.62	5.2	19	0.70	0.7	2	0.25	5.7	5	0.70	1.3	1	24	3	27
	FFS	0.89	0.2	1	0.70	0.0	0	0.25	0.0	0	0.70	0.0	0	1	0	1
	Total		28.6	72		12.9	19		35.9	21		12.8	5	93	24	117
DNR Total			**56.8**	**135**		**16.7**	**25**		**35.9**	**21**		**12.8**	**5**	**156**	**30**	**187**
Federal	Existing	0.68	0.5	2	0.70	0.0	0	0.25	0.0	0	0.70	0.0	0	2	0	2
	Projected	0.20	0.8	1	0.70	0.1	0	0.25	0.0	0	0.70	0.0	0	1	0	1
	Total		**1.3**	**3**		**0.1**	**0**		**0.0**	**0**		**0.0**	**0**	**3**	**0**	**3**
Other	Existing	0.31	69.5	127	0.70	75.0	96	0.25	12.4	6	0.70	22.6	7	132	103	235
	Projected	0.13	87.5	67	0.70	143.0	77	0.25	6.6	1	0.70	33.7	5	68	81	149
	Total		**157.0**	**194**		**218.0**	**172**		**19.0**	**7**		**56.3**	**12**	**201**	**184**	**385**
Total			215.1	331		234.8	198		54.9	28		69.1	17	359	215	574

Note: values for acres, *K*, and *K'* may not sum due to rounding.

Table G-2D. SWWA 2067—No Management Scenario. Current and Projected Future Habitat Abundance (Thousands of Acres) and Capability of Forests to Support Marbled Murrelet Populations (*K'*) (See Section II in Chapter 4.0 for Description of No Management Scenario).

			< 40 Miles from Marbled Murrelet-Dense Marine Waters					> 40 Miles from Marbled Murrelet-Dense Marine Waters								
			Interior		Edge				Interior		Edge					
Land	Stage	*P* for Stage	Thousands of Acres	*K*	*P* for Edge	Thousands of Acres	*K*	*P* for > 40 mi.	Thousands of Acres	*K*	*P* for Edge	Thousands of Acres	*K*	*K* Int.	*K* Edge	*K'*
DNR MMMA	LTS	0.25	3.5	5	0.70	0.8	1	0.25	0.0	0	0.70	0.0	0	5	1	6
	UDS	0.36	4.9	10	0.70	0.9	1	0.25	0.0	0	0.70	0.0	0	10	1	12
	BDS	0.47	8.8	24	0.70	1.2	2	0.25	0.0	0	0.70	0.0	0	24	2	27
	NDS	0.62	20.7	75	0.70	2.6	7	0.25	0.0	0	0.70	0.0	0	75	7	82
	FFS	0.89	0.6	3	0.70	0.1	0	0.25	0.0	0	0.70	0.0	0	3	0	4
	Total		38.5	119		5.6	11		0.0	0		0.0	0	119	11	130
DNR Non-MMMA	LTS	0.25	6.9	10	0.70	4.1	4	0.25	9.6	4	0.70	3.8	1	14	5	19
	UDS	0.36	8.9	19	0.70	6.3	9	0.25	17.2	9	0.70	7.2	3	28	12	40
	BDS	0.47	5.3	15	0.70	3.4	7	0.25	8.6	6	0.70	2.7	1	21	8	29
	NDS	0.62	4.9	18	0.70	2.1	5	0.25	5.6	5	0.70	2.1	1	23	7	29
	FFS	0.89	2.8	14	0.70	1.9	7	0.25	4.8	6	0.70	0.9	1	21	8	28
	Total		28.7	76		17.8	32		45.8	30		16.6	7	106	39	145
DNR Total			**67.2**	**194**		**23.4**	**44**		**45.8**	**30**		**16.6**	**7**	**224**	**51**	**275**
Federal	Existing	0.68	0.5	2	0.70	0.0	0	0.25	0.0	0	0.70	0.0	0	2	0	2
	Projected	0.20	0.9	1	0.70	0.1	0	0.25	0.0	0	0.70	0.0	0	1	0	1
	Total		**1.4**	**3**		**0.1**	**0**		**0.0**	**0**		**0.0**	**0**	**3**	**0**	**3**
Other	Existing	0.31	69.5	127	0.70	75.0	96	0.25	12.4	6	0.70	22.6	7	132	103	235
	Projected	0.13	102.4	78	0.70	223.2	119	0.25	10.2	2	0.70	64.4	9	80	128	208
	Total		**171.8**	**205**		**298.2**	**215**		**22.6**	**8**		**87.0**	**16**	**213**	**231**	**444**
Total			240.4	402		321.7	259		68.4	38		103.6	23	440	282	722

Note: values for acres, *K*, and *K'* may not sum due to rounding.

Table G-2E. OESF 2004—No Management Scenario. Current and Projected Future Habitat Abundance (Thousands of Acres) and Capability of Forests to Support Marbled Murrelet Populations (*K′*) (See Section II in Chapter 4.0 for Description of No Management Scenario).

			Interior		Edge			
Land	Stage	*P* for Stage	Thousands of Acres	*K*	*P* for Edge	Thousands of Acres	*K*	*K'*
DNR MMMA	LTS	0.25	0.2	0	0.70	0.1	0	0
	UDS	0.36	1.3	3	0.70	0.3	0	3
	BDS	0.47	2.7	7	0.70	0.5	1	8
	NDS	0.62	5.4	20	0.70	1.0	3	22
	FFS	0.89	0.4	2	0.70	0.1	0	2
	Total		10.1	33		2.0	4	37
DNR Non-MMMA	LTS	0.25	6.4	9	0.70	1.5	2	11
	UDS	0.36	7.0	15	0.70	1.6	2	17
	BDS	0.47	14.0	39	0.70	3.2	6	45
	NDS	0.62	17.6	64	0.70	2.9	7	72
	FFS	0.89	4.6	24	0.70	0.6	2	26
	Total		49.5	151		9.8	20	171
DNR Total			**59.6**	**183**		**11.8**	**24**	**207**
Federal	Existing	0.68	203.2	813	0.70	79.3	222	1,035
Other	Existing	0.31	29.3	53	0.70	30.2	39	92
Total			292.1	1,050		121.3	285	1,335

Note: values for acres, *K*, and *K′* may not sum due to rounding.

Table G-2F. OESF 2013—No Management Scenario. Current and Projected Future Habitat Abundance (Thousands of Acres) and Capability of Forests to Support Marbled Murrelet Populations (*K'*) (See Section II in Chapter 4.0 for Description of No Management Scenario).

			Interior		Edge			
Land	Stage	*P* for Stage	Thousands of Acres	*K*	*P* for Edge	Thousands of Acres	*K*	*K'*
DNR MMMA	LTS	0.25	0.2	0	0.70	0.1	0	0
	UDS	0.36	1.4	3	0.70	0.3	0	3
	BDS	0.47	2.9	8	0.70	0.5	1	9
	NDS	0.62	6.6	24	0.70	0.7	2	26
	FFS	0.89	0.9	4	0.70	0.1	0	5
	Total		12.0	40		1.6	3	43
DNR Non-MMMA	LTS	0.25	6.3	9	0.70	1.9	2	11
	UDS	0.36	6.1	13	0.70	2.2	3	16
	BDS	0.47	12.3	34	0.70	3.1	6	40
	NDS	0.62	14.7	54	0.70	1.6	4	58
	FFS	0.89	12.0	63	0.70	1.2	4	67
	Total		51.5	173		10.1	20	193
DNR Total			**63.5**	**213**		**11.7**	**23**	**236**
Federal	Existing	0.68	203.3	813	0.70	79.3	222	1,035
	Projected	0.20	39.8	47	0.70	3.8	3	50
	Total		**243.1**	**860**		**83.1**	**225**	**1,085**
Other	Existing	0.31	29.3	53	0.70	30.2	39	92
	Projected	0.13	11.4	9	0.70	12.3	7	15
	Total		**40.7**	**62**		**42.5**	**45**	**107**
Total			347.3	1,135		137.3	294	1,429

Note: values for acres, *K*, and *K'* may not sum due to rounding.

Table G-2G. OESF 2031—No Management Scenario. Current and Projected Future Habitat Abundance (Thousands of Acres) and Capability of Forests to Support Marbled Murrelet Populations (*K'*) (See Section II in Chapter 4.0 for Description of No Management Scenario).

			Interior		Edge			
Land	Stage	*P* for Stage	Thousands of Acres	*K*	*P* for Edge	Thousands of Acres	*K*	*K'*
DNR MMMA	LTS	0.25	0.6	1	0.70	0.2	0	1
	UDS	0.36	1.1	2	0.70	0.3	0	3
	BDS	0.47	2.3	6	0.70	0.3	1	7
	NDS	0.62	8.7	32	0.70	0.7	2	34
	FFS	0.89	2.0	10	0.70	0.1	0	11
	Total		14.7	52		1.7	4	55
DNR Non-MMMA	LTS	0.25	5.3	8	0.70	1.7	2	10
	UDS	0.36	6.9	15	0.70	1.9	3	17
	BDS	0.47	13.4	37	0.70	2.8	5	42
	NDS	0.62	19.7	72	0.70	1.8	5	76
	FFS	0.89	14.7	77	0.70	1.0	4	80
	Total		60.0	208		9.2	18	226
DNR Total			**74.7**	**260**		**10.9**	**22**	**282**
Federal	Existing	0.68	206.8	827	0.70	75.7	212	1,039
	Projected	0.20	82.3	97	0.70	1.6	1	98
	Total		**289.1**	**924**		**77.3**	**213**	**1,137**
Other	Existing	0.31	30.4	56	0.70	29.1	37	93
	Projected	0.13	23.1	18	0.70	46.4	25	42
	Total		**53.5**	**73**		**75.5**	**62**	**135**
Total			417.3	1,257		163.7	297	1,554

Note: values for acres, *K*, and *K'* may not sum due to rounding.

Table G-2H. OESF 2067—No Management Scenario. Current and Projected Future Habitat Abundance (Thousands of Acres) and Capability of Forests to Support Marbled Murrelet Populations (*K'*) (See Section II in Chapter 4.0 for Description of No Management Scenario).

			Interior		Edge			
Land	Stage	*P* for Stage	Thousands of Acres	*K*	*P* for Edge	Thousands of Acres	*K*	*K'*
DNR MMMA	LTS	0.25	0.2	0	0.70	0.2	0	0
	UDS	0.36	5.0	11	0.70	1.5	2	13
	BDS	0.47	4.5	12	0.70	1.1	2	14
	NDS	0.62	11.6	42	0.70	1.4	3	46
	FFS	0.89	5.2	27	0.70	0.4	1	29
	Total		26.5	93		4.5	9	102
DNR Non-MMMA	LTS	0.25	27.8	41	0.70	9.3	10	50
	UDS	0.36	9.0	19	0.70	3.6	5	24
	BDS	0.47	13.7	38	0.70	4.1	8	46
	NDS	0.62	18.6	68	0.70	2.5	6	74
	FFS	0.89	22.7	119	0.70	1.5	6	124
	Total		91.9	285		20.9	35	319
DNR Total			**118.4**	**378**		**25.4**	**44**	**422**
Federal	Existing	0.68	206.7	827	0.70	75.8	212	1,039
	Projected	0.20	96.1	113	0.70	2.2	2	115
	Total		**302.8**	**940**		**78.0**	**214**	**1,154**
Other	Existing	0.31	30.4	55	0.70	29.1	37	93
	Projected	0.13	26.0	20	0.70	62.1	33	53
	Total		**56.4**	**75**		**91.2**	**70**	**146**
Total			477.65	1,393		194.7	329	1,722

Note: values for acres, *K*, and *K'* may not sum due to rounding.

Table G-2I. Straits 2004—No Management Scenario. Current and Projected Future Habitat Abundance (Thousands of Acres) and Capability of Forests to Support Marbled Murrelet Populations (*K′*) (See Section II in Chapter 4.0 for Description of No Management Scenario).

			Interior		Edge			
Land	Stage	*P* for Stage	Thousands of Acres	*K*	*P* for Edge	Thousands of Acres	*K*	*K'*
DNR Non-MMMA	LTS	0.25	6.4	9	0.70	2.1	2	12
	UDS	0.36	17.7	38	0.70	3.6	5	43
	BDS	0.47	16.6	46	0.70	5.0	10	56
	NDS	0.62	0.1	1	0.70	0.0	0	1
	FFS	0.89	0.0	0	0.70	0.0	0	0
	Total		**40.8**	**93**		**10.8**	**17**	**111**
Federal	Existing	0.68	193.2	773	0.70	93.0	260	1,033
Other	Existing	0.31	13.9	25	0.70	24.1	31	56
Total			248.0	892		127.9	309	1,200

Note: values for acres, *K*, and *K′* may not sum due to rounding.

Table G-2J. Straits 2013—No Management Scenario. Current and Projected Future Habitat Abundance (Thousands of Acres) and Capability of Forests to Support Marbled Murrelet Populations (*K′*) (See Section II in Chapter 4.0 for Description of No Management Scenario).

			Interior		Edge			
Land	Stage	*P* for Stage	Thousands of Acres	*K*	*P* for Edge	Thousands Of Acres	*K*	*K'*
DNR Non-MMMA	LTS	0.25	5.0	7	0.70	2.6	3	10
	UDS	0.36	13.1	28	0.70	5.1	8	35
	BDS	0.47	11.5	32	0.70	5.4	10	42
	NDS	0.62	0.9	3	0.70	0.6	1	5
	FFS	0.89	0.0	0	0.70	0.0	0	0
	Total		**30.5**	**70**		**13.7**	**22**	**92**
Federal	Existing	0.68	193.1	772	0.70	93.1	261	1,033
	Projected	0.20	50.9	60	0.70	4.4	4	64
	Total		**244.0**	**832**		**97.5**	**264**	**1,097**
Other	Existing	0.31	13.8	25	0.70	24.2	31	56
	Projected	0.13	1.3	1	0.70	2.7	1	2
	Total		**15.1**	**26**		**26.9**	**32**	**59**
Total			289.7	929		138.1	319	1,248

Note: values for acres, *K*, and *K′* may not sum due to rounding.

Table G-2K. Straits 2031—No Management Scenario. Current and Projected Future Habitat Abundance (thousands of acres) and Capability of Forests to Support Marbled Murrelet Populations (*K'*) (See Section II in Chapter 4.0 for Description of No Management Scenario).

Land	Stage	*P* for Stage	Interior: Thousands of Acres	Interior: *K*	Edge: *P* for Edge	Edge: Thousands of Acres	Edge: *K*	*K'*
DNR Non-MMMA	LTS	0.25	3.4	5	0.70	1.8	2	7
	UDS	0.36	9.1	19	0.70	4.3	6	26
	BDS	0.47	13.5	37	0.70	4.0	8	45
	NDS	0.62	6.1	22	0.70	2.7	7	29
	FFS	0.89	0.0	0	0.70	0.0	0	0
	Total		**32.2**	**84**		**12.8**	**23**	**107**
Federal	Existing	0.68	199.4	798	0.70	86.8	243	1,041
	Projected	0.20	99.5	117	0.70	6.5	5	122
	Total		**299.0**	**915**		**93.4**	**248**	**1,163**
Other	Existing	0.31	14.2	26	0.70	23.8	30	56
	Projected	0.13	5.1	4	0.70	18.1	10	14
	Total		**19.3**	**30**		**41.9**	**40**	**70**
Total			350.4	1,029		148.1	311	1,340

Note: values for acres, *K*, and *K'* may not sum due to rounding.

Table G-2L. Straits 2067—No Management Scenario. Current and Projected Future Habitat Abundance (Thousands of Acres) and Capability of Forests to Support Marbled Murrelet Populations (*K'*) (See Section II in Chapter 4.0 for Description of No Management Scenario).

Land	Stage	*P* for Stage	Interior: Thousands of Acres	Interior: *K*	Edge: *P* for Edge	Edge: Thousands of Acres	Edge: *K*	*K'*
DNR Non-MMMA	LTS	0.25	4.2	6	0.70	1.7	2	8
	UDS	0.36	15.0	32	0.70	6.0	9	41
	BDS	0.47	12.2	34	0.70	4.4	8	42
	NDS	0.62	1.7	6	0.70	0.6	2	8
	FFS	0.89	5.6	29	0.70	1.9	7	36
	Total		**38.8**	**108**		**14.6**	**28**	**135**
Federal	Existing	0.68	199.5	798	0.70	86.7	243	1,041
	Projected	0.20	117.4	138	0.70	8.4	7	145
	Total		**316.9**	**936**		**95.2**	**250**	**1,186**
Other	Existing	0.31	14.2	26	0.70	23.8	30	56
	Projected	0.13	6.5	5	0.70	28.1	15	20
	Total		**20.7**	**31**		**52.0**	**45**	**76**
Total			376.4	1,075		161.7	323	1,397

Note: values for acres, *K*, and *K'* may not sum due to rounding.

II. REPORTING RESULTS FOR HABITAT ACREAGE AND POTENTIAL HABITAT CAPABILITY (*K'*) FROM MANAGEMENT SCENARIO ANALYSIS

There are three reasons for differences in how acres and potential habitat capability (*K'*) are reported by SDS category and P_{stage} in this document and how they were projected in the management scenario analysis:

1. Stands that had at one time been forest plantations were assigned a P_{stage} of 0.25 in 2067 if they were dominated by western hemlock or western redcedar, regardless of SDS category
2. Douglas-fir dominated stands were projected to transition among P_{stages} at a slower rate (per Figure 4-3 in chapter 4.0)
3. Some DNR-managed lands do not have SDS classification available; thus IVMP data were used for these lands and classified using Green et al. (1993) in the same way as was done for the non-DNR-managed lands (see section 4.4 in chapter 4.0)

Details of these differences are outlined below.

G.1 Western Hemlock or Western Redcedar Plantations

Stands that had at one time been forest plantations were assigned a P_{stage} value of 0.00, regardless of SDS category; however, in 2067, they were assigned a P_{stage} value of 0.25 if they were dominated by western hemlock or western redcedar. Thus, there are some acres of several SDS categories included in the P_{stage} category of 0.25. This is discussed in section 4.6 in chapter 4.0.

G.2 Douglas-Fir Dominated Stands

Douglas-fir dominated stands were projected to transition among P_{stage} values at a slower rate than stands of other species (see Figure 4-3 in chapter 4.0); thus Douglas-fir dominated stands were assigned a lower P_{stage} value for each SDS category. To simplify the presentation, in Tables G-1 and G-2 (as well as Table 5-1 in chapter 5.0), all acres of Douglas-fir dominated stands were included with their matching P_{stage} value regardless of SDS category (see Table G-3). See Tables G-6 and G-7 for a breakdown of total acres for every combination of SDS category and P_{stage} value in all three analysis units and all four time periods for the Habitat Management scenario and No Management scenario, respectively. The projection of these stands in the management scenario analysis is discussed in section 4.6 in chapter 4.0.

Table G-3. Crosswalk for Habitat Acres in Douglas-Fir Dominated Stands Projected in the Management Scenario Analysis as Compared to Reported Acres by SDS Category and P_{stage} Value in Tables 5-1, G-1 and G-2.

Projected in Management Scenario Analysis		**Reported in Tables 5-1, G-1 and G-2**	
Stand Development Stage	P_{stage} value	Stand Development Stage	P_{stage} value
Understory Development	0.25	Large Tree Exclusion	0.25
Botanically Diverse	0.25	Large Tree Exclusion	0.25
Botanically Diverse	0.36	Understory Development	0.36
Niche Diversification	0.25	Large Tree Exclusion	0.25
Niche Diversification	0.47	Botanically Diverse	0.47
Fully Functional	0.62	Niche Diversification	0.62

G.3 DNR-Managed Lands without SDS Classification

Some DNR-managed lands do not have SDS data available, primarily road rights-of-ways and lands for which DNR has no forest inventory data. Thus, IVMP data were used in those areas and classified using Green et al. (1993) in the same way as was done for the non-DNR-managed lands (see section 4.4 in chapter 4.0). To simplify the presentation, in Table 5-1 and the G-1 and G-2 tables, the acres of both existing and projected IVMP Late-Seral forests were reported with the 0.25 and 0.36 P_{stage} values (Large Tree Exclusion and Understory Development, respectively) (Table G-4). See Tables G-6 and G-7 for a summary of total acres for IVMP Late-Seral forest stages on DNR-managed lands for all three analysis units and all four time periods for the Habitat Management scenario and No Management scenario, respectively.

In order to represent the acres to which a 0.31 P_{stage} value was assigned to IVMP Existing Late-Seral forests (see section 4.4 in chapter 4.0), approximately half of the acres were included with the 0.25 P_{stage} value (Large Tree Exclusion) and approximately half of the acres were included with the 0.36 P_{stage} value (Understory Development). In order to represent the acres to which a 0.13 P_{stage} value was assigned to Projected IVMP Late-Seral forests (see section 4.5 in chapter 4.0), approximately half of the acres were included with the 0.25 P_{stage} value (Large Tree Exclusion).

Table G-4. Crosswalk for Habitat Acres on DNR-Managed Lands without SDS Classification Projected in the Management Scenario Analysis as Compared to Reported Acres by SDS Category and P_{stage} Value in Tables G-1, G-2, and 5-1 (in Chapter 5.0).

Projected in Management Scenario Analysis		**Reported in Tables 5-1, G-1, and G-2**	
IVMP class	P_{stage} value	SDS (proportion attributed)	P_{stage} value
Late-Seral (Existing)	0.31	Large Tree Exclusion (half)	0.25
		Understory Development (half)	0.36
Late-Seral (Projected)	0.13	Large Tree Exclusion (half)	0.25
		Not reported in table (half)	0.00

To simplify three figures in chapter 5.0 (Figures 5-4, 5-6, and 5-8) only five forest stand development stages are indicated to contribute to *K′* totals. However, the IVMP Existing and Projected Late-Seral forests also contribute to *K′* on DNR-managed lands, and the *K′* from those Late-Seral forests is included in the Large Tree Exclusion and Understory Development categories in the figures (Table G-5). See Tables G-8 and G-9 for a summary of *K′* for IVMP Late-Seral forests on DNR-managed lands in all three analysis units and all four time periods for the Habitat Management and No Management scenarios, respectively. Half of the total *K′* created on Existing IVMP Late-Seral forests is reported with the Large Tree Exclusion category, and half is reported with the Understory Development category. All *K′* created on IVMP Projected Late-Seral forests was included with the Large Tree Exclusion category.

Table G-5. Crosswalk for *K'* on DNR-Managed Lands without SDS Classification Projected in the Management Scenario Analysis Compared to that Reported by SDS Category in Figures 5-4, 5-6, and 5-8 (in Chapter 5.0).

IVMP class for which *K'* is calculated for Management Scenario Analysis	**SDS within which *K'* is reported in Figures 5-4, 5-6, and 5-8**
Late-Seral (Existing)	Large Tree Exclusion (half) Understory Development (half)
Late-Seral (Projected)	Large Tree Exclusion (all)

Table G-6. Acreages of Current and Projected Future Habitat on DNR-Managed Forests by Forest Stage and P_{stage} Value for Four Time Periods for the Three Analysis Units under the Habitat Management Scenario.

		Acres of DNR-Managed Forest											
		SWWA				Straits				OESF			
Forest Stage	P_{stage}	2004	2013	2031	2067	2004	2013	2031	2067	2004	2013	2031	2067
Existing Late-Seral	0.31	3,230	3,230	3,230	3,230	1,379	1,379	1,379	1,379	1,486	1,486	1,486	1,486
Projected Late-Seral	0.13	0	1,846	4,762	6,332	0	162	722	1,174	0	328	1,232	1,573
LTS	0.25	49,473	36,061	24,408	19,683	7,815	6,877	4,089	4,282	7,409	7,453	6,133	18,739
UDS	0.25	0	0	0	947	0	0	0	204	0	0	0	15,026
	0.36	42,039	39,770	33,983	43,871	20,638	17,462	12,780	20,303	9,431	9,226	9,209	17,957
BDS	0.25	0	0	0	257	0	0	0	137	0	0	0	1,862
	0.36	0	0	7,421	2	0	0	0	0	0	0	259	0
	0.47	29,526	25,220	28,761	29,590	21,647	16,957	17,530	16,592	20,480	18,896	18,752	23,509
NDS	0.47	0	0	2,874	649	0	0	0	0	0	0	514	55
	0.62	868	3,440	19,440	32,622	152	1,475	8,801	2,360	26,897	23,688	30,981	32,931
FFS	0.62	0	0	0	902	0	0	0	0	0	0	0	8
	0.89	123	230	424	22,043	5	4	20	7,517	5,643	14,144	17,728	30,551
Total		125,259	109,797	125,303	160,131	51,637	44,316	45,320	53,948	71,345	75,221	86,293	143,698

Table G-7. Acreages of Current and Projected Future Habitat on DNR-Managed Forests by Forest Stage and P_{stage} value for Four Time Periods for the Three Analysis Units under the No Management Scenario.

Forest Stage	P_{stage}	Acres of DNR-Managed Forest											
		SWWA				Straits				OESF			
		2004	2013	2031	2067	2004	2013	2031	2067	2004	2013	2031	2067
Existing Late-Seral	0.31	3,230	3,230	3,230	3,230	1,379	1,379	1,379	1,379	1,486	1,486	1,486	1,486
Projected Late-Seral	0.13	0	1,846	4,762	6,332	0	162	722	1,174	0	328	1,232	1,573
LTS	0.25	49,473	37,696	31,961	22,598	7,815	6,877	4,089	4,282	7,409	7,629	6,454	19,014
UDS	0.25	0	0	0	947	0	0	0	204	0	0	0	15,026
	0.36	42,039	39,770	35,520	43,640	20,638	17,462	12,780	20,303	9,431	9,229	9,442	18,392
BDS	0.25	0	0	0	257	0	0	0	137	0	0	0	1,862
	0.47	29,526	25,220	28,908	30,072	21,647	16,957	17,530	16,592	20,480	18,896	18,827	23,399
NDS	0.62	868	3,440	19,543	37,877	152	1,475	8,801	2,360	26,897	23,688	30,981	34,097
FFS	0.89	123	230	424	11,035	5	4	20	7,517	5,643	14,144	17,728	29,772
Total		125,259	111,432	124,348	155,989	51,637	44,316	45,320	53,948	71,345	75,400	86,149	144,622

Table G-8. Total *K'* of Current and Projected Future Habitat on DNR-Managed Forests by Forest Stage and P_{stage} Value for Four Time Periods for the Three Analysis Units under the Habitat Management Scenario.

Forest Stage	P_{stage}	Potential Habitat Capability (*K'*)											
		SWWA				Straits				OESF			
		2004	2013	2031	2067	2004	2013	2031	2067	2004	2013	2031	2067
Existing Late-Seral	0.31	3	3	3	3	2	2	2	2	2	2	2	2
Projected Late-Seral	0.13	0	1	3	4	0	0	0	1	0	0	1	1
LTS	0.25	42	31	23	15	11	9	5	6	10	10	9	25
UDS	0.25	0	0	0	1	0	0	0	0	0	0	0	21
	0.36	53	43	39	49	42	34	25	39	19	18	18	35
BDS	0.25	0	0	0	0	0	0	0	0	0	0	0	3
	0.36	0	0	15	0	0	0	0	0	0	0	1	0
	0.47	49	40	52	53	56	42	45	42	54	49	49	60
NDS	0.47	0	0	8	2	0	0	0	0	0	0	1	0
	0.62	3	10	50	92	1	5	29	8	94	84	110	114
FFS	0.62	0	0	0	3	0	0	0	0	0	0	0	0
	0.89	1	1	2	86	0	0	0	36	28	72	91	154
Total		151	128	195	308	111	92	107	135	207	236	282	414

Table G-9. Total *K'* of Current and Projected Future Habitat on DNR-Managed Forests by Forest Stage and P_{stage} Value for Four Time Periods for the Three Analysis Units under the No Management Scenario.

Forest Stage	P_{stage}	Potential Habitat Capability (*K'*)											
		SWWA				Straits				OESF			
		2004	2013	2031	2067	2004	2013	2031	2067	2004	2013	2031	2067
Existing Late-Seral	0.31	3	3	3	3	2	2	2	2	2	2	2	2
Projected Late-Seral	0.13	0	1	3	4	0	0	0	1	0	0	1	1
LTS	0.25	42	33	34	19	11	9	5	6	10	11	9	26
UDS	0.25	0	0	0	1	0	0	0	0	0	0	0	21
	0.36	53	43	42	50	42	34	25	39	19	18	19	36
BDS	0.25	0	0	0	0	0	0	0	0	0	0	0	3
	0.47	49	40	52	55	56	42	45	42	54	49	49	60
NDS	0.62	3	10	50	111	1	5	29	8	94	84	110	120
FFS	0.89	1	1	2	32	0	0	0	36	28	72	91	153
Total		151	131	187	275	111	92	107	135	207	236	282	422

APPENDIX H

MARBLED MURRELET POTENTIAL HABITAT CAPABILITY (*K'*) MODEL SENSITIVITY ANALYSIS

H.1 Introduction

Sensitivity analyses are conducted to identify how variation in the output of a mathematical model can be allocated to different sources of uncertainty in the input of the model (Chatterjee and Hadi 1988). To address uncertainty in the definition of the marbled murrelet potential habitat capability (*K'*) model component estimates and/or the validity of model assumptions, we completed a sensitivity analysis to identify the components of the *K'* model (see chapter 4.0 for *K'* model rationale and methodology) where estimation uncertainty would most greatly affect the final calculation of potential habitat capability (*K'*).

The magnitude of three sources of model input uncertainty warranted further investigation through a sensitivity analysis:

1. Estimation uncertainty regarding the influence of stand development on the capability of habitat to support marbled murrelets for each unique stand development stage (hereafter referred to as proportional influence values, which includes all P_{stage} values for DNR-managed land, existing Late-Seral habitat on Federally managed land, and plantation projected Late-Seral habitat for Other ownerships; see Appendix B for descriptions of stand development stages)
2. Estimation uncertainty for proportional influence coefficients corresponding with edge habitat and habitat greater than 40 miles from marine waters with a high density of marbled murrelets (marbled murrelet-dense marine waters)
3. Classification accuracy of acreage determined to be marbled murrelet habitat

H.2 Methods

H.2a Uncertainty Regarding the Proportional Influence of Stand Development on Potential Habitat Capability

In the *K′* model, the proportional influence values and multipliers were not always the result of mathematical calculations; therefore, the magnitude of uncertainty for their estimates was unknown.

As a result, we chose a standard amount of variation to compare the relative sensitivity of model components. There was no rationale for assigning different magnitudes of potential estimation uncertainty to different stand development stages. Therefore we assumed that each proportional influence value (associated with each unique forest development stage and ownership combination and ranging from 0.13 to 0.89) had the same potential magnitude of estimation uncertainty. To simulate a constant estimation uncertainty for each proportional influence value of the *K'* calculation, we added random normal variation with a standard deviation of 0.05 to each of the unique proportional influence values for the developmental stage and ownership combinations. We calculated a distribution of *K'* for individual variation of each proportional influence value by adding random variation to the selected proportional influence value and running the model through 10,000 iterations while recording each output value of *K'*. We did not construct confidence intervals around the *K'* estimate and instead report the standard deviation of the distribution of *K'* as a sensitivity index to eliminate confusion regarding the purpose of analysis results. The random normal variation with a standard deviation of 0.05 was consistent across all proportional influence values, allowing the results to be reported as a relative index that can be compared among model components and analysis units.

Sensitivity analyses for estimation uncertainty of proportional influence values (P_{stage} values) were completed at all simulated time steps (decades 0, 1, 3 and 7) using acreage values (DNR unpublished data) from the Habitat Management scenario (see section 4.14 in chapter 4.0 for description).

H.2b Uncertainty Regarding the Proportional Influence of Edge Habitat and Habitat Greater than 40 Miles Inland

To investigate the *K'* calculation's sensitivity to uncertainty in the estimation of the proportional influence multipliers for edge habitat (P_{edge}; 0.7 for acreage within 164 feet (50 meters) of an early seral edge; see section 4.8) and distance from marine foraging areas ($P_{>40}$; 0.25 for lands > 40 miles [64 kilometers] from marbled murrelet-dense marine waters; see section 4.10), the P_{edge}, and $P_{>40}$ multipliers were varied using the parameters of the random normal distribution with a standard deviation of 0.05.

We report sensitivity index values for proportional influence multipliers (P_{edge} and $P_{>40}$) as the standard deviation of the *K'* distribution resulting from the 10,000 iteration simulations. We combined this analysis across ownerships and only report the cumulative sensitivity index values in order to assess the sensitivity of the *K'* estimate in the P_{edge} and $P_{>40}$ estimates. We completed sensitivity analyses for the multipliers at all simulated time steps (decades 0, 1, 3 and 7) by using acreage values (DNR unpublished data) from the Habitat Management scenario (see section 4.14 in chapter 4.0 for description). A sensitivity analysis for the $P_{>40}$ multiplier was only completed for the SWWA Analysis Unit, which was the only analysis unit with marbled murrelet habitat identified more than 40 miles (64 kilometers) from marbled murrelet-dense marine waters.

H.2c Uncertainty in the Classification of Habitat Acreage

Estimation uncertainty in determining the total acreage of existing habitat in each of the stand development stages was likely proportional to the total acreage in the stage. The most probable manifestation of acreage estimation uncertainty would be to classify acreage as a developmental stage above or below the realized stage. Therefore, to assess the relative influence of acreage estimation uncertainty from any of the DNR stand development stages, we transferred 10% of the acreage within each stand development stage to the development stage above or below at random. We repeated this process for acreage in each stand development stage on DNR-managed land with two exceptions:

1. Ten percent of the acreage in the Large Tree stand development stage (the lowest of the five DNR stages considered to be marbled murrelet habitat; P_{stage}=0.25) was allowed at random (approximately 50% of the time) to go to the stage above (Understory Development; P_{stage}=0.36) or (approximately 50% of the time) become non-habitat (P_{stage}=0)

2. Ten percent of the acreage in the Fully Functional stand development stage (P_{stage}=0.89) was allowed at random (approximately 50% of the time) to go to the stage below or remain in the Fully Functional habitat stage (approximately 50% of the time)

Two habitat designations suitable for marbled murrelet occupancy existed for non-DNR-managed lands. As a result of fewer identified stand development stages, and larger differences in the proportional influence values between stages on non-DNR–managed land, the magnitude of classification uncertainty for Late-Seral designated habitat was assumed to be larger. As a result, we varied classification of acreage from the existing Late-Seral designation (Federally managed land and Other ownerships) more significantly than acreage within DNR stand development stages. However, any habitat acreage classification error would originate from GIS data layer discrepancies that we assumed would be consistent across all ownerships. Therefore, the frequency of uncertainty in classifying the structural stage would likely be the same. We shifted 10% of the acreage in existing Late-Seral habitat from Federally managed land (P=0.68) at random to Fully Functional habitat (P=0.89) or Botanically Diverse habitat (P=0.47). The change in proportional influence for the habitat that was shifted was ± 21% as compared with the ± 15% average within DNR-managed lands. Likewise, we multiplied 10% of existing Late-Seral habitat in Other ownerships by proportional influence values 21% above and below (at random) the designated P_{stage} value of 0.31 (i.e., 0.10 and 0.52). We report sensitivity index values as the standard deviation of the *K'* distribution resulting from 10,000 iterations of the model. We used Habitat Management scenario (see section 4.14 in chapter 4.0 for description) acreage values (DNR unpublished data) for all analyses. The original habitat acreage classification was completed for current conditions. Any estimation uncertainty would only have occurred at time step 0 and therefore the acreage classification analysis was not modeled through simulation decades 1, 3, and 7.

H.2d Sensitivity Index Comparison between Analyses

The magnitudes of the sensitivity index values for both P_{stage} and habitat classification analyses were driven by the amount each was varied. Because we set the allowable variation as equal for each of the *K'* model components within the proportional influence analyses, sensitivity index values could be directly compared, with higher sensitivity index values reflecting greater model component sensitivity (i.e., uncertainty in the component estimate will cause greater bias in the final estimate of *K'*). Although the proportional influence values and multipliers were varied by a fixed amount (random normal variation with SD=0.05), there was no justification for a comparable threshold for the acreage classification analysis. As a result of this limitation, direct comparison of the sensitivity index values between the acreage classification analysis and the proportional influence analysis was not possible. However, because components from each analysis unit were varied using the same criteria within each of the separate analyses, we were able to calculate a cumulative sensitivity index value for analysis unit-ownership combinations, allowing proportional comparison of sensitivity indices among analysis units.

H.3 Results

H.3a Relative Effects of Uncertainty Regarding the Proportional Influence on Potential Habitat Capability of Stand Development, Edge Habitat, and Habitat Greater than 40 Miles Inland

Southwest Washington (SWWA)

In the SWWA Analysis Unit, the *K'* estimate was most sensitive to the estimation of proportional influence values for the existing and projected Late-Seral habitat in Other ownerships (non-DNR; non-Federal) (Sensitivity Index [SI]=25.84; Table H-1). The percent of the cumulative P_{stage} sensitivity index corresponding to Late Seral habitat in Other ownerships ranged from 63.2-75.5% and increased for each subsequent simulation decade (Figure H-1). The percentages were calculated by dividing the sum of the sensitivity index values for existing and projected habitat on Other ownerships by the cumulative sensitivity index for the decade. On DNR-managed land, the highest sensitivity index values in simulation decade zero were in the Large Tree and Understory Development stand development stages (SI=5.70 and 5.14 respectively; Table H-1; Figure H-2). The highest levels of sensitivity for P_{stage} value estimation shift to increasingly older stand development stages through the four simulation decades (Table H-1; Figure H-2). In simulation decade seven, the estimation of the P_{stage} value for the Niche Diversification stand development stage has the highest influence on potential *K'* model variation (SI=6.01; Table H-1; Figure H-2). The Federally managed land in SWWA totals only 0.2% of the total habitat acreage, ranging from roughly 450-1450 acres (182-587 hectares) depending on the simulation decade. As a result, the sensitivity of the *K'* estimate to variation of the proportional influence values associated with Federal habitat was comparatively low. The

Table H-1. *K'* Model Component Proportional Influence Sensitivity Index Values and the Percent of Analysis Unit Total Acreage for the SWWA Analysis Unit by Decade of Simulation, Proportional Influence Value and Multiplier (see Appendix B for descriptions of stand development stages).

		MULTIPLIERS		DNR						FEDERAL		OTHER		Cumulative Sensitivity Index (excluding multipliers)
		Edge	Ocean	LTS	UDS	BDS	NDS	FFS	ALL	Existing	Projected	Existing	Projected	
Decade of Simulation		0.70	0.25	P_{stage} 0.25	0.36	0.47	0.62	0.89	Sub-Total	0.68	0.20	0.31	0.13	
0	Sensitivity Index	7.21	3.66	5.70	5.14	3.83	0.20	0.03	14.90	0.13	NA	25.84	NA	**40.87**
	% of total unit acreage	42.12	32.29	16.38	13.92	9.78	0.29	0.04	40.41	0.16	NA	59.43	NA	
1	Sensitivity Index	7.75	3.06	3.68	3.51	2.65	0.60	0.06	10.50	0.13	0.12	16.29	12.06	**39.10**
	% of total unit acreage	49.89	24.14	8.86	9.77	6.20	0.85	0.06	25.73	0.12	0.11	44.10	29.94	
3	Sensitivity Index	8.69	3.04	3.39	3.45	4.29	3.23	0.11	14.47	0.14	0.25	15.95	29.95	**60.76**
	% of total unit acreage	52.95	21.42	4.29	5.97	6.36	3.92	0.07	20.62	0.08	0.16	31.54	47.60	
7	Sensitivity Index	11.14	3.83	1.81	4.10	3.73	6.01	3.71	19.36	0.14	0.26	15.49	45.03	**80.28**
	% of total unit acreage	58.36	23.19	2.69	6.13	4.08	4.55	3.14	20.58	0.07	0.13	24.53	54.69	

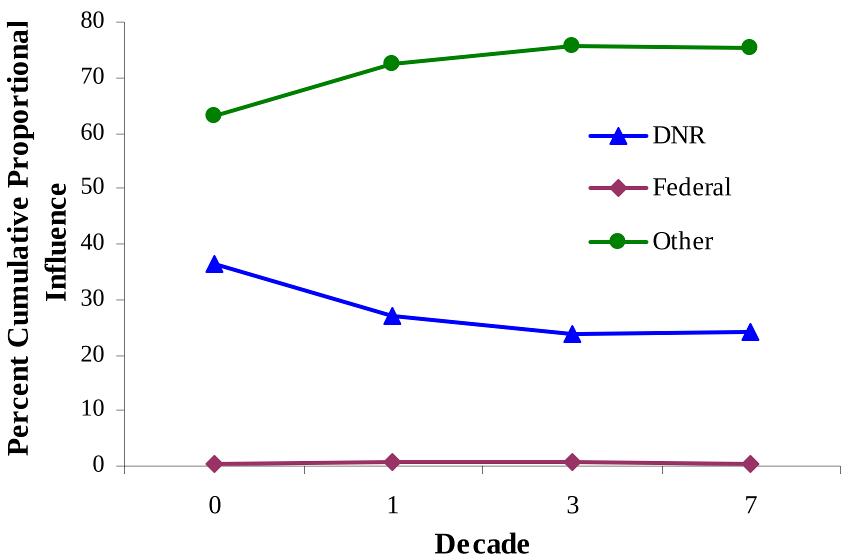


Figure H-1. Percent of the Cumulative Proportional Influence Sensitivity Index Corresponding to each Ownership in the SWWA Analysis Unit (excluding P_{edge} and $P_{>40}$).

proportional influence multiplier associated with edge habitat was more sensitive to uncertainty throughout all four simulation decades than the proportional influence multiplier associated with habitat greater than 40 miles (64 kilometers) from marbled murrelet-dense marine waters (Table H-1). The sensitivity index for the proportional influence multiplier associated with edge habitat increased through each subsequent simulation decade (Table H-1).

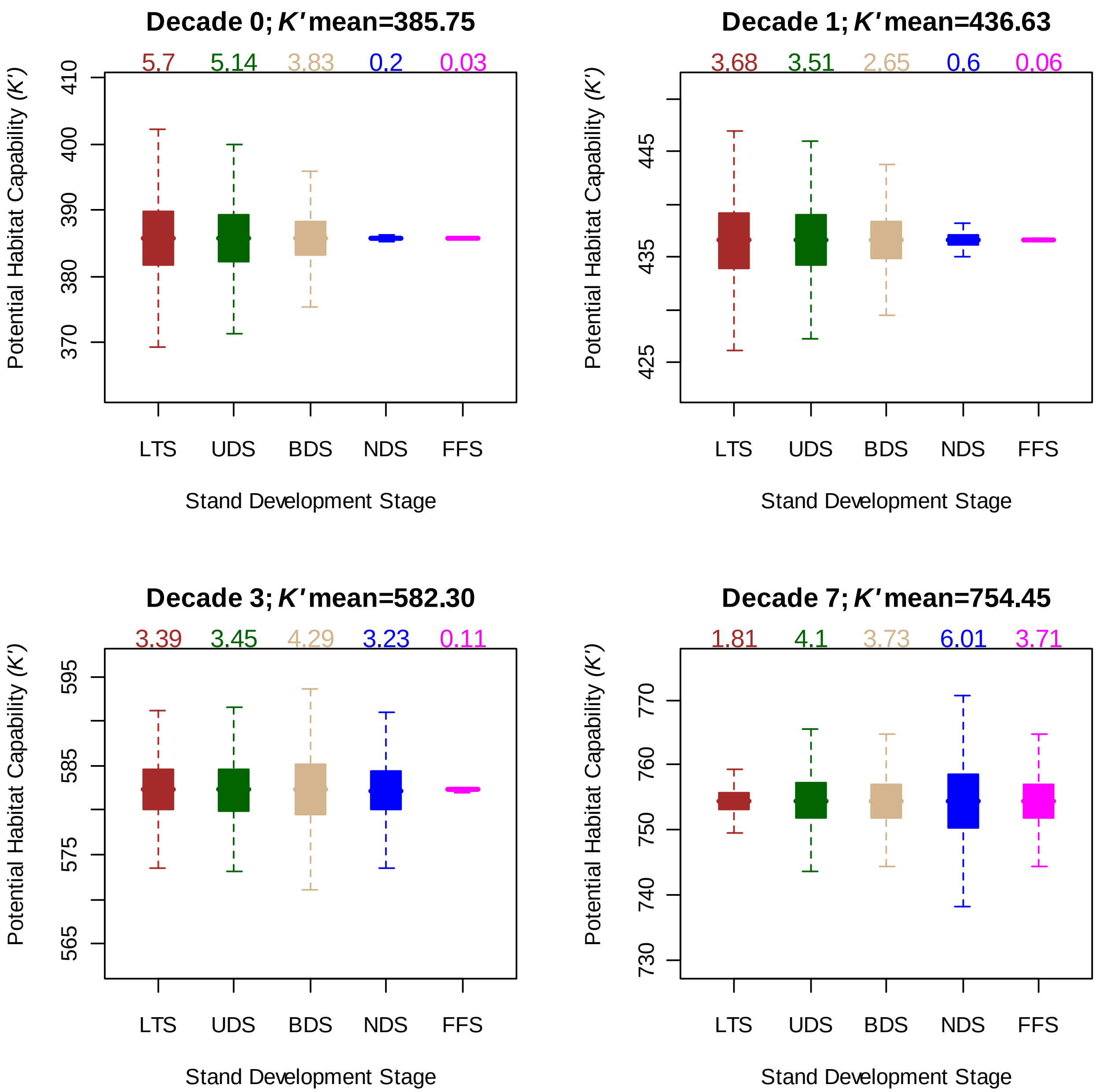


Figure H-2. *K'* Variation and Resulting Sensitivity Index Values for DNR-Managed Land within the SWWA Analysis Unit by Decade of Simulation and Stand Development Stage (see Appendix B for descriptions of stand development stages).

Olympic Experimental State Forest (OESF)

In the OESF Analysis Unit, the *K'* estimate was most sensitive to the estimation of proportional influence values for the existing and projected Late-Seral habitat on Federally managed land (Table H-2). The percent of the cumulative P_{stage} sensitivity index corresponding to Late Seral habitat in Federally managed ownerships ranged from 62.5-69.2% and remained fairly consistent throughout all simulation decades (Figure H-3). Within DNR ownership, the P_{stage} value for the Niche Diversification stand development stage retained the highest sensitivity index values in all simulation decades (Table H-2; Figure H-4). The P_{stage} value associated with Fully Functional habitat also plays an increasingly significant role in total model sensitivity through each successive simulation decade (Table H-2; Figure H-4). The sensitivity of the proportional influence multiplier associated with edge habitat remained relatively consistent through each subsequent simulation decade (Table H-2).

Table H-2. *K'* Model Component Proportional Influence Sensitivity Index Values and the Percent of Analysis Unit Total Acreage for the OESF Analysis Unit by Decade of Simulation, Proportional Influence Value and Multiplier (see Appendix B for descriptions of stand development stages).

		MULTI-PLIER	DNR						FEDERAL		OTHER		Cumulative Sensitivity Index (excluding edge multiplier)
		Edge	LTS	UDS	BDS	NDS	FFS	All	Exist-ing	Project-ed	Exist-ing	Project-ed	
Decade of Simulation			P_{stage}					Sub-Total					
		0.70	0.25	0.36	0.47	0.62	0.89		0.68	0.20	0.31	0.13	
0	Sensitivity Index	16.2	1.86	2.39	4.99	6.76	1.47	17.47	62.90	NA	10.55	NA	**90.92**
	% of total unit acreage	39.75	1.80	2.29	4.97	6.53	1.37	16.96	68.59	NA	14.45	NA	
1	Sensitivity Index	16.35	1.77	2.15	4.56	6.28	3.83	18.59	62.53	11.78	10.66	4.22	**107.78**
	% of total unit acreage	28.27	1.54	1.91	3.91	4.91	2.93	15.20	58.52	9.03	12.33	4.91	
3	Sensitivity Index	15.74	1.52	2.24	4.57	8.42	4.93	21.68	63.50	23.89	10.74	11.72	**131.53**
	% of total unit acreage	28.11	1.06	1.59	3.28	5.44	3.06	14.43	48.80	14.49	10.28	12.00	
7	Sensitivity Index	15.69	4.13	3.88	5.19	8.14	7.88	29.22	62.63	28.88	10.78	14.96	**146.47**
	% of total unit acreage	29.80	2.80	4.93	3.79	4.93	4.57	21.02	42.23	14.69	8.90	13.16	

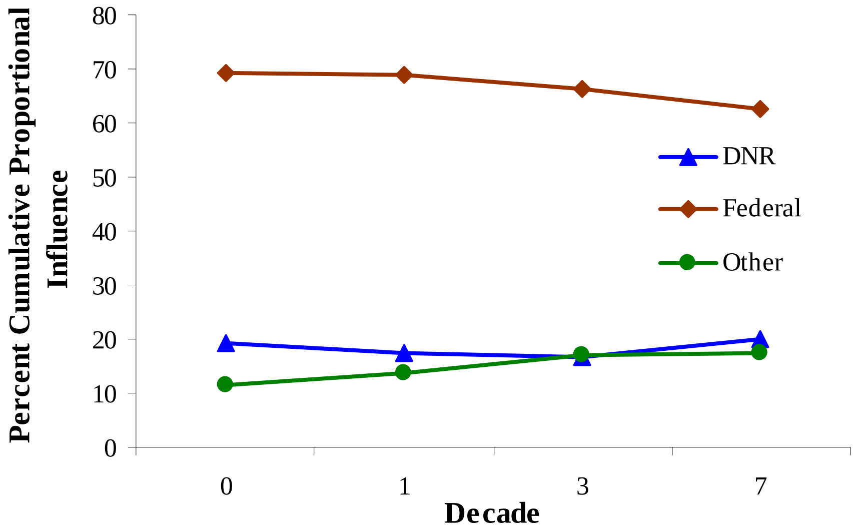


Figure H-3. Percent of the Cumulative Proportional Influence Sensitivity Index Corresponding to each Ownership in the OESF Analysis Unit (excluding P_{edge}).

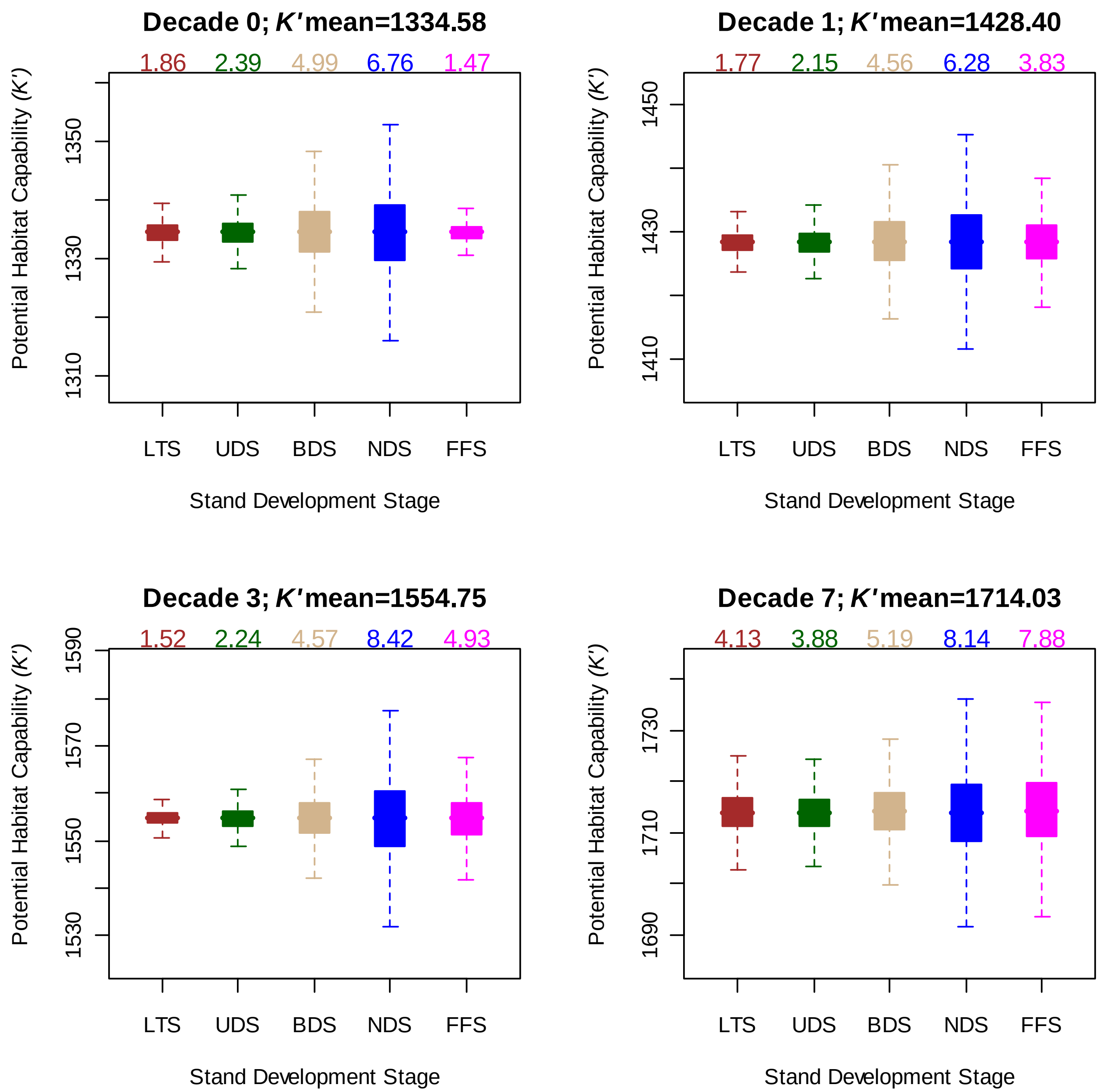


Figure H-4. *K'* Variation and Resulting Sensitivity Index Values for DNR-Managed Land within the OESF Analysis Unit by Decade of Simulation and Stand Development Stage (see Appendix B for descriptions of stand development stages).

Straits

In the Straits Analysis Unit, the *K'* estimate was most sensitive to the estimation of proportional influence values for the existing and projected Late-Seral habitat on Federally managed land (Table H-3). The percent of the cumulative P_{stage} sensitivity index corresponding to Late Seral habitat on Federally managed land ranged from 76.4-82.2% (Figure H-5). For DNR-managed

Table H-3. *K'* Model Component Proportional Influence Sensitivity Index Values and the Percent of Analysis Unit Total Acreage for the Straits Analysis Unit by Decade of Simulation, Proportional Influence Value and Multiplier (see Appendix B for descriptions of stand development stages).

		MULTI-PLIER	DNR						FEDERAL		OTHER		Cumulative Sensitivity Index (excluding edge multiplier)
		Edge	LTS	UDS	BDS	NDS	FFS	ALL	Exist-ing	Project-ed	Exist-ing	Project-ed	
Decade of Simulation		0.70	P_{stage} 0.25	0.36	0.47	0.62	0.89	Sub-Total	0.68	0.20	0.31	0.13	
0	Sensitivity Index	18.85	1.83	5.17	5.01	0.04	0.00	12.05	59.84	NA	6.47	NA	**78.36**
	% of total unit acreage	41.91	2.09	5.51	5.78	0.04	0.00	13.42	76.42	NA	10.16	NA	
1	Sensitivity Index	18.52	1.43	3.82	3.58	0.29	0.00	9.12	60.15	14.99	6.47	0.67	**91.40**
	% of total unit acreage	32.19	1.61	4.10	3.98	0.35	0.00	10.03	67.13	12.97	8.92	0.94	
3	Sensitivity Index	17.53	0.89	2.75	4.07	1.88	0.00	9.59	61.85	29.43	6.46	3.98	**111.31**
	% of total unit acreage	29.60	0.82	2.57	3.53	1.77	0.00	8.70	57.61	21.36	7.66	4.66	
7	Sensitivity Index	17.45	0.99	4.51	3.74	0.52	1.73	11.49	61.37	34.77	6.36	6.13	**120.12**
	% of total unit acreage	29.97	0.80	3.82	3.12	0.44	1.40	9.59	53.38	23.47	7.10	6.46	

land, the P_{stage} value for the Understory Development and Botanically Diverse stand development stages retained the highest sensitivity index values in all simulation decades (Table H-3; Figure H-6). The sensitivity of the proportional influence multiplier associated with edge habitat remained relatively consistent through each of the simulation decades even though the percent of total analysis unit habitat acreage in edge decreased (Table H-3).

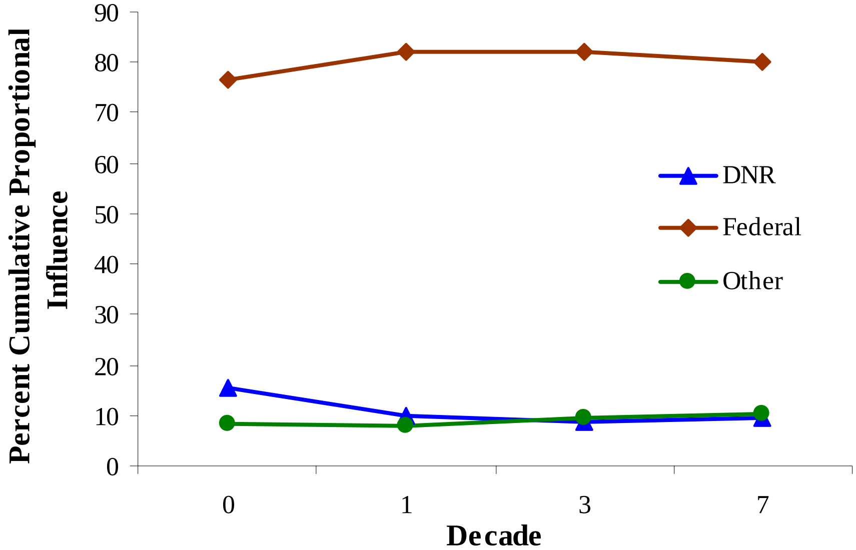


Figure H-5. Percent of the Cumulative Proportional Influence Sensitivity Index Corresponding to each Ownership in the Straits Analysis Unit (excluding P_{edge}).

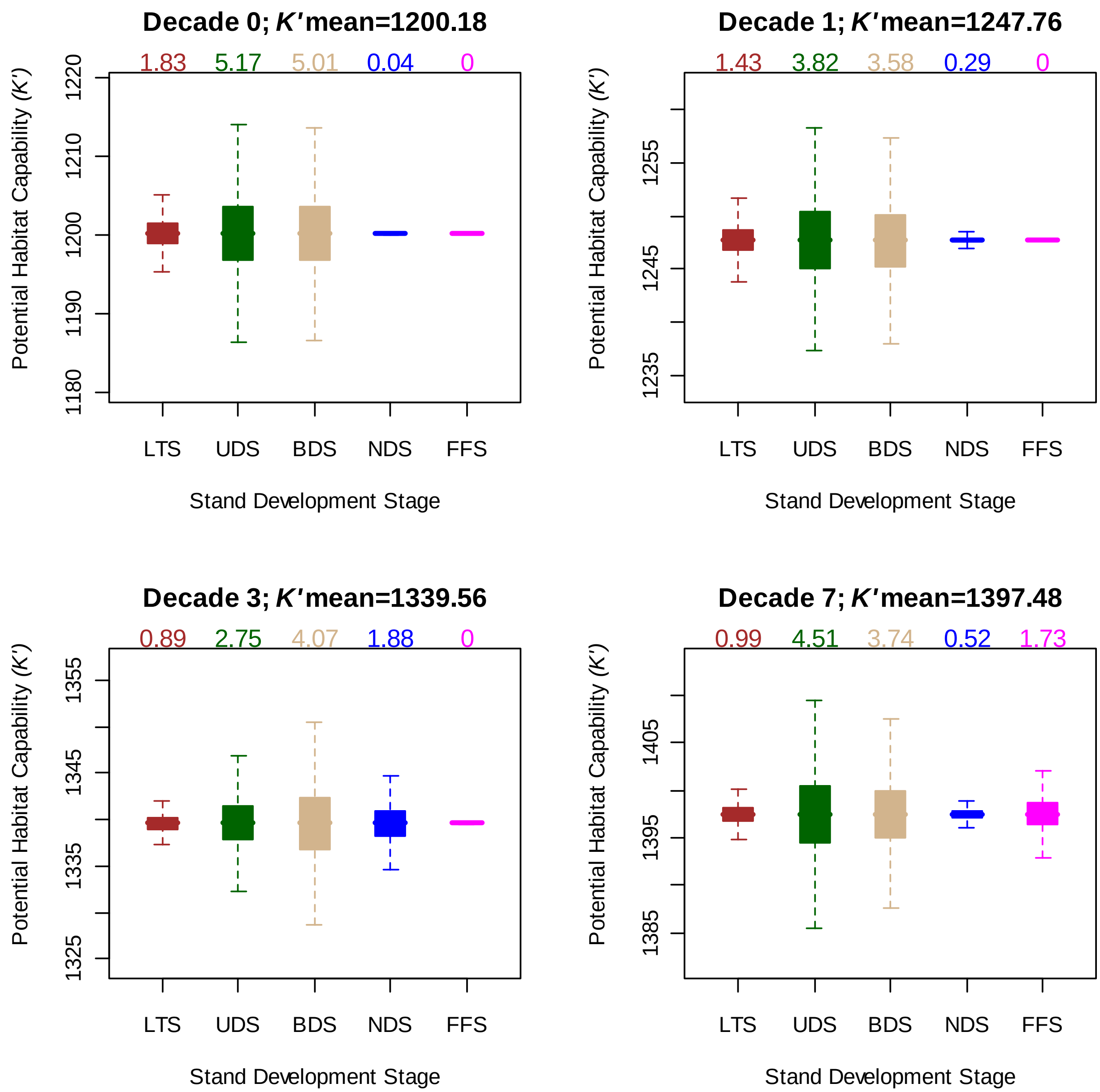


Figure H-6. *K'* Variation and Resulting Sensitivity Index Values for DNR-Managed Land within the Straits Analysis Unit by Decade of Simulation and Stand Development Stage (see Appendix B for descriptions of stand development stages).

H.3b Relative Effects of Uncertainty in the Classification of Habitat Acreage

In the SWWA Analysis Unit, the *K'* estimate was most sensitive to habitat acreage classification uncertainty in existing Late-Seral habitat designations in Other ownerships (Table H-4). In the OESF and Straits Analysis Units the *K'* estimate was most sensitive to habitat acreage classification uncertainty in existing Late-Seral habitat on Federally managed land (Table H-4). As expected, the OESF Analysis Unit, which had the largest total acreage of defined marbled

Table H-4. *K'* Model Component Habitat Acreage Classification Sensitivity Index Values and the Percent of the Total Habitat Acreage (from all three analysis units) Associated with each Proportional Influence Value by Analysis Unit (see Appendix B for descriptions of stand development stages).

		DNR						FEDERAL	OTHER	Cumulative Sensitivity Index
		LTS	UDS	BDS	NDS	FFS	ALL	Existing	Existing	
Analysis Unit		P_{stage} 0.25	0.36	0.47	0.62	0.89	Sub-Total	0.68	0.31	
SWWA	Sensitivity Index	3.03	1.61	1.36	0.10	0.01	6.11	0.06	15.8	**21.97**
	% of total acreage	4.55	3.86	2.71	0.08	0.01	11.21	0.04	16.49	**27.74**
OESF	Sensitivity Index	0.75	0.58	1.48	3.18	0.43	6.42	31.96	6.24	**44.62**
	% of total acreage	0.68	0.87	1.88	2.47	0.52	6.42	25.96	5.47	**37.85**
Straits	Sensitivity Index	0.77	1.27	1.54	0.02	0.00	3.60	31.91	3.81	**39.32**
	% of total acreage	0.72	1.90	1.99	0.01	0.00	4.62	26.30	3.50	**34.41**

murrelet habitat, also had the highest cumulative sensitivity index values for habitat acreage classification uncertainty totaled across all ownerships. On DNR-managed land, *K'* had comparatively higher sensitivity to habitat acreage classification uncertainty in the Large Tree stand development stage in the SWWA Analysis Unit, the Niche Diversification stand development stage in the OESF Analysis Unit, and the Botanically Diverse stand development stage in the Straits Analysis Unit (Table H-4; Figure H-7).

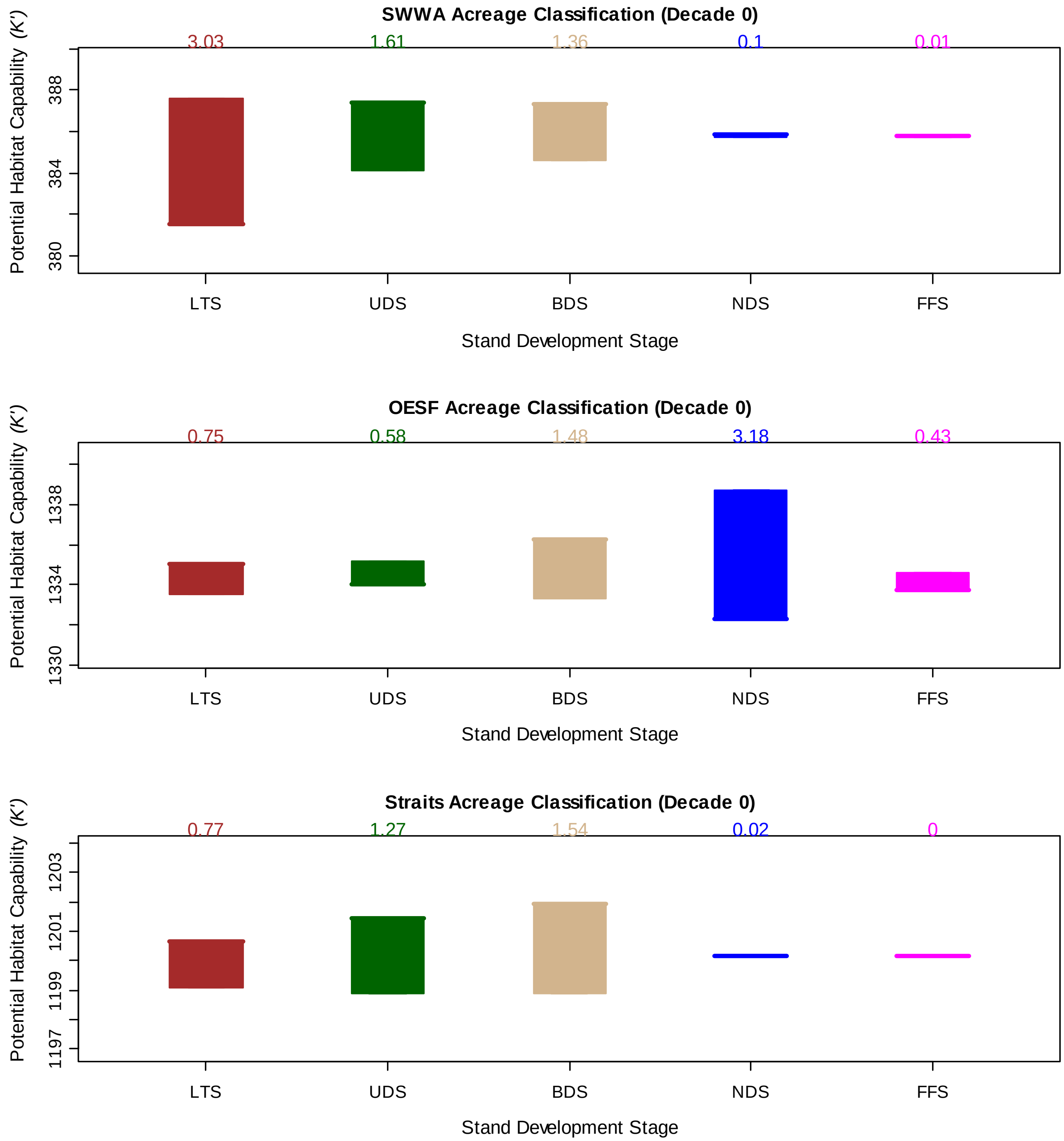


Figure H-7. *K'* Variation and Resulting Habitat Acreage Classification Sensitivity Index Values for DNR-Managed Land within each Analysis Unit by Stand Development Stage (see Appendix B for descriptions of stand development stages).

H.3c Cumulative Sensitivity Index Comparisons

Cumulative Model Sensitivity Indices increase with each subsequent simulation decade, suggesting, as it might be expected, that estimation or classification uncertainty compounds

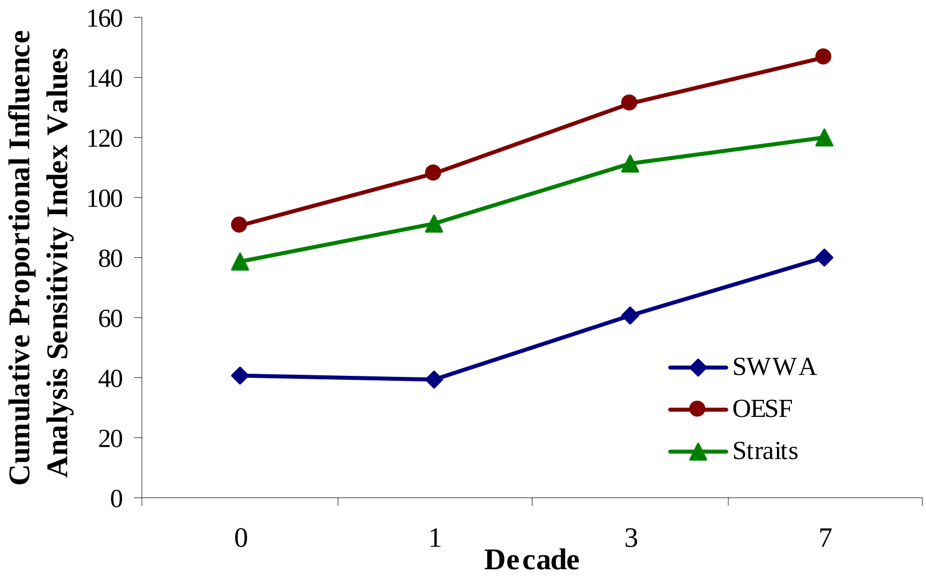


Figure H-8. Cumulative *K'* Model Sensitivity Index Values for Proportional Influence Analyses by Analysis Unit across Simulation Decades.

through time (Figure H-8). The acreage classification analysis cumulative sensitivity index values remained approximately eight percent of the total sensitivity for each analysis unit (TableH-5; Figures H-9, H-10 and H-11). In the SWWA Analysis Unit, the model components where estimation or classification uncertainty would weigh most heavily on the resulting estimate of *K'* are the proportional influence values from Other ownerships (including proportional influence values for existing and projected Late-Seral habitat designations) (Table H-5; Figure H-9). In the OESF and Straits Analysis Units, the model components where estimation or classification uncertainty would weight most heavily on the resulting estimate of *K'* are the proportional influence values from Federally managed land (including proportional influence values for existing and projected Late-Seral habitat designations) (Table H-5; Figures H-10 and H-11).

Table H-5. *K'* Model Component Cumulative Sensitivity Index Values for all Analysis Units by Decade of Simulation and Analysis Type.

Analysis Unit	Analysis Type	Decade	Proportional Influence Multipliers	DNR	Federal	Other	Cumulative Sensitivity Index
SWWA	**Proportional Influence**	**0**	10.87	14.90	0.13	25.84	**40.87**
		1	10.81	10.50	0.25	28.35	**39.10**
		3	11.73	14.47	0.39	45.90	**60.76**
		7	14.97	19.36	0.40	60.52	**80.28**
		All Decades	**48.38**	**59.23**	**1.17**	**160.61**	**221.01**
	Acreage Classification	**0**		6.11	0.06	15.80	**21.97**
OESF	**Proportional Influence**	**0**	16.20	17.47	62.90	10.55	**90.92**
		1	16.35	18.59	74.31	14.88	**107.78**
		3	15.74	21.68	87.39	22.46	**131.53**
		7	15.69	29.22	91.51	25.74	**146.47**
		All Decades	**63.98**	**86.96**	**316.11**	**73.63**	**476.70**
	Acreage Classification	**0**		6.42	31.96	6.24	**44.62**
Straits	**Proportional Influence**	**0**	18.85	12.05	59.84	6.47	**78.36**
		1	18.52	9.12	75.14	7.14	**91.40**
		3	17.53	9.59	91.28	10.44	**111.31**
		7	17.45	11.49	96.14	12.49	**120.12**
		All Decades	**72.35**	**42.25**	**322.40**	**36.54**	**401.19**
	Acreage Classification	**0**		3.60	31.91	3.81	**39.32**

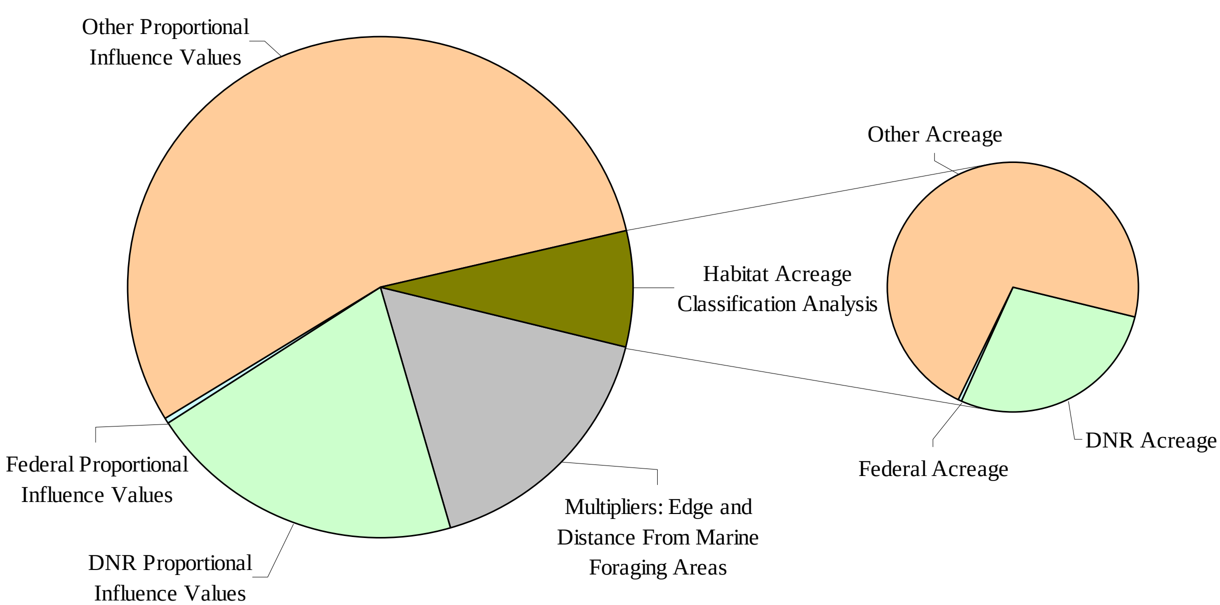


Figure H-9. *K'* Variation and Resulting Sensitivity Index Values for All Ownerships within the SWWA Analysis Unit by Analysis Type (proportional influence, multipliers and habitat acreage classification).

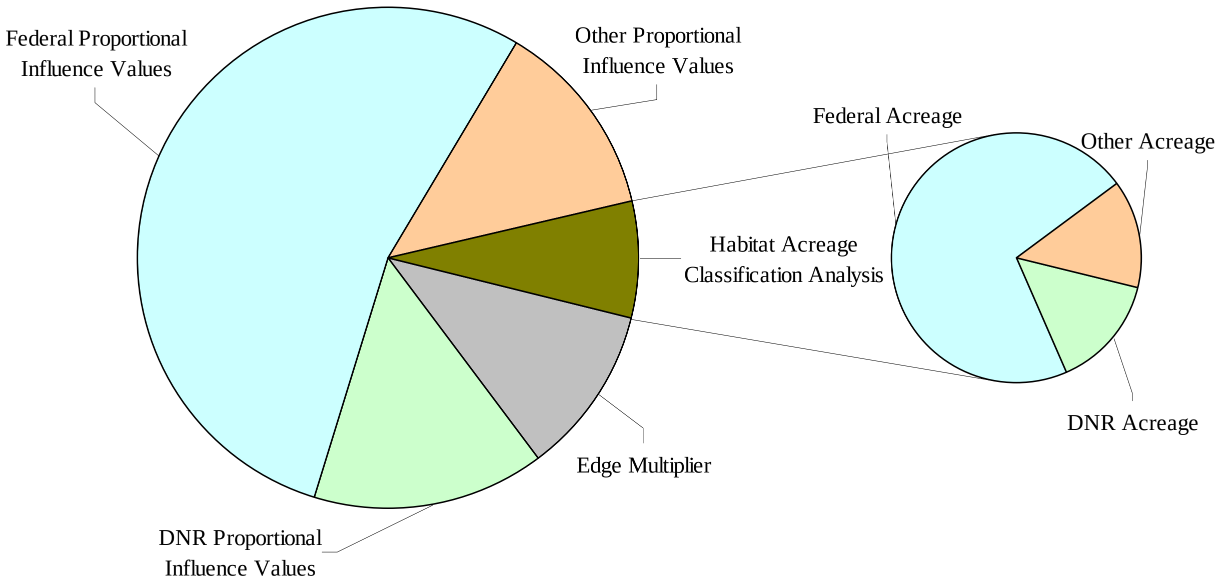


Figure H-10. *K'* Variation and Resulting Sensitivity Index Values for All Ownerships within the OESF Analysis Unit by Analysis Type (proportional influence, multipliers and habitat acreage classification).

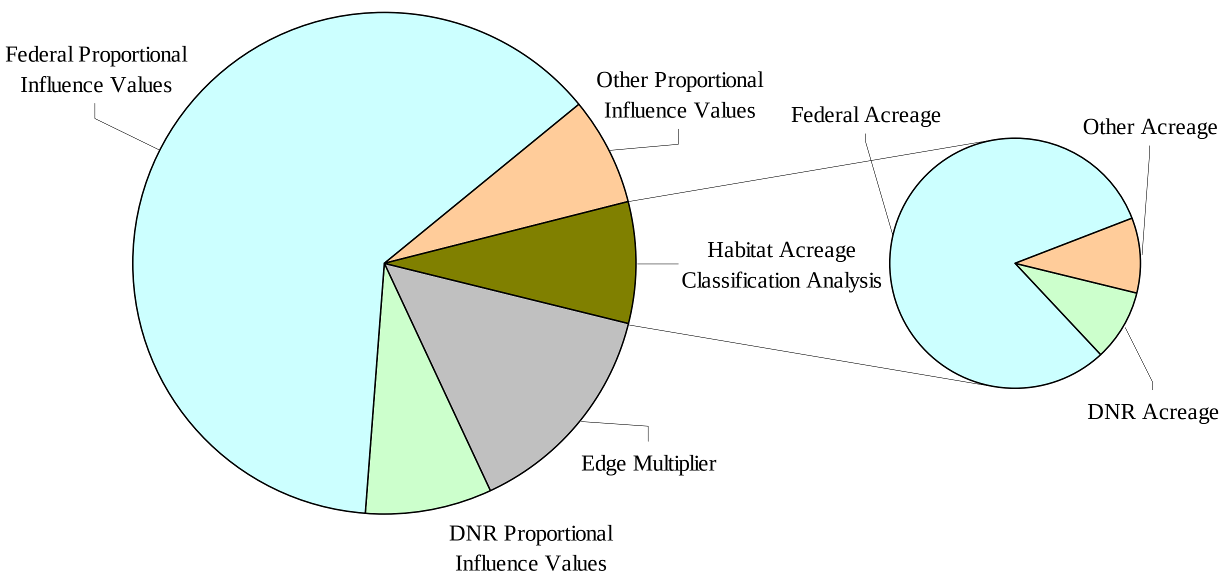


Figure H-11. *K'* Variation and Resulting Sensitivity Index Values for All Ownerships within the Straits Analysis Unit by Analysis Type (proportional influence, multipliers and habitat acreage classification).

H.4 Discussion and Conclusion

The sensitivity analysis of the marbled murrelet potential habitat capability (*K'*) model does not evaluate the model as a whole, but instead describes which components of the model weigh most heavily in the reported outcome. The output of the sensitivity analysis is comparable relative to other model components. The results should be used to add an additional level of transparency to chapters 4.0 and 5.0. Therefore, the sensitivity analysis discussion and conclusion follows the general order of the summary and discussion of *K'* analysis hypotheses and assumptions as described in chapter 5.0 (section 5.5).

1. **Habitat area**

   Assumption: 170 acres (69 hectares) of forest habitat per marbled murrelet approximates an ecological density or carrying capacity in Washington.

   Application of Sensitivity Analysis Results: The sensitivity analysis for the *K'* calculation does not address concerns of uncertainty for the 170 acres of habitat per marbled murrelet assumption. Any estimation uncertainty regarding this assumption would simply result in a linear adjustment of the current, calculated *K'*.

2. **Stand characteristics**

   Assumption: Forest stands that were assigned a certain growth stage have a consistent abundance of nesting platforms and complexity of canopy structure allowing designation of unique proportional influence values for marbled murrelets for each forest growth stage–ownership combination.

   Application of Sensitivity Analysis Results: The magnitude of *K'* sensitivity resulting from uncertainty in the estimation of each of the proportional influence values for each analysis unit–ownership–simulation decade combination is discussed below:

   » In the **SWWA** Analysis Unit, uncertainty in the estimation of proportional influence values for Other ownerships (non-Federal, non-DNR-managed land) is likely to produce the most variation in the calculated estimate of *K'*. However, DNR-managed land (13% of the total acreage in the analysis unit) make up approximately 40% of the current habitat acreage in SWWA (Table H-1).

   - For DNR-managed land, uncertainty in the proportional influence values for the Large Tree and Understory Development stages have the largest effect on the estimation of potential habitat capability (*K'*) at decade 0 and simulation decade 1.

Subsequently (simulation decade 3 and 7), the weight of influence on *K'* shifts to a more even spread across all stand development stages, except Fully Functional.

- Estimation uncertainty for the Federal proportional influence values has little effect (0.3 to 0.6% of the cumulative analysis unit proportional influence value sensitivity index) on the sensitivity of *K'* for the SWWA Analysis Unit through each of the simulation years due to the small amount of Federal acreage within the analysis unit (Figure H-1 and H-9).
- The percent of total *K'* sensitivity resulting from proportional influence values for Other ownerships increases through simulation decade 3, leveling for decade 7 (Figure H-1).
- Existing marbled murrelet habitat acreage on Other ownerships was estimated to have a comparatively low P_{stage} value (0.31). We chose to vary this P_{stage} value within the same parameters as the other stand development stage ownership combinations (random normal with SD=0.05) for the sake of consistency and comparison. However, because of the magnitude of *K'* sensitivity associated with this model component, we discovered that the estimate of *K'* for SWWA depends heavily on this average P_{stage} value that has been designated for all existing marbled murrelet habitat on Other ownerships. Therefore, it is important to note that the acreage included under this umbrella proportional influence designation occurs across several land owners with a wide variety of forest practices, thus suggesting a potential reduction in confidence of the cumulative potential habitat capability estimate for SWWA.

» In the **OESF** Analysis Unit, uncertainty in the estimation of proportional influence values for Federal lands is likely to have the largest effect on variation in the calculated estimate of *K'*.

- On DNR-managed land, uncertainty in the proportional influence values for the Niche Diversification stand development stage has the largest effect on the estimation of potential habitat capability (*K'*) across all time steps. The Botanically Diverse stand development stage carries substantial influence at decade 0 and simulation decade 1, and the Fully Functional stage plays a larger role in simulation decades 3 and 7. The cumulative percent of total *K'* sensitivity from P_{stage} estimation uncertainty represented by DNR-managed land ranges from approximately 16-20% (Figure H-3).

- The percent of total *K'* sensitivity resulting from proportional influence values for Federally managed land declines slightly from 69.5% to 62.5% through the four simulation decades (Figure H-3).
- Estimation uncertainty for Other ownership proportional influence values is similar to the sum total of P_{stage} uncertainty on DNR lands on the sensitivity of *K'* for the OESF Analysis Unit and increases slightly through each of the simulation decades (Figure H-3 and H-10).

» In the **Straits** Analysis Unit, uncertainty in the estimation of proportional influence values for Federal lands is likely to have the largest effect on variation of *K'*.

- On DNR-managed land, uncertainty in the proportional influence values for the Understory Development and Botanically Diverse stand development stages have the largest effect on the estimation of potential habitat capability (*K'*) across all time steps. The cumulative percent of total *K'* sensitivity from P_{stage} estimation uncertainty represented by DNR-managed land ranges from approximately 9-15% (Figure H-5).
- The percent of total *K'* sensitivity resulting from proportional influence values for Federally managed land in the Straits Analysis Unit increases through simulation decade 3 and then decreases slightly in decade 7 (Figure H-5).
- The sensitivity of *K'* is similarly affected by estimation uncertainty for Other ownership proportional influence values and proportional influence values from DNR-managed land within the Straits Analysis Unit through each of the simulation decades (Figure H-5 and H-11).

» In summary, cumulative *K'* sensitivity within each analysis unit is roughly proportional to projected *K'*. The variation from direct proportionality comes from disparity in the proportions of stand development stage acreage among analysis units, and the unique levels of uncertainty associated with each stand development stage–ownership combination. When total analysis unit habitat acreage is controlled for (i.e., cumulative analysis unit sensitivity values are divided by the total acreage in each analysis unit; viewed as an estimate of sensitivity per acre), the OESF Analysis Unit has the highest proportional cumulative sensitivity.

3. **Forest succession**

Assumption: Forest growth models and ownership databases adequately project the contribution to *K'* by stand development stages.

Application of Sensitivity Analysis Results: The sensitivity analysis describes the varying implications of habitat classification uncertainty by providing the magnitude of *K'* calculation sensitivity corresponding with uncertainty in the classification of habitat acreage within each unique combination of analysis unit, ownership, and stand development stage.

» *K'* sensitivity to habitat acreage classification uncertainty is roughly proportional to habitat acreage values in each forest development stage. There is a larger effect of habitat acreage classification uncertainty on *K'* values in stand development stage-ownership combinations where classification error would lead to designated habitat acreage becoming non-habitat. This includes the Large Tree forest development stage on DNR-managed land and the projected Late-Seral habitat for Other ownerships and Federally managed land.

» In the **SWWA** Analysis Unit, the uncertainty of habitat acreage classification for Other ownerships has the largest potential (71.9% of the cumulative analysis unit habitat acreage classification sensitivity index) to produce variation in *K'* (Figure H-9).

» In **OESF** and **Straits** Analysis Units, the uncertainty of habitat acreage classification for Federally managed land has the largest potential (71.6% and 81.2% of the cumulative analysis unit habitat acreage classification sensitivity index respectively) to produce variation in *K*' (Figures H-10 and H-11).

4. **Edge effects**

Assumption: Edge effects within marbled murrelet inland habitat play a predictably negative role, such that acreage within 164 feet (50 meters) of an early seral edge has 70% of the contribution to *K'* as habitat that is more interior.

Application of Sensitivity Analysis: The sensitivity analysis describes the potential variation of *K'* resulting from estimation uncertainty of the proportional influence multiplier (0.7) resulting from designated habitat acreage being within 164 feet (50 meters) of an early seral stand edge (P_{edge}). The analysis was completed for the cumulative effect of the multiplier across all ownerships within each analysis unit–simulation decade combination. The percentage of the total *K'* sensitivity corresponding to uncertainty in the edge multiplier peaked in decade 0 in the OESF and Straits Analysis Units (Table H-1). The percentage of total SWWA habitat in edge settings increases with each simulation decade from 42.1% to

58.3% (Table H-1). Likewise, sensitivity to the proportional influence multiplier associated with edge habitat increases with each simulation year in SWWA. The estimation of the edge habitat multiplier plays a fairly significant role in the overall variation of *K'*. In the Straits Analysis Unit, uncertainty in the edge multiplier will have more effect on *K'* than the cumulative uncertainty of all DNR proportional influence values combined. In the OESF and SWWA Analysis Units, uncertainty in the edge habitat multiplier has approximately 70% as much potential impact on the variation of *K'* as the does the cumulative uncertainty of all DNR proportional influence values.

5. **Distance from marine foraging areas**

   Assumption: There is a threshold distance of 40 miles (64 kilometers) from marbled murrelet-dense marine waters, beyond which the proportional influence of marbled murrelet inland habitat decreases to 25% of what it would be within 40 miles of marbled murrelet-dense marine waters.

   Application of Sensitivity Analysis: The sensitivity analysis describes the potential variation of *K'* resulting from the estimation uncertainty of the proportional influence multiplier (0.25) resulting from habitat being outside of 40 miles from marbled murrelet-dense marine waters ($P_{>40}$). The SWWA Analysis Unit was the only one with habitat beyond 40 miles from marbled murrelet dense marine waters. The sensitivity of *K'* to the uncertainty in the distance from marine foraging areas multiplier (0.25) was calculated across DNR-managed land and Other ownerships. There was no Federally managed habitat identified outside of 40 miles from marbled murrelet-dense marine waters. The *K'* sensitivity for uncertainty in the distance from foraging areas multiplier was between 35% and 50% of the sensitivity recorded for edge habitat for current day conditions and each of the three simulation decades.

This page intentionally left blank.