U.S. Fish & Wildlife Service

Revised Recovery Plan for the Northern Spotted Owl (*Strix occidentalis caurina*)

Cover photo:

Revised Recovery Plan for the Northern Spotted Owl (*Strix occidentalis caurina*)

Region 1
U.S. Fish and Wildlife Service
Portland, Oregon

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Disclaimer

Recovery plans describe reasonable actions and criteria that are considered necessary to recover listed species. Recovery plans are approved and published by the U.S. Fish and Wildlife Service ("Service" or "we" in narrative, (except as otherwise indicated) "USFWS" in citations, "FWS" in tables) and are sometimes prepared with the assistance of recovery teams, contractors, State agencies, and others. The 2011 Revised Recovery Plan for the Northern Spotted Owl (Revised Recovery Plan) does not necessarily represent the view or official position of any individual or organization—other than that of the Service—involved in its development. Although the northern spotted owl is a subspecies of spotted owl, we sometimes refer to it as a species when discussing it in the context of the ESA or other laws and regulations.

Approved recovery plans are subject to modification as dictated by new findings, changes in species status, and the completion of recovery actions. The objectives in this Revised Recovery Plan will be achieved subject to availability of funding and the capability of the involved parties to participate while addressing other priorities. This Revised Recovery Plan replaces, in its entirety, the 2008 Recovery Plan.

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Electronic Copy

A copy of the Revised Recovery Plan and other related materials can be found at: http://www.fws.gov/species/nso.

Acknowledgments

The Service gratefully acknowledges the effort and commitment of the many individuals involved in the conservation and recovery of the northern spotted owl who participated in the preparation of both the 2008 Recovery Plan and this Revised Recovery Plan. Without their individual expertise and support, this Revised Recovery Plan would not have been possible as it is the culmination of many years of labor. This Revised Recovery Plan is the culmination of many hours of discussion, research and analysis by a large number of scientific experts and managers over several years.

This revision to the 2008 Recovery Plan has been led by the Service and builds upon the efforts of numerous individuals from several different agencies, academia, State governments and private organizations; their names and affiliations are listed in Appendix H. The Service is indebted to all of these individuals for the information provided during the preparation of this Revised Recovery Plan. Their names, affiliations, and roles are listed below. Their participation in the revision process does not imply these contributors or their sponsoring agencies agree with the recommendations and conclusions of this Revised Recovery Plan.

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EXECUTIVE SUMMARY

Current Status

The northern spotted owl (*Strix occidentalis caurina*) (spotted owl) inhabits structurally complex forests from southwest British Columbia through the Cascade Mountains and coastal ranges in Washington, Oregon, and California, as far south as Marin County (Appendix A). After a status review (USFWS 1990a), the spotted owl was listed under the Endangered Species Act (ESA) as threatened on June 26, 1990 (USFWS 1990b) because of widespread loss of spotted owl habitat across the spotted owl's range and the inadequacy of existing regulatory mechanisms to conserve the spotted owl. Past habitat loss and current habitat loss are also threats to the spotted owl, even though loss of habitat due to timber harvest has been greatly reduced on Federal lands over the past two decades. Many populations of spotted owls continue to decline, especially in the northern parts of the subspecies' range, even with extensive maintenance and restoration of spotted owl habitat in recent years. Managing sufficient habitat for the spotted owl now and into the future is important for its recovery. However, it is becoming more evident that securing habitat alone will not recover the spotted owl. Based on the best available scientific information, competition from the barred owl (*S. varia*) poses a significant and complex threat to the spotted owl.

Based on the best available scientific information, competition from the barred owl (*S. varia*) poses a significant threat to the spotted owl.

Habitat Requirements

Scientific research and monitoring indicate spotted owls generally rely on mature and old-growth forests because these habitats contain the structures and characteristics required for nesting, roosting, and foraging. Although spotted owls can disperse through highly fragmented forested areas, the stand-level and landscape-level attributes of forests needed to facilitate successful dispersal have not been thoroughly evaluated or described.

Delisting

In order to consider a species recovered, analysis of five listing factors must be conducted and the threats from those factors reduced or eliminated. The five listing factors are:

A. The present or threatened destruction, modification, or curtailment of the species' habitat or range;
B. Overutilization for commercial, scientific, or educational purposes;
C. Disease or predation;
D. Inadequacy of existing regulatory mechanisms;
E. Other natural or manmade factors affecting its continued existence.

Recovery Strategy

Currently, the most important range-wide threats to the spotted owl are competition with barred owls, ongoing loss of spotted owl habitat as a result of timber harvest, habitat loss or degradation from stand replacing wildfire and other disturbances, and loss of amount and distribution of spotted owl habitat as a result of past activities and disturbances. To address these threats, this recovery strategy includes four basic steps:

1. Completion of a rangewide habitat modeling tool;
2. Habitat conservation and active forest restoration;
3. Barred owl management; and
4. Research and monitoring.

In addition to describing specific actions to address the barred owl threat, this Revised Recovery Plan continues to recognize the importance of maintaining habitat for the recovery and long-term survival of the spotted owl.

The U.S. Fish and Wildlife Service (Service) recognizes the barred owl constitutes a significantly greater threat to spotted owl recovery than was envisioned when the spotted owl was listed in 1990. As a result, the Service recommended in the 2008 Recovery Plan that specific actions to address the barred owl threat begin immediately. These actions are currently underway, and this Revised Recovery Plan builds on these actions.

In addition to describing specific actions to address the barred owl threat, this Revised Recovery Plan continues to recognize the importance of maintaining and restoring high value habitat for the recovery and long-term survival of the spotted owl.

Maintaining and restoring sufficient habitat is important to address the threats the spotted owl faces from a loss of habitat due to harvest, loss or alteration of habitat from stand replacing fire, loss of genetic diversity, and barred owls (Forsman *et al.* 2011). The 2008 Recovery Plan established a network of Managed Owl Conservation Areas (MOCAs) across the range of the species. Based on scientific peer review comments the Service is not incorporating the previously recommended MOCA network into this Revised Recovery Plan. We will update spotted owl critical habitat; in the interim, we recommend land managers continue to implement the standards and guidelines of the Northwest Forest Plan (NWFP) throughout the range of the species, as well as fully consider other recommendations in this Revised Recovery Plan. We also support the updating of existing land management plans.

The estimated time to delist the species is 30 years if all actions are implemented and effective. While the 2008 Recovery Plan identified an interim 10-year timeframe, this revision identifies several actions that will take many years to implement effectively. Therefore, the Service believes that this Revised Recovery Plan can be fully implemented in a 30-year timeframe. A longer time to delisting would be required if these assumptions are not met. Total cost for delisting over these 30 years is $127.1 million (see Section IV; Implementation Schedule and Cost Estimates for specific costs).

Due to the uncertainties associated with the effects of barred owl interactions with the spotted owl and habitat changes that may occur as a result of climate change, the Service intends to implement this Revised Recovery Plan aggressively and will use the 5-year review process to evaluate recovery implementation and success. The Service and other implementers of this Revised Recovery Plan will have to employ an active adaptive management strategy to achieve results and focus on the most important actions for recovery. Adaptive management is a systematic approach for improving resource management by learning from the results of explicit management policies and practices and applying that learning to future management decisions.

After the 2008 Recovery Plan was finalized, an inter-organizational Northern Spotted Owl Recovery Plan implementation structure was established that included multiple interagency recovery implementation teams. This implementation structure will be reevaluated and updated in accordance with this Revised Recovery Plan.

Recovery Goal

The goal of every Recovery Plan is to improve the status of the species so it can be removed from protection under the ESA. The long-term goal for the spotted owl is the same.

Recovery Objectives

The objectives of this Revised Recovery Plan are:

1. Spotted owl populations are sufficiently large and distributed such that the species no longer requires listing under the ESA;
2. Adequate habitat is available for spotted owls and will continue to exist to allow the species to persist without the protection of the ESA; and
3. The effects of threats have been reduced or eliminated such that spotted owl populations are stable or increasing and spotted owls are unlikely to become threatened again in the foreseeable future.

Recovery Criteria

There are four Recovery Criteria in this Revised Recovery Plan. Recovery Criteria are measurable, achievable goals that we believe will result from implementation of the recovery actions in this Revised Recovery Plan. Achievement of these criteria will take time and is intended to be measured over the life of the plan, not on a short-term basis and should not be considered near-term recommendations. Not all recovery actions necessarily need to be implemented for the Service to consider initiating the delisting process based on the statutory criteria for determining whether a species should be listed (16 U.S.C. § 1533(a)(1)).

Recovery Criterion 1 – Stable Population Trend: The overall population trend of spotted owls throughout the range is stable or increasing over 10 years, as measured by a statistically reliable monitoring effort.

Recovery Criterion 2 – Adequate Population Distribution: Spotted owl subpopulations within each province (*i.e.*, recovery unit) (excluding the Willamette Valley Province) achieve viability, as informed by the HexSim population model or some other appropriate quantitative measure.

Recovery Criterion 3 – Continued Maintenance and Recruitment of Spotted Owl Habitat: The future range-wide trend in spotted owl nesting/roosting and foraging habitat is stable or increasing throughout the range, from the date of Revised Recovery Plan approval, as measured by effectiveness monitoring efforts or other reliable habitat monitoring programs.

Recovery Criterion 4 – Post-delisting Monitoring: To monitor the continued stability of the recovered spotted owl, a post-delisting monitoring plan has been developed and is ready for implementation within the States of Washington, Oregon, and California, as required in section 4(g)(1) of the ESA.

Recovery Actions

Recovery actions are near-term recommendations to guide the activities needed to accomplish the recovery objectives and achieve the recovery criteria. This Revised Recovery Plan presents 33 actions that address overall recovery through maintenance and restoration of spotted owl habitat, monitoring of avian diseases, development and implementation of a delisting monitoring plan, and management of the barred owl. These actions are organized following the five listing factors described earlier.

Organization of Revised Recovery Plan

This Revised Recovery Plan is organized into four main sections with supporting appendices and retains the structure of the 2008 Plan. After Section I the Introduction, Section II gives a summary of recovery goals, objectives, and strategy. This section also gives an overview of how this recovery strategy for spotted owls fits within a broader ecosystem management approach. Section III describes recovery units, criteria, and the actions that are necessary to recover the species. These recovery actions are organized according to the five factors considered when a species is listed under section 4(a)(1) of the ESA. Section IV outlines the Plan's implementation schedule and cost estimates.

This Revised Recovery Plan also includes several appendices. These appendices provide background information, literature cited, a description of the spotted owl habitat modeling tool, and other important supporting information.

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Acronyms and Abbreviations

BLM	U.S. Bureau of Land Management
BOWG	Barred Owl Work Group
CAL FIRE	California Department of Forestry and Fire Protection
CDFG	California Department of Fish and Game
CI	confidence interval
CO_2	carbon dioxide
dbh	diameter at breast height
DCA	Designated Conservation Area
DFLWG	Dry forest Landscape Work Group
ENSO	El Niño-Southern Oscillation
ESA	Endangered Species Act
FEMAT	Forest Ecosystem Management Assessment Team
FS	U.S. Forest Service
FWS	U.S. Fish and Wildlife Service
HCA	Habitat Conservation Area
HCP	Habitat Conservation Plan
ISC	Interagency Scientific Committee
KPWG	Klamath Province Work Group
LRMP	Land and Resource Management Plan (for BLM and FS)
LSR	Late-Successional Reserve
MOCA	Managed Owl Conservation Area
NPS	National Park Service
NRF	Nesting/roosting and foraging
NSO	Northern spotted owl
NSOIT	Northern Spotted Owl Implementation Team
NWFP	Northwest Forest Plan
ODF	Oregon Department of Forestry
PDO	Pacific Decadal Oscillation
SE	standard error
SEI	Sustainable Ecosystems Institute
SHA	Safe Harbor Agreement
SOSEA	Spotted Owl Special Emphasis Areas
TBD	to be determined
USFWS	U.S. Fish and Wildlife Service (Service)
USGS	U.S. Geological Survey
WDNR	Washington Department of Natural Resources
WNV	West Nile virus

I. INTRODUCTION

Development of This Revised Recovery Plan

This Revised Recovery Plan builds extensively on the 1992 Draft Recovery Plan for the Northern Spotted Owl (USFWS 1992b), the 1994 NWFP (USDA and USDI 1994a, b), and the 2008 Recovery Plan for the Northern Spotted Owl (USFWS 2008b).

In 1993, President Clinton announced the NWFP which was intended to serve three roles: (1) a program to manage forests to achieve both sustainable timber production and protection of biological diversity; (2) a system for coordinating Federal agency implementation of the forest management efforts and receiving advice from non-federal interests; and (3) an initiative for providing economic assistance for those individuals and communities who were adversely affected by the reduction in the timber program. The 1994 NWFP signaled a unique approach to Federal land management in that it sought to embody (Pipkin 1998):

1. A shift to an ecosystem approach that crosses jurisdictional boundaries;
2. Active and meaningful public participation;
3. A balancing of commodity production and ecosystem viability;
4. Increased adaptive management efforts that support reevaluation and adjustments based on science;
5. A commitment to improved interagency processes; and
6. Federal agencies sharing responsibility for the implementation of a set of standards and guidelines for managing a common resource.

Due to its broad, over-arching nature and comprehensive scientific information, the 1994 NWFP was widely viewed as the Federal government's contribution to the recovery of the spotted owl since it contained the information used to develop the draft 1992 Northern Spotted Owl Recovery Plan. The NWFP was directly incorporated into 4 National Forest land and resource management plans (LRMPs) and amended the LRMPs or resource management plans (RMPs) that guide the management of each of the 15 National Forests and 6 Bureau of Land Management (BLM) Districts across the range of the spotted owl. These plans adopted a series of reserves and management guidelines that were intended to protect spotted owls and their habitat as well as other species.

As time passed, the public and land managers expressed a desire for a spotted owl recovery plan that explicitly outlined and described the management actions and habitat needs of the species. The U.S. Fish and Wildlife Service (Service) responded by publishing in May, 2008, the Recovery Plan for the Northern Spotted Owl, which was created after 2 years of scientific meetings, peer review, input from a wide variety of experts and more than 70,000 public comments.

The 2008 Recovery Plan identified two predominant threats: increasing competition from barred owls, and habitat loss from timber harvest and fire. The main elements of the 2008 Recovery Plan included: (1) a network of conservation areas on Federal lands west of the Cascade Crest; (2) a new approach to habitat management on Federal lands east of the Cascade Crest that maintains spotted owl habitat in a fire-prone landscape; (3) barred owl removal experiments; and (4) maintenance of substantially all older forests on Federal lands west of the Cascade Crest to reduce spotted owl and barred owl competitive interactions as we evaluate barred owl management options.

In June 2008, the Service received reviews of the 2008 Recovery Plan from the American Ornithologists' Union, Society for Conservation Biology and The Wildlife Society. These scientific peer reviews were consistent in their comments, noting that the recovery plan provided a "solid conceptual framework for recovery." However, the comments were critical of several key aspects of the 2008 Recovery Plan, particularly addressing threats posed by habitat loss from fire and concerns regarding the adequacy of reserves and their management.

Both the 2008 Recovery Plan and the 2008 revised critical habitat designation for the northern spotted owl, which is based on the 2008 Recovery Plan, were challenged in court, *Carpenters' Industrial Council v. Salazar*, 1:08-cv-01409-EGS (D.D.C.). In addition, on December 15, 2008, the Inspector General of the Department of the Interior issued a report entitled "Investigative Report of the Endangered Species Act and the Conflict between Science and Policy," which concluded that the integrity of the agency decision-making process for the 2008 Recovery Plan was potentially jeopardized by improper political influence. As a result, the Federal government filed a motion in the lawsuit for remand of the 2008 Recovery Plan and the 2008 critical habitat designation. On September 1, 2010, the Court issued an opinion remanding the 2008 Recovery Plan to the Service for issuance of a revised recovery plan within nine months. On May 6, 2011, the Court granted our request for a 30-day extension to allow time to consider the comments we received on Appendix C, which describes the modeling process, during an additional 30-day comment period. This Revised Recovery Plan is the result of the process to consider revisions to the 2008 Recovery Plan.

This Revised Recovery Plan is based on the best scientific information available, addressing the scientific peer reviewers' comments and including more recent scientific information involving climate change and habitat modeling. This Revised Recovery Plan focuses largely on five topics:

1. Conservation of spotted owl sites and high value spotted owl habitat;
2. Ecological forestry and active forest restoration to meet the challenges of climate change and altered ecological processes;
3. The threat posed by barred owls and management options to address it;
4. The potential need for State and private lands to contribute to spotted owl recovery in certain areas; and

5. Completion of a habitat modeling framework as an informational tool to better enable future land management decisions.

While this document retains some aspects of the 2008 Recovery Plan such as the strategy to assess and address threats from the barred owl and support for forest restoration treatments, it presents the most comprehensive, up-to-date evaluation of spotted owl science, conservation needs and management alternatives. With it, the Service seeks to engage Federal, State and private landowners in developing a comprehensive, landscape-level approach that furthers the recovery of the spotted owl.

The following is a chronology of the process involved in writing this Revised Recovery Plan.

- September 2010: 2010 Draft Revised Recovery Plan released for public comment and scientific peer review.
- Fall, 2010: Service holds eight stakeholder briefings and workshops regarding development of the habitat modeling tool.
- October 2010: Service posts to website a map depicting the results of the first two steps of the modeling tool.
- December 2010: Service posts summary results of the third step of the modeling tool.
- November 15, 2010: public comment period closes, but is extended until December 15, 2010.
- April 22, 2011: 30-day public comment period opened for review of and comment on updated spotted owl habitat modeling information contained in draft Appendix C.

Recovery Planning and Timeframes

The Endangered Species Act of 1973, as amended (16 USC 1531 *et seq*.)(ESA), establishes policies and procedures for identifying and conserving species of plants and wildlife that are endangered or threatened with extinction. To help identify and guide species recovery efforts, section 4(f) of the ESA directs the Secretary of the Interior to develop and implement recovery plans for listed species. These plans are to include:

1. A description of site-specific management actions necessary for conservation and survival of the species;
2. Objective, measurable criteria that, when met, will allow the species to be delisted; and
3. Estimates of the time and funding required to achieve the plan's goals and intermediate steps.

Recovery plans are not regulatory documents; rather, they are created by the Service as guidance to bring about recovery and establish criteria to be used in evaluating when recovery has been achieved. There may be many paths to recover a species. Recovering a wide-ranging species takes time and significant effort from a multitude of entities. Recovering a species is a dynamic process, and judging when a species is recovered requires an adaptive management approach that is sensitive to the best available information and risk tolerances. Given the adaptive nature of this iterative process, recovery may be achieved without fully following the guidance provided in this Revised Recovery Plan.

Recovery Plan Objectives, Criteria, and Actions

The ultimate goal of this Revised Recovery Plan is to recover the spotted owl so that protections afforded by the ESA are no longer necessary, allowing us to delist the species. Its objectives describe a scenario in which the spotted owl's population is stable or increasing, well-distributed, and affected by manageable threats. To meet this goal and these objectives, interim expectations are defined to guide us as we learn more about the multiple uncertainties surrounding this species.

This Revised Recovery Plan was developed using the best scientific information available and a "step-down" approach of objectives, criteria and actions. Recovery objectives are broad statements that describe the conditions under which the Service would consider the spotted owl to be recovered. Recovery criteria serve as objective, measurable guidelines to assist in determining when an endangered species has recovered to the point that it may be downlisted to threatened, or that the protections afforded by the ESA are no longer necessary and the species may be delisted. Recovery actions are the Service's recommendations to guide the activities needed to accomplish the recovery criteria. Recovery actions are recommended throughout the U.S. range of the spotted owl and are designed to address the specific threats identified in this Revised Recovery Plan. Implementation of the full suite of recovery actions will involve participation from the States, Federal agencies, non-federal landowners and the public.

The recovery criteria and actions are described at the beginning of this Revised Recovery Plan. Information concerning the spotted owl's biology is in Appendix A, and a description of the threats to the spotted owl is presented in Appendix B.

Five-year Status Reviews

A 5-year review of a listed species is required by section 4(c)(2) of the ESA, and considers all new available information concerning the population status of the species and the threats that affect it. This process can serve as an integral component of tracking recovery implementation, updating scientific understanding and evaluating status of the species. The Service conducts these periodic reviews to ensure the listing classification of a species as threatened or endangered is accurate. A 5-year status review considers the best scientific and commercial information that has become available since the original listing determination or last review such as: species biology, habitat conditions, conservation measures, threat status and trends, and any other new information. The Service publishes a notice in the Federal Register announcing the initiation of these reviews and provides the public an opportunity to submit relevant information regarding the species and its threats.

A 5-year review is intended to indicate whether a change in a species listing classification is warranted. Changes in classification recommended in a 5-year review could include delisting, reclassification from threatened to endangered (*i.e.*, uplisting), reclassification from endangered to threatened (*i.e.*, downlisting), or no change is warranted at this time. The 5-year review does not involve rule-making, so no change to a species classification is made at the time a review is completed. If a change is recommended in the completed review, the Service would need to initiate a separate rule-making process to propose the change.

Delisting Process

When sufficient progress toward recovery has been made, a separate effort will assess the spotted owl's status in relation to the five listing factors found in section 4(a)(1) of the ESA to determine whether delisting is appropriate (see Executive Summary). A change in status (downlisting or delisting) requires a separate rule-making process based on an analysis of the same five factors (referred to as the listing factors) considered in the listing of a species, as described in section 4(a)(1) of the ESA. These include:

A. The present or threatened destruction, modification, or curtailment of its habitat or range;
B. Overutilization for commercial, recreational, scientific, or educational purposes;
C. Disease or predation;
D. The inadequacy of existing regulatory mechanisms;
E. Other natural or manmade factors affecting its continued existence.

This subsequent review may be initiated without all of the recovery criteria in this Revised Recovery Plan having been fully met. For example, one or more criteria may have been exceeded, while other criteria may not have been fully accomplished. In this instance, the Service may judge that, overall, the threats have been minimized sufficiently and the species' population health is robust enough to be considered for delisting. If sufficient progress toward recovery has not been made, the spotted owl may retain its current status. If the spotted owl's condition deteriorates, it may be necessary to change its status to "endangered."

New recovery opportunities or scientific information may arise that were unknown at the time this Revised Recovery Plan was created. New opportunities may encompass more effective means of achieving recovery or measuring recovery. In addition, new information may alter the extent to which criteria need to be met for recognizing recovery of the species. Conversely, new information may result in new challenges, and achieving recovery may be more difficult than we now believe.

Assumptions Made in Drafting the Revised Recovery Plan

There are numerous land management plans and strategies being implemented to help recover the spotted owl. This Revised Recovery Plan is not meant to negate or supplant these other plans. However, these plans may be subject to change, so this Revised Recovery Plan is meant to be a stand-alone document that describes steps necessary to recover the spotted owl. The recommendations described in the Revised Recovery Plan are meant to be successful on their own; that is, they are not dependent on the continuance of any other conservation or management plan to be successful, unless specifically noted.

Implementation of the full suite of recovery actions will involve participation from the States, Federal agencies, non-federal landowners and the public.

Listing History and Recovery Priority

The spotted owl was listed as threatened on June 26, 1990. On a scale of 1C (highest) to 18 (lowest) (USFWS 1983a, b), the Service recovery priority number for the spotted owl is 12C. We assigned this number per our guidelines for the following reasons: the spotted owl faces a "moderate" degree of threat which equates to a continual population decline and threat to its habitat, although extinction is not imminent. It received a "low recovery potential" because there is uncertainty regarding our ability to alleviate the barred owl impacts to spotted owls and the techniques are still experimental; and because of the spotted owl's taxonomic status as a subspecies and inherent conflicts with development, construction, or other economic activity given the economic value of older forest spotted owl habitat (USFWS 1983a, b). Despite the definitions that led us to a 12C Recovery priority number, the Service is optimistic regarding the spotted owl's potential for recovery if immediate challenges such as barred owls are managed.

The spotted owl was listed in 1990 as a result of widespread loss and adverse modification of spotted owl habitat across its entire range and the inadequacy of existing regulatory mechanisms to conserve the spotted owl.

Reasons for Listing and Assessment of Threats

The spotted owl was listed as threatened throughout its range "due to loss and adverse modification of spotted owl habitat as a result of timber harvesting and exacerbated by catastrophic events such as fire, volcanic eruption, and wind storms" (USFWS 1990b:26114). More specifically, threats to the spotted owl included low populations, declining populations, limited habitat, declining habitat, inadequate distribution of habitat or populations, isolation of populations within physiographic provinces, predation and competition, lack of coordinated conservation measures, inadequacy of regulatory mechanisms and vulnerability to natural disturbance (USFWS 1992b). These threats were characterized for each province as severe, moderate, low or unknown (USFWS 1992b). The range of the spotted owl is divided into 12 physiographic provinces from Canada to northern California and from the Pacific Coast to the eastern Cascades (see Appendix A, Figure A-1). Declining habitat was recognized as a severe or moderate threat to the spotted owl throughout its range, isolation of populations was identified as a severe or moderate threat in 11 provinces, and a decline in population was a severe or moderate threat in 10 provinces. Together, these three factors represented the greatest concerns about range-wide conservation of the spotted owl. Limited habitat was considered a severe or moderate threat in nine provinces, and low populations was a severe or moderate concern in eight provinces, suggesting that these factors were also a concern throughout the majority of the spotted owl's range. Vulnerability to natural disturbances was rated as low in five provinces.

The Service conducted a 5-year review of the spotted owl in 2004 (USFWS 2004b), based in part on the content of an independent scientific evaluation of the status of the spotted owl (Courtney *et al.* 2004) performed under contract with the Service. For that evaluation, an assessment was conducted of how the threats described in 1990 might have changed by 2004. Some of the key ideas relative to threats identified in 2004 were: (1) "Although we are certain that current harvest effects are reduced, and that past harvest is also probably having a reduced effect now as compared to 1990, we are still unable to fully evaluate the current levels of threat posed by harvest because of the potential for lag effects" (Courtney and Gutiérrez 2004:11-7); (2) "Currently the primary source of habitat loss is catastrophic wildfire, although the total amount of habitat affected by wildfires has been small" (Courtney and Gutiérrez 2004:11-8); and (3) "We are convinced that Barred Owls are having a negative impact on Spotted Owls at least in some areas" (Gutiérrez *et al.* 2004:7-43) and "there are no grounds for optimistic views suggesting that Barred Owl impacts on Northern Spotted Owls have been already fully realized" (Gutiérrez *et al.* 2004:7-38).

On June 1, 2006, we convened a meeting of seven experts to help identify the most current threats facing the species. Six of the seven were experts on the biology of the spotted owl, and a seventh was an expert on fire ecology. The workshop was conducted as a modified Delphi expert panel in which the seven experts scored the severity of threat categories. The baseline assumption of this meeting was that existing habitat conservation strategies (*e.g.,* the NWFP) would be in place. With that assumption, the experts identified and ranked threats to the spotted owl. The 2007 Recovery Team then had an opportunity to interact with them to discuss their individual rankings and thoughts on spotted owl threats. The experts re-ranked the threats if they felt this was relevant given the substance of the discussion.

These experts identified past habitat loss, current habitat loss, and competition from barred owls as the most pressing threats to the spotted owl, even though timber harvest recently has been greatly reduced on Federal lands. They noted that evidence of these three threats is presented in the scientific literature. The range of threat scores made by the individual experts was narrowest for barred owl competition and slightly greater for habitat threats, indicating that there was more agreement about the threat from barred owls. The experts identified disease and the effect of climate change on vegetation as potential and more uncertain future threats.

The experts also ranked the threats by importance in each province. Among the 12 physiographic provinces, the more fire-prone provinces (Eastern Washington Cascades and Eastern Oregon Cascades, California Cascades, Oregon and California Klamath) scored high on threats from ongoing habitat loss as a result of wildfire and the effects of fire exclusion on vegetation change. West-side provinces (Western Washington Cascades and Western Oregon Cascades, Western Washington Lowlands, Olympic Peninsula, and Oregon Coast Range) generally scored high on threats from the negative effects of habitat fragmentation and ongoing habitat loss as a result of timber harvest. The province with the fewest number of threats was Western Oregon Cascades, and the provinces with the greatest number of threats were the Oregon Klamath and the Willamette Valley. For a more complete description of the threats, see Appendix B.

Barred Owls

It is the Service's position that the threat from barred owls is extremely pressing and complex, requiring immediate consideration. Barred owls have been found in all areas where surveys have been conducted for spotted owls. In addition, barred owls inhabit all forested areas throughout Washington, Oregon, and northern California where nesting opportunities exist, including areas outside of the specific range of the spotted owl (Kelly and Forsman 2003, Buchanan 2005, Gutiérrez *et al.* 1995, 2007, Livezey 2009a). Consequently, the Service assumes barred owls now occur at some level in all areas used now or in the past by spotted owls.

The workshop panel unanimously identified past habitat loss, current habitat loss, and competition from barred owls as the most-pressing threats to the spotted owl, even though timber harvest recently has been greatly reduced on Federal lands.

Addressing the threats associated with past and current habitat loss must be conducted simultaneously with addressing the threats from barred owls. Addressing the threat from habitat loss is relatively straightforward with predictable results. However, addressing a large-scale threat of one raptor on another, closely related raptor has many uncertainties.

At this time, the long-term removal of significant numbers of barred owls, along with a suite of other recovery actions, will be assessed as a possible approach to recover the spotted owl. Before considering whether to fund and fully implement such an action, however, the Service needs to be confident this removal would benefit spotted owls. The Service is currently developing a draft Environmental Impact Statement to assess the effects of barred owl removal experiments proposed in this Revised Recovery Plan.

Because barred owls compete with spotted owls for habitat and resources for breeding, feeding and sheltering, ongoing loss of habitat has the potential to intensify the competition by reducing the total amount of these resources available to the spotted owl and bringing barred owls into closer proximity with the spotted owl. In order to reduce or not increase this potential competitive pressure while the threat from barred owls is being addressed, this Revised Recovery Plan now recommends conserving and restoring older, multi-layered forests across the range of the spotted owl.

Habitat Management

In addition to addressing the barred owl threat, the Service agrees with scientific experts that it is necessary to conserve the highest value spotted owl habitat to address the key threats. The 2008 Recovery Plan recommended establishing Managed Owl Conservation Areas (MOCAs) on Federal lands to provide the important habitat needed for the species to recover over the long-term. The Service is not making this recommendation in this Revised Recovery Plan. Instead, we rely on the habitat conservation network of the NWFP, in addition to other habitat conservation recommendations contained within this Revised Recovery Plan. In addition, we have completed a range-wide, multi-step habitat modeling tool, described in Appendix C, that will help evaluate and inform the Service's designation of critical habitat, and the development of future land management plans by Federal land managers, and the consideration of management options by State, Tribal, or private landowners as recommended by this Revised Recovery Plan.

In addition, given the continued decline of the species, the apparent increase in severity of the threat from barred owls, and information indicating a recent loss of genetic diversity for the species, this Revised Recovery Plan also recommends retaining more occupied spotted owl sites and unoccupied, high value spotted owl habitat on all lands. Vegetation management actions that may have short-term impacts but are potentially beneficial to occupied spotted owl sites in the long-term meet the goals of ecosystem conservation. Such actions may include silvicultural treatments that promote ecological restoration and are expected to reduce future losses of spotted owl habitat and improve overall forest ecosystem resilience to climate change, which should result in more habitat retained on the landscape for longer periods of time.

In the more disturbance-prone provinces on the east side of the Cascade Mountains and in the Klamath Province, the Dry Forest Landscape and Klamath Province Work Groups (these are recovery implementation teams established as recommended by the 2008 Recovery Plan) are working to develop strategies that incorporate the dynamic natural disturbance regime in a manner that provides for long-term ecological sustainability through the restoration of ecological processes while conserving spotted owl habitat over the long-term. Some land management units, such as the Okanagan-Wenatchee National Forest, have published such strategies (USDA 2010).

II. RECOVERY GOAL, OBJECTIVES, CRITERIA, AND STRATEGY

Recovery Goal

The long-term goal of this recovery plan is to improve the status of the spotted owl so it can be removed from protection under the ESA.

Recovery Objectives

The objectives of this Revised Recovery Plan are:

1. Spotted owl populations are sufficiently large and distributed such that the species no longer requires listing under the ESA;
2. Adequate habitat is available for spotted owls and will continue to exist to allow the species to survive without the protection of the ESA; and
3. The effects of threats have been reduced or eliminated such that spotted owl populations are stable or increasing and spotted owls are unlikely to become threatened again in the foreseeable future.

Recovery Criteria

There are four recovery criteria in this Revised Recovery Plan. Recovery criteria are measurable, achievable goals that we believe will result from implementation of the recovery actions in this Revised Recovery Plan. Achievement of these criteria will take time and is intended to be measured over the life of the plan, not on a short-term basis and should not be considered near-term recommendations. This plan is designed to meet these criteria at which time the Service will make a decision about whether to propose delisting the spotted owl. Not all recovery actions need to be implemented and not all recovery criteria need to be fully achieved for the Service to consider delisting.

Recovery Criterion 1 - Stable Population Trend: The overall population trend of spotted owls throughout the range is stable or increasing over 10 years, as measured by a statistically-reliable monitoring effort.

Recovery Criterion 2 – Adequate Population Distribution: Spotted owl subpopulations within each province (*i.e.*, recovery unit) (excluding the Willamette Valley Province) achieve viability, as informed by the HexSim population model or some other appropriate quantitative measure.

Recovery Criterion 3 – Continued Maintenance and Recruitment of Spotted Owl Habitat: The future range-wide trend in spotted owl nesting/roosting and foraging (NRF) habitat is stable or increasing throughout the range, from the date of Revised Recovery Plan approval, as measured by effectiveness monitoring efforts or other reliable habitat monitoring programs.

Recovery Criterion 4 – Post-delisting Monitoring: To monitor the continued stability of the recovered spotted owl, a post-delisting monitoring plan has been developed and is ready for implementation within the States of Washington, Oregon, and California (as required by section 4(g)(1) of the ESA).

Recovery Strategy

Currently, the most important range-wide threats to the spotted owl are competition with barred owls, ongoing loss of spotted owl habitat as a result of timber harvest, loss or modification of habitat from uncharacteristic wildfire, and loss of amount and distribution of spotted owl habitat as a result of past activities and disturbances. To address these threats, this recovery strategy includes five basic steps:

1. Development of a range-wide habitat modeling framework;
2. Barred owl management;
3. Monitoring and research;
4. Adaptive management; and
5. Habitat conservation and active forest restoration.

These five steps are described in detail below.

Development of Range-wide Habitat Modeling Framework

The first step in this recovery strategy is to develop a state-of-the-science modeling framework for evaluating spotted owl habitat and populations. Scientific peer reviewers were critical of the 2008 Recovery Plan's MOCA reserve strategy and the general lack of updated habitat modeling capacity. The Service agreed with this concern; the MOCA recommendation is not contained in this Revised Recovery Plan.

When listed as threatened in 1990 (USFWS 1990), habitat loss and fragmentation of old-growth forest were identified as major factors contributing to declines in spotted owl populations. As older forest became reduced to smaller and more isolated patches, the ability of spotted owls to successfully disperse and establish territories was reduced (Lamberson *et al.* 1992). Lamberson *et al.* (1992) identified that there appeared to be a sharp threshold in the amount of habitat below which spotted owl population viability plummeted. In order to promote spotted owl recovery, earlier plans including the 1992 Draft Recovery Plan for the Northern Spotted Owl (USFWS 1992) and the Northwest Forest Plan (USDA and USDI 1994) established spotted owl habitat reserve networks to promote species recovery. The goal of these conservation reserves was to achieve a high likelihood of long-term persistence while minimizing impacts on resources with economic value. For territorial species such as the spotted owl, Lamberson *et al.* (1994) concluded that size, spacing and shape of reserved areas all had strong influence on population persistence, and reserves that could support a minimum of 20 spotted owl territories were more likely to maintain spotted owl populations than smaller reserves. They also found that juvenile dispersal was facilitated in areas large enough to support at least 20 spotted owl territories. In addition to size, spacing between reserves had a strong influence on successful dispersal (Lamberson *et al.* 1992). Forsman *et al.* (2002) reported dispersal distances of 1,475 spotted owls in Oregon and Washington for 1985–1996. Median maximum dispersal distance (the straight-line distance between the natal site and the farthest location) for radio-marked juvenile male spotted owls was 12.7 miles, and that of female spotted owls was 17.2 miles (Forsman *et al.* 2002: Table 2). Dispersal data and other studies on the amount and configuration of habitat necessary to sustain spotted owls provided the foundation for developing previous spotted owl habitat reserve systems.

Although we are not recommending a new habitat conservation network, we recommend utilizing the best available information, including modeling data, to evaluate and refine such a network that will continue to support the recovery of the spotted owl. The NWFP currently provides a network of reserve land use allocations that protects habitat for late-successional forest species, including the demographic and dispersal needs of the spotted owl. Anthony *et al.* (2006) and Forsman *et al.* (2011) have reported that demographic rates for spotted owls on long-term Federal monitoring areas that contained late-successional reserves were higher than those from other long-term study areas. We believe a habitat conservation network designed using the best available science is necessary to recover the spotted owl. The NWFP reserve network, in addition to other habitat conservation recommendations in this Revised Recovery Plan (*e.g.*, Recovery Actions 10, 32 and 6), meets that need in the near term until the Forest Service and BLM revise their respective management plans. We recommend that any future revisions in Federal land management plans take into account the need for appropriately spaced, large habitat conservation areas for spotted owls. The upcoming critical habitat revision process will help identify whether any additional areas or adjustments to that network are warranted.

Therefore, we recommend continued application of the reserve network of the NWFP until the 2008 designated spotted owl critical habitat is revised and/or the land management agencies amend their land management plans taking into account the guidance in this Revised Recovery Plan. We have developed a modeling framework that can provide information for numerous spotted owl recovery actions and management decisions, including revisions to the spotted owl critical habitat designation. This spatially-explicit modeling effort is designed to allow for a more in-depth evaluation of various habitat features that affect the distribution of spotted owl territories and the factors influencing spotted owl populations. Different land management scenarios can then be evaluated for their relative potential contribution to spotted owl recovery. This modeling effort is described in detail in Appendix C. The Service hopes this modeling framework or similar approaches will be used by Federal, State, and private scientists to make better informed decisions concerning what areas should be conserved for spotted owls.

Barred Owl Management

The second step in this recovery strategy is to move forward with a scientific evaluation of potential management options to reduce the impact of barred owls on spotted owls. Barred owls pose perhaps the most significant short-term threat to spotted owl recovery. This threat is better understood now than when the spotted owl was listed. Barred owls have reduced spotted owl site occupancy, reproduction, and survival. Because the abundance of barred owls continues to increase, effectively addressing this threat depends on initiating action as soon as possible. The recovery actions address research involving the competition between spotted and barred owls, experimental control of barred owls and, if recommended by research, management of barred owls. Discussion of the barred owl threat occurs throughout this document, especially in Listing Factor E and Appendix B.

Monitoring and Research

The third step in this recovery strategy is to continue implementing a robust monitoring and research program for the spotted owl. This Revised Recovery Plan recommends activities be implemented to track progress toward recovery, to inform changes in recovery actions by a process of adaptive management, and ultimately to help determine when delisting is appropriate. The following primary elements of this strategy will provide information required to evaluate progress toward the Recovery Criteria. The monitoring and research results can be considered within the 5-year review process which is required under the ESA.

Monitoring of Spotted Owl Population Trend

Currently, this monitoring is done within a network of demographic study areas, but it may be possible to monitor trends using other reliable methods. Recognizing that the demographic monitoring efforts are costly, it is recommended that, in the absence of another method that would provide reliable trend data at an improved cost-effectiveness, these existing studies should be continued while other methods are piloted and tested. The current demographic studies provide region-specific demographic data that provide the basis for many of the current and proposed studies of spotted owl ecology. Also, because monitoring in the demographic study areas has been ongoing for approximately two decades, the data from these efforts allow trend estimates in the near-term that would not be available for a considerable length of time if new methods were implemented.

A Comprehensive Effort of Barred Owl Research and Monitoring

This is needed to experimentally determine the effects of barred owls on spotted owls and to incorporate this information into management to reduce negative effects to a level that would promote spotted owl recovery.

Given the immediacy of the barred owl threat, the continuation of monitoring in the demographic study areas provides a timely opportunity to integrate barred owl removal experiments to assess any demographic response of spotted owls to removal of barred owls. Assessing the demographic response will help the Service determine whether the effects of this threat could be reduced or eliminated by a larger-scale control program.

Continued Habitat Monitoring

The Effectiveness Monitoring program initiated by the NWFP includes tracking the status and trends of spotted owl habitat (Davis and Lint 2005). This monitoring program will allow us to assess progress towards meeting **Recovery Criterion 3: Continued Maintenance and Recruitment of Spotted Owl Habitat** and help the Service determine whether the threat of habitat loss has been reduced or eliminated such that spotted owls are unlikely to become threatened again in the foreseeable future.

Inventory of Spotted Owl Distribution

The recovery of the spotted owl is predicated on maintaining the current rangewide distribution of the species within each of the 12 provinces (see Recovery Unit discussion). When trend data indicate that populations are stable or increasing in the provinces as specified in Recovery Criterion 1, sampling should also be considered to evaluate spotted owl distribution in all provinces.

Explicit Consideration for Climate Change Mitigation Goals Consistent with Spotted Owl Recovery Actions

There is significant overlap between many of the spotted owl recovery goals described in this Revised Recovery Plan and opportunities to mitigate impacts due to climate change. The Service is applying Secretarial Order No. 3289: *Addressing the Impacts of Climate Change on America's Water, Land, and Other Natural and Cultural Resources* into our forest management activities. This Secretarial Order directs DOI agencies to analyze potential climate change impacts when undertaking long-range planning exercises, developing multi-year management plans, and making major decisions regarding potential use of resources under the Service's purview. This direction applies to this Revised

Recovery Plan, which includes a detailed treatment of climate change and its potential impact on spotted owl recovery.

Adaptive Management

Risk, Uncertainty and Changing Management

When writing a recovery plan, the Service must use the best scientific information available. However, the information available rarely addresses all of the questions at hand, meaning there is usually some degree of uncertainty. Hence, recovery plans include an element of risk management (especially for wide-ranging species which face a multitude of threats) because the Service must make recommendations and decisions in the face of incomplete information and uncertainty.

In the face of significant scientific uncertainty, we propose aggressive strategies to address the threats from habitat loss, barred owls and climate change. It is understood that this Revised Recovery Plan's expression of risk, as embodied by the recovery strategy and actions, may not match the risk tolerance of every interested party. However, it is the conclusion of the Service that the actions in this Revised Recovery Plan are necessary to achieve the plan's goal for the conservation and survival of the species.

In order to deal with uncertainty and risk the Service will employ an active program of adaptive management. Adaptive management includes identifying areas of uncertainty and risk, implementing a research and monitoring approach to clarify these areas, and making decisions to change management direction that is not working while still maintaining management flexibility (see Thomas *et al.* 1990, USFWS 1992b). Where possible, the implementation of the recovery actions included within this Revised Recovery Plan should be designed in a manner that provides feedback on the efficacy of management actions such that the design of future actions can be improved.

What is Adaptive Management?

Adaptive management is a systematic approach for improving resource management by learning from the results of explicit management policies and practices and applying that learning to future management decisions (Holling 1978, Walters 1986, Gregory *et al*. 2006). This tool is useful when there is substantial uncertainty about appropriate strategies for managing natural resources. Although adaptive management is a form of "learning by doing," its purposefulness and systematic approach distinguish it from learning by trial and error where management direction changes in the face of failed policies and actions (Stankey *et al*. 2005, Gregory *et al.* 2006). Bormann *et al.* (2007:187) provide a practical description of and purpose for adaptive management:

> "Adaptive management requires exploring alternative ways to meet management objectives, predicting the outcomes of alternatives based on what is known, implementing one—or if possible, more than one—of these alternatives, monitoring to learn which alternative best meets the management objectives, and then using results to update knowledge and adjust management actions. Adaptive management is not an end in itself, but a means to more effective decisions and enhanced benefits; thus, its true measure is in how well it helps meet environmental, social, and economic goals, adds to scientific knowledge, and reduces tensions among stakeholders."

Key components of adaptive management include: (1) treating management actions and policies as formal experiments that yield new information; (2) embracing risk and uncertainty as opportunities for learning; and (3) applying the knowledge gained from management experiments to subsequent actions (Holling 1978, Stankey *et al*. 2003, Stankey *et al.* 2005). We elaborate on each of these components below.

Treating management actions as experiments is a fundamental component of the adaptive management process. Key to this is clearly articulating questions about the effects of implementing management actions, formally re-casting these questions as testable hypotheses, implementing them as experiments to be tested, and monitoring the results. Yet this is often where the process fails. For example, in a critique of the NWFP adaptive management program, Stankey *et al*. (2003) found a major fault to be a predominant reliance on decision-making approaches that were informal and incremental, yet widely accepted as an adaptive management approach. Articulating measurable management objectives and forming them into explicit hypotheses that can be tested is what ultimately separates adaptive management from learning by trial and error.

The second key component in successfully implementing adaptive management, as identified above, requires embracing risk and uncertainty as opportunities for learning. The need for adaptive management is driven by the existing uncertainty surrounding appropriate management treatments and how ecosystems may respond to those treatments. A risk-averse mentality of not acting until more information is known may ultimately result in implementing ongoing, ineffectual policies that may not only further threaten resources of concern, but also suppress experimental actions that could provide learning to inform and improve future management. While there are costs and risks in applying experimental treatments, failing to experiment also carries costs and risks (Wildavsky 1988, as cited in Stankey *et al*. 2003). As Stankey *et al*. (2003:45) noted, "The irony here is that while continuation of policies that have not worked seems to ensure continued failure, undertaking actions where outcomes are uncertain is resisted because of the inability to ensure that unwanted effects will not result." Testing clearly formed hypotheses in a systematic manner under identifiable, bounded settings and monitoring the outcomes will go far in improving future management and developing more resilient policies while minimizing risk to resources.

The knowledge gained from testing hypotheses must be documented and applied to future actions if learning is to happen and if the policy or decision-making process is to be informed and improved. Thus, it is vital that the question asked as part of the experiment is relevant to managers. To speed the pace of learning, Williams *et al.* (2009) recommend that alternative management options be applied and tested, and that these options are sufficiently different to produce observable responses that can be detected by monitoring.

Goals and Steps in an Adaptive Management Process for the Spotted Owl

The overarching purpose of implementing adaptive management for spotted owl recovery is to reduce key scientific uncertainties with respect to spotted owl management and recovery and apply that knowledge to future spotted owl management decisions. An adaptive management program must deliver biological and ecological information relevant to spotted owl recovery; key objectives to facilitate this need are:

1. Identify and fill key gaps in our knowledge base
2. Improve our understanding of ecosystem responses, thresholds and dynamics
3. Learn about the effectiveness of alternate management policies and activities
4. Document and disseminate the knowledge gained so that it is available in future management

Several sources of information are available that outline steps in designing and implementing adaptive management programs (Williams *et al.* 2009, BCMFR undated). Typical steps in adaptive management include:

1. Assess and define the problem – including defining measurable management objectives and potential management treatments, along with key indicators and projected responses for each objective.

2. Design the management treatment and monitoring plan – including clarifying response thresholds that will trigger management adjustments, and identifying which management adjustments are needed.

3. Implement the management treatment and monitoring program – including documenting any deviation from the plan.

4. Monitor treatment implementation and results following the protocol designed in Step 2.

5. Evaluate results – including comparing outcomes to forecasts made in Step 1, as well as communicating results to others facing similar management issues.

6. Adjust or revise hypothesis and management as necessary – including identifying where uncertainties have been reduced and where they remain unresolved, as well as adjusting the model used to predict outcomes developed in Step 1 so that it reflects the hypothesis supported by the results.

The Service encourages existing recovery plan work groups to develop Steps 1 and 2 in the above adaptive management steps for problems relevant to their chartered tasks. Developing a clearly articulated problem and objective statement, combined with an implementation and monitoring plan, will provide an adaptive management framework that allows us to learn from future management activities. Work groups will forward frameworks to the Service for presentation to the Regional Interagency Executive Committee for consideration at the executive level under the existing Northwest Forest Plan process. The Service will work with these agencies to look for opportunities to implement Steps 3 through 6 of the above adaptive management steps consistent with the framework developed under Steps 1 and 2.

Below is a list of potential questions that may drive development of an adaptive management framework. It is not meant to be comprehensive, nor is it necessarily a prioritized list. Further articulation of these questions may be needed to develop frameworks that will be most informative. Additional questions are expected to arise as the Revised Recovery Plan is implemented. For example, results gleaned from Recovery Action 8, as well as implementation of the modeling process described in Appendix C, are expected to provide additional questions for adaptive management.

Questions that may for consideration under adaptive management include:

- What vegetation management treatments best accelerate the development of forest structure associated with spotted owl habitat functions while maintaining or restoring natural disturbance and provide greater ecosystem resiliency? What are the effects of these vegetation management treatments on spotted owl occupancy, demography, and habitat use immediately following treatment and at specified time periods after treatment? What are the effects of these treatments on spotted owl prey abundance and availability immediately following treatments and at specified time periods after treatment? What are the effects of the above vegetation management treatments on the habitat components that spotted owls and their prey use? How effective are these vegetation management treatments in developing desired forest structure and how long does this development take?
- What are the effects of wildland and prescribed fire on the structural elements of spotted owl habitat (compare burned and unburned areas, as well as different fire severities)? What are the effects on spotted owl habitat use? What are the effects of these fires on abundance of spotted owl prey? How does the scale of high severity burn patches affect foraging use by spotted owls? How does the

pattern and distribution of burned and unburned patches, or patches of differing burn severities, affect spotted owl use for foraging, roosting, and nesting?

- Can strategically-placed restoration treatments be used to reduce the risk of spotted owl habitat being burned by high severity fire within dry forest ecosystems?
- What are the effects of epidemic forest insect outbreaks on spotted owl occupancy and habitat use immediately following the event and at specified time periods after treatment?
- What is the nature of the competitive interaction between spotted and barred owls, and how might those interactions be managed in terms of direct intervention (*e.g.,* barred owl control) or indirectly through habitat management (*e.g.,* vegetation management treatments)?

Habitat Conservation and Active Forest Restoration

The fifth component of this recovery strategy is derived from the stated purpose of the ESA: "to provide a means whereby the ecosystems upon which endangered species and threatened species depend may be conserved." Consistent with this purpose, it is the Service's goal that this spotted owl recovery strategy be embedded within -- and be consistent with -- a broader framework of conservation of forest ecosystems for the Pacific Northwest. This approach will provide more resilient forested habitat in the face of climate change and other stressors, thereby conserving more spotted owl habitat on the landscape for longer periods of time. Species-specific needs of the spotted owl should not be the sole determinant of landscape management decisions. Rather, spotted owl recovery objectives should fit within a broader strategy whose goals include the conservation of the full assemblage of species and ecological processes in that landscape so that it will be more resilient to future losses of spotted owl habitat or ecosystem change resulting from climate change and other disturbances.

The NWFP was developed to meet this goal for spotted owls and many other late-successional forest species. It continues to provide the basic landscape conservation framework for Federal lands in the range of the spotted owl (Noon and Blakesley 2006, Strittholt *et al.* 2006, Spies *et al.* 2010a,b), and the recommendations in this Revised Recovery Plan affirm and build upon the scientific principles of the NWFP. These principles include managing for the maintenance of ecological processes and applying adaptive management strategies to gain new scientific insight (FEMAT 1993, pg. VIII-5).

Although spotted owl recovery still relies heavily upon the principles of the NWFP as its foundation, there have been several significant developments that affect spotted owl recovery since the NWFP was first implemented 17 years ago. These include:

- *The continued decline of the spotted owl populations and low occupancy rates in large habitat reserves, and the growing negative impact from barred owl invasions of spotted owl habitats* (Forsman *et al.* 2011, Dugger *et al.* in press), *which is greater than anticipated in the NWFP*. We recommend increased conservation and restoration of spotted owl sites and high-value spotted owl habitat to help ameliorate this impact.
- *Climate change combined with effects of past management practices are exacerbating changes in forest ecosystem processes and dynamics, including patterns of wildfires, insect outbreaks and disease, to a degree greater than anticipated in the NWFP* (Perry *et al*. 2011). Land managers need to consider this uncertainty and how best to integrate knowledge of management-induced landscape pattern and disturbance regime changes with climate change when making spotted owl management decisions.
- *Scientific principles of forest management continue to evolve since implementation of the NWFP. "Ecological forestry," "natural disturbance-based management," "resilience management" and other related perspectives have emerged as accepted forest management approaches* (Long 2009, Moritz *et al.* 2011). We recommend spotted owl management decisions be implemented within a broader landscape approach based on the conservation of natural ecological patterns and processes.

These issues are not mutually exclusive, and spotted owl recovery depends on the integration of all three. Extant, high-quality spotted owl habitat must be managed, restored, and conserved in the face of a declining population and the potential threats from barred owls. Active, restoration-focused management to address climate change and dynamic ecosystem processes is also necessary in many areas, with the goal of maintaining or restoring forest ecosystem structure, composition and processes so they are sustainable and resilient under current and future climate conditions. Each of these issues is described in more detail below, and site-specific recommendations addressing these issues are contained in various recovery actions later in this Revised Recovery Plan.

This Recovery Strategy requires action in the face of uncertainty. We agree with Carey (2007, pg. 345, 349): "(A)ctive management for ecological values trades short-term negative effects for long-term gains…Collaborative management must be willing to accept short-term impacts and short-term risks to achieve long-term benefits and long-term risk reduction; overly zealous application of the precautionary principle often is a deliberate, conscious management decision to forego long-term increases in forest health and resilience to avoid short-term responsibility or controversy."

In other words, land managers should not be so conservative that, to avoid risk, they forego actions that are necessary to conserve the forest ecosystems that are necessary to the long-term conservation of the spotted owl. But they should also not be so aggressive that they subject spotted owls and their habitat to treatments where the long-term benefits do not clearly outweigh the short-term risks. Finding the appropriate balance to this dichotomy will remain an ongoing challenge for all who are engaged in spotted owl conservation. All Federal actions will be subject to section 7 consultation allowing for site-specific analyses of the effect on spotted owls.

If carefully applied, we believe this Recovery Strategy and the recommendations in this Revised Recovery Plan will recover the spotted owl and sustain its recovery in the long-term by conserving the ecosystem upon which it relies. We also believe this approach is a land management perspective that is embraced by most forest ecologists and biologists and is well published in the scientific literature. It builds on what is already occurring in parts of the Pacific Northwest (see USDA 2010 and Gaines *et al.* 2010) and is consistent with the basic tenets of the NWFP. It provides opportunities for land managers to address multiple management goals in an integrated fashion, including recovery of the spotted owl, conservation of other fish and wildlife species, habitat restoration, fuels management, and timber production. It may also provide a common ground where adversarial stakeholders in the forest management debate can find some agreement and move forward.

III. RECOVERY UNITS, CRITERIA, AND ACTIONS

Recovery Units

Unlike previous versions of the spotted owl recovery plan, this Revised Recovery Plan identifies discrete recovery units throughout the entire range of the spotted owl such that each unit provides an essential survival and recovery function for the species. Recovery units defined on this basis are useful for purposes of managing the species and for applying the jeopardy standard under section 7 of the ESA to proposed Federal actions (USFWS and NMFS 1998, NMFS and USFWS 2010). When a proposed Federal action is likely to impair or preclude the capacity of a recovery unit to provide both the survival and recovery function it provides, that action may represent jeopardy to the species, provided the analysis describes not only how the action affects the recovery unit's capability but also the relationship of the recovery unit to both the survival and recovery of the listed species as a whole (NMFS and USFWS 2010).

In this Revised Recovery Plan, recovery units differ from management units, and are also not synonymous with critical habitat units; the former is a unit of the listed species, the latter is a unit of the species' habitat.

The recovery units defined in this Revised Recovery Plan are intended to assist managers in re-establishing or maintaining: (1) historical or current genetic flow between spotted owl populations; (2) current and historic spotted owl population and habitat distribution; and (3) spotted owl meta-population dynamics. Because the recovery units are defined on a biological basis, the recovery criteria for the spotted owl address each identified recovery unit.

In 1990, the Interagency Scientific Committee decided to subdivide the range of the spotted owl into "smaller areas for practical and analytical purposes" and used the physiographic provinces as a basis for their analysis (Thomas *et al.* 1990: 61). The physiographic provinces (also referred to as "provinces") incorporate physical, biological and environmental factors that shape broad-scale landscapes. The provinces reflect differences in geology (*e.g.*, uplift rates, recent volcanism, tectonic disruption) and climate (*e.g.*, precipitation, temperature, glaciation). In turn, these factors result in broad-scale differences in soil development, natural plant communities and ultimately, forest zones. Studies have demonstrated biological differences in the numbers, distribution, habitat use patterns, and prey of spotted owls relative to the different forest zones that occur within its range (Thomas *et al.* 1990). The Northern Spotted Owl Recovery Team (USFWS 1992b) divided the range of the spotted owl into 12 provinces based on differences in vegetation, soils, geologic history, climate, land ownership and political boundaries.

Given the above definitions and background information, the physiographic provinces meet the criteria for use as recovery units (see Figure A-1 in Appendix

A). The provinces collectively cover the range of the species, and each is essential for the conservation of the spotted owl (Thomas *et al.* 1990). The provinces are based on physical, biological and environmental factors that affect spotted owl numbers, distribution, habitat use patterns, habitat conditions, and prey species abundance. These provinces have been scientifically accepted, have been in use since 1990, and are integrated into management regimes and administrative purposes. In addition, most of the physiographic provinces contain long-term monitoring areas for the spotted owl, which yield robust scientific information to assess population dynamics and trends within each area and provide a good basis for analysis at recovery-unit and range-wide scales. Their long-standing monitoring information, biological basis and accepted use by managers should lead to an efficient transition to their adoption as recovery units. Using this rationale, we are proposing to adopt the physiographic province designations in place since 1990 as recovery units, with the exception of the Willamette Valley province, which is comprised largely of non-habitat for the spotted owl.

Recovery Criteria

Recovery criteria serve as objective, measurable guidelines to assist in determining when an endangered species has recovered to the point that it may be downlisted to threatened, or that the protections afforded by the ESA are no longer necessary and the species may be delisted. However, meeting all or most of the recovery criteria does not automatically result in delisting, and does not meeting all criteria preclude delisting. A change in status (downlisting or delisting) requires a separate rule-making process based on an analysis of the same five factors (referred to as the listing factors) considered in the listing of a species, as described in section 4(a)(1) of the ESA. These include:

A. The present or threatened destruction, modification, or curtailment of its habitat or range;
B. Overutilization for commercial, recreational, scientific, or educational purposes;
C. Disease or predation;
D. The inadequacy of existing regulatory mechanisms; and
E. Other natural or manmade factors affecting its continued existence.

Recovery criteria in this Revised Recovery Plan represent our best assessment of the conditions that may result in a determination in a 5-year review that delisting the spotted owl is warranted, which we would follow by a formal regulatory rule-making process to delist the species. Recovery actions are the Service's recommendations to guide the activities needed to accomplish the recovery criteria. Ultimately, a positive response by spotted owl populations to the recovery actions will mean recovery is occurring. Such a positive response will be measured in accordance with the population-related recovery criterion.

When the Service listed the spotted owl, we identified population decline, small population size, and related demographic conditions as threats. In the current assessment, these conditions were viewed as results of other threats and not threats *per se*. However, recovery actions are identified here that are intended to address and ameliorate such demographic conditions and address the key threats to the species. Recovery criteria are measurable and achievable goals that we believe will result from implementation of the recovery actions in this Revised Recovery Plan. Achievement of these criteria will take time and is intended to be measured over the life of the plan, not on a short-term basis.

Recovery Criterion 1 - Stable Population Trend: The overall population trend of spotted owls throughout the range is stable or increasing over 10 years, as measured by a statistically-reliable monitoring effort.

Recovery Criterion 2 – Adequate Population Distribution: Spotted owl subpopulations within each province (*i.e.*, recovery unit) (excluding the Willamette Valley Province) achieve viability, as measured by the HexSim population model or some other appropriate quantitative measure.

Recovery Criterion 3 – Continued Maintenance and Recruitment of Spotted Owl Habitat: The future range-wide trend in spotted owl nesting, roosting, foraging habitat is stable or increasing throughout the range, from the date of Revised Recovery Plan approval, as measured by effectiveness monitoring efforts or other reliable habitat-monitoring programs.

Recovery Criterion 4 – Post-delisting Monitoring: To monitor the continued stability of the recovered spotted owl, a post-delisting monitoring plan has been developed and is ready for implementation within the States of Washington, Oregon, and California (as required by section 4(g)(1) of the ESA).

Recovery Actions

In this Revised Recovery Plan, we have retained some of the original recovery actions from the 2008 Recovery Plan, introduced some new recovery actions, and revised some from the 2008 Recovery Plan to reflect new information, and updated status, in order to clarify our intent or respond to public comments. Generally, recovery actions follow the order of the listing factors. However, the first recovery action pertaining to implementation of this Revised Recovery Plan and Recovery Actions 2-4, which address Recovery Criterion 1, do not fit into any of the listing factors and so are presented first. The first recovery criterion assesses the spotted owl's population status. The Service believes this criterion is the best way to assess whether the five listing factors—that is, the threats facing the spotted owl—are addressed. For a more complete description of the threats to the spotted owl addressed by these recovery actions, see Appendix B.

Northern Spotted Owl Recovery Implementation Oversight

This Recovery Action pertains to all listing factors.

- ***Recovery Action 1: For each State, the FWS will designate offices that will coordinate implementation of the spotted owl recovery plan. These offices will work with local and regional partners to best ensure actions taken within that management jurisdiction are meeting the intention of the recovery plan while taking local context and variation into account. The Oregon Fish and Wildlife Office will remain the overall lead for the species and provide technical assistance and oversight to the other FWS offices as needed.*** We have established and lead an interagency and inter-organizational Northern Spotted Owl Implementation Team (NSOIT) designed to help coordinate implementation of this Revised Recovery Plan throughout the range of the species.

Monitoring and Inventory

These Recovery Actions also pertain to all listing factors.

- ***Recovery Action 2: Continue annual monitoring of the population trend of spotted owls to determine if the population is decreasing, stationary or increasing.*** Monitoring in demographic study areas is currently the primary method to assess the status of populations of spotted owls. Other statistically valid monitoring methods (*i.e.*, analytically robust and representative of the entire province and range) may be possible and could potentially fulfill this recovery action.

- ***Recovery Action 3: Conduct occupancy inventory or predictive modeling needed to determine if Recovery Criteria 1 and 2 have been met.*** It is expected this inventory will begin when it appears the spotted owl is close to meeting Recovery Criterion 1. Modeling techniques have improved recently, so predictive modeling may be part of the methodology for estimating spotted owl occupancy across the range.

LISTING FACTOR A: THE PRESENT OR THREATENED DESTRUCTION, MODIFICATION, OR CURTAILMENT OF THE SPECIES' HABITAT OR RANGE.

The key threats identified that relate to this listing factor are: (1) loss of habitat and changes in distribution of habitat as a result of past activities and disturbances, due especially to timber harvest and permanent conversion of habitat; and (2) ongoing habitat loss from natural disturbance (especially fire), timber harvest, and permanent conversion of habitat (see Appendix B).

Therefore, this Revised Recovery Plan recommends two basic strategies to address these threats: (1) conserve more occupied habitat and unoccupied high-value habitat; and (2) encourage and initiate active management actions that restore, enhance, and promote development of high value habitat, consistent with broader ecological restoration goals.

- ***Recovery Action 4: Use the habitat modeling process described above and in Appendix C to identify and implement recovery actions and conservation measures that would contribute to spotted owl recovery, including testing the efficacy of various habitat conservation network scenarios at conserving spotted owl habitat. Use the results from this effort to inform decisions concerning the possible development of habitat conservation networks.***

The following discussion provides the background and justification for the various recovery actions that address Listing Factor A. First, it is important to understand the potential changes in spotted owl habitat conditions and landscape ecological processes due to ongoing climate change. These changes are occurring throughout the spotted owl's range but are currently most serious in the drier portions of the range, and they affect both the species' habitat and its distribution. Second, we address emerging scientific principles of forestry science and "ecological forestry," and how forest scientists are trying to manage spotted owl habitat for resiliency and uncertainty in the face of climate change. And third, we discuss how the science of spotted owl recovery can fit within and be compatible with the broader forest ecosystem science and strategies that land managers are applying in order to be make spotted owl conservation efforts sustainable into the future. These strategies differ from moist forests to dry forest, and on Federal land versus private lands. Specific recovery actions are presented in the context of the relevant sections where management issues are discussed.

Climate Change and Forest Ecosystems

Climate change, combined with effects from past management practices, is exacerbating changes in forest ecosystem processes and dynamics to a greater degree than originally anticipated in the NWFP. This includes patterns of wildfire, insect outbreaks, drought, and disease. Many researchers believe there is a need to manage forests within an increasingly dynamic and unpredictable future that is driven by climate change (Perera *et al.* 2004, Millar *et al.* 2007, Kurz *et al.* 2008, Heyerdahl *et al.* 2008, Blate *et al.* 2009, Kennedy and Wimberly 2009, Krawchuk *et al.* 2009, Littell *et al.* 2008, 2009, 2010, Reinhardt *et al.* 2008, Johnson and Franklin 2009, Mitchell *et al.* 2009, Spies *et al.* 2010a,b). The preponderance of recent scientific research and opinion on climate change has coalesced around several key points concerning temperature, precipitation, wildfire, and insect and disease outbreaks.

Temperature and Precipitation

In the Pacific Northwest, mean annual temperatures rose 0.8° C (1.5° F) in the 20th century and are expected to continue to warm from 0.1° to 0.6° C (0.2 ° to 1 ° F) per decade (Mote and Salathe 2010). Global climate models project an increase of 1 to 2 percent in annual average precipitation, with some predicting wetter autumns and winters with drier summers (Mote and Salathe 2010). University of Washington researchers (Salathe *et al.* 2009) have developed finer-resolution, regional, predictive climate models that account for local terrain and other factors that affect weather (*e.g.*, snow cover, cloudiness, soil moisture, and circulation patterns) in the Pacific Northwest. These models agree with the global climate models in projecting warmer, drier summers and warmer, wetter autumns and winters for the Pacific Northwest, which will result in diminished snowpack, earlier snowmelt, and an increase in extreme heat waves and precipitation events.

On the cooler, moister west side of the Cascades, the summer water deficit is projected to increase two- to three-fold over current conditions (Littell 2009). East of the Cascade Crest, summer soil deficits may not change as much or may even moderate slightly over current conditions (Elsner *et al.* 2009). Researchers expect some ecosystems to become more water-limited, more sensitive to variability in temperature, and more prone to disturbance (McKenzie *et al.* 2009). There is evidence that the productivity of many high-elevation forests, where low summer temperature and winter snowpack limits the length of the growing season, is increasing in the Pacific Northwest as temperatures rise, potentially increasing the elevation of the tree line (Graumlich *et al.* 1989, Case and Peterson 2009). Conversely, productivity and tree growth in many low-elevation Pacific Northwest forests is likely to decrease due to the longer, warmer summers (Case and Peterson 2009). This may result in a change in species composition or reduction in the acreage of existing low-elevation forests.

Wildfire

Wildfire size and frequency have been increasing in the dry, fire prone forests of the western U.S. as a result of changing climatic conditions and past management activities (Westerling *et al.* 2006, Heyerdahl *et al.* 2008, Reinhardt *et al.* 2008, Wiedinmyer and Hurteau 2010, Spies *et al.* 2010a), although some researchers have suggested finer scale exceptions to this general pattern (Odion *et al.* 2004, Heyerdahl *et al.* 2008, Krawchuk *et al.* 2009, Hanson *et al.* 2009, 2010). According to Schafer *et al.* (2010), "An increase in fire activity is expected for *all* major forest types in Oregon" (emphasis original), and areas burned by fire in the Pacific Northwest are likely to increase substantially in the coming century (Hessburg *et al.* 2005, 2007, Kennedy and Wimberly 2009, Littell *et al.* 2009, 2010, Shafer *et al.* 2010).

Natural landscape resilience mechanisms have been decoupled by fire exclusion and wildfire suppression activities (Hessburg *et al.* 2005, Moritz *et al.* 2011).

Before the era of management, patchworks of burned and recovering vegetation, caused by mostly small and medium-sized fires, reduced the likelihood of the largest fires, which usually resulted from extreme weather events. Twentieth-century fire suppression eliminated most of these fires, and forest landscapes are now susceptible to large wildfires.

Stand-replacing events and disturbances will speed up ecological "conversions" (*e.g.*, forests to shrublands) (Joyce *et al.* 2008, Blate *et al.* 2009, Littell *et al.* 2010). Dry forests are at greater risk to large scale disturbances (Agee and Skinner 2005, Mitchell *et al.* 2009), but recent research suggests "that large disturbances are likely in west-side forests that have not traditionally been thought of as fire prone," and "it is therefore reasonable to expect increased fire activity" in such forests (Littell *et al.* 2010). Dry forests are treated in greater detail later in this section.

Older forests in the range of the spotted owl are being lost due to fire (Spies *et al.* 2006, 2010b, Ager *et al.* 2007a, Clark 2007, Healey *et al.* 2008, Kennedy and Wimberly 2009, Hanson *et al.* 2009, 2010), especially east of the Cascades and in the Klamath Province. However, some patches of habitat may be more resistant to climate change effects than others. A study on the east side of the Cascade Mountains found that areas of high soil and fuel moisture had historically created fire refugia where late-successional forest persisted longer (Camp *et al.* 1997). These patches were often near streams or valley bottoms, had perched water tables, or were near headwalls where soil moisture was higher. They were also often at higher elevations where total precipitation was higher or on northern aspects of mountains where terrain was shaded longer. Daley *et al.* (2009) found that cold air pooling in some mountain valleys may decouple or shelter the local microclimate from regional climate conditions. These studies imply that some areas on the landscape may resist climate-driven disturbances that may affect spotted owls and their habitat.

Insect and Disease Outbreaks

Climate change is affecting the location, size and intensity of insect outbreaks, which in turn affect fire and other forest processes (Joyce *et al.* 2008, Kurz *et al.* 2008, Littell *et al.* 2009, 2010, Latta *et al.* 2010, Spies *et al.* 2010a). Warming temperatures have led to mountain pine beetle outbreaks, with large-scale effects in some western forests, including in the eastern Cascades. In warmer winters more mountain pine beetles survive and shorten their generation time, resulting in larger and more severe outbreaks. Drought can heighten the susceptibility of host trees to attack (Littell *et al.* 2010). Littell *et al.* (2010) suggest that the greatest likelihood of mountain pine beetle attack is when conditions are hot and dry combined with a fairly short period of extreme vapor pressure deficit, when trees are most vulnerable. In the future, outbreaks are projected to increase at higher elevations and decrease at lower elevations (Littell *et al.* 2010), with uncertain implications for spotted owls. Littell *et al.* (2010) have projected that the combination of increased tree susceptibility and mountain pine beetle outbreaks could lead to the loss of pine species in the eastern Cascades as early as the 2040s.

Mixed conifer stands in the eastern Cascades, which include pine species, provide den sites and food resources for bushy-tailed woodrats, an important prey species of spotted owls (Lehmkuhl *et al.* 2006a). Warmer winters have also been shown to increase the incidence of Swiss needle cast, a fungal disease in Douglas-fir on the Oregon coast (Manter *et al.* 2005) inhibiting tree growth, and causing severe chlorosis and defoliation. We are uncertain how significantly this will affect spotted owl habitat.

Effects of Weather and Climate on Spotted Owl Demography

The influence of weather and climate on spotted owl populations was evidenced in northern California (Franklin *et al.* 2000), Oregon, and Washington (Glenn 2009). Climate accounted for 84 and 78 percent of the temporal variation in population change of spotted owls in the Tyee and Oregon Coast Range study areas, respectively (Glenn 2009). Climate and barred owls together accounted for nearly all (~100 percent) of the changes in spotted owl survival in the Oregon Coast Range (Glenn 2009).

Wet, cold weather during the winter or nesting season, particularly the early nesting season, has been shown to negatively affect spotted owl reproduction (Olson *et al.* 2004, Dugger *et al.* 2005), survival (Franklin *et al.* 2000, Olson *et al.* 2004, Glenn 2009), and recruitment (Franklin *et al.* 2000). Cold, wet weather may reduce reproduction and/or survival during the breeding season due to declines or decreased activity in small mammal populations so that less food is available during reproduction when metabolic demands are high (Glenn 2009). Wet, cold springs or intense storms during this time may reduce the time it takes for an adult bird to starve (Franklin *et al.* 2000). Cold, wet weather may also inhibit the male spotted owl's ability to bring food to incubating females or nestlings (Franklin *et al.* 2000). Cold, wet nesting seasons may increase the mortality of nestlings due to chilling (Franklin *et al.* 2000) and reduce the number of young fledged per pair per year (Franklin *et al.* 2000, Glenn 2009). Wet, cold weather may decrease survival of dispersing juveniles during their first winter thereby reducing recruitment (Franklin *et al.* 2000).

Drought or hot temperatures during the previous summer have also reduced spotted owl recruitment and survival (Franklin *et al.* 2000, Glenn 2009). Drier, warmer summers and drought conditions during the growing season strongly influence primary production in forests, food availability, and the population sizes of small mammals (Glenn 2009). Northern flying squirrels, for example, forage primarily on ectomycorrhizal fungi (truffles), many of which grow better under mesic, or moist, conditions (Lehmkuhl *et al.* 2004). Drier, warmer summers, or the high-intensity fires, which such conditions support, may change the range or availability of these fungi, affecting northern flying squirrels and the spotted owls that prey on them. Periods of drought are associated with declines in annual survival rates for other raptors due to a presumed decrease in prey availability (Glenn 2009).

Survival, recruitment, and reproduction increased with precipitation in the late spring or summer (Olson *et al.* 2004, Glenn 2009). Olson *et al.* (2004) found that while survival decreased with early-nesting season precipitation, it increased with late-nesting season precipitation. This is probably due to reducing the potential for drought to occur.

In addition to effects on habitat, the heat itself may have physiological effects on spotted owls. Weathers *et al.* (2001) suggest California spotted owls (*Strix occidentalis occidentalis*) are less heat-tolerant than other owls responding to temperatures of 30 to 34 $^{\circ}$ C (86 $^{\circ}$– 93 $^{\circ}$ F) with increased breathing rates, fluffing of feathers, and wing drooping. Northern spotted owls in an earlier study (Barrows 1981) showed signs of heat stress at even more modest temperatures of 27 to 31 $^{\circ}$ C (81 $^{\circ}$–88 $^{\circ}$ F). We have no current information on how this affects survival or reproduction.

The presence of high-quality habitat appears to buffer the negative effects of cold, wet springs and winters on survival of spotted owls as well as ameliorate the effects of heat. High-quality spotted owl habitat was defined in a northern California study area as a mature or old growth core within a mosaic of different seral stages (Franklin *et al.* 2000). The high-quality habitat might help maintain a stable prey base, thereby reducing the cost of foraging during the early breeding season when energetic needs are high (Carey *et al.* 1992, Franklin *et al.* 2000).

Barred Owls, Spotted Owls, and Climate Change

Although the scientific literature has explored the link between climate change and the invasion by barred owls, changing climate alone is unlikely to have caused the invasion (Livezey 2009b). In general, climate change can increase the success of introduced or invasive species in colonizing new territory (Dale *et al.* 2001). Invasive animal species are more likely to be generalists, such as the barred owl, than specialists, such as the spotted owl and adapt more successfully to a new climate than natives (Dukes and Mooney 1999).

Implications for Spotted Owl Conservation

While a change in forest composition or extent is likely as the result of climate change, the rate of that change is uncertain. In forests with long-lived dominant tree species, mature individuals can survive these stresses, so direct effects of climate on forest composition and structure would most likely occur over a longer time scale (100 to 500 years) in some areas than disturbances such as wildfire or insect outbreaks (25 to 100 years)(McKenzie *et al.* 2009). Some changes appear to be already occurring. Regional warming and consequent drought stress appear to be the most likely drivers of an increase in the mortality rate of trees in recent decades in the western United States. The increase was evident across regions (Pacific Northwest, California), elevations (*i.e.*, topography), tree size, type of trees, and fire-return-intervals (van Mantgem *et al.* 2009).

As summarized above, it is clear that ecosystem-level changes are occurring within the spotted owl's forest habitat. Therefore, many of the recovery actions proposed for spotted owls must take into account the uncertainty associated with climate change predictions. There are short-term risks and tradeoffs for long-term benefits when assessing the relative merits of active management (Roloff *et al.* 2005, Spies *et al.* 2006, Carey 2007, Millar *et al.* 2007, Blate *et al.* 2009). As discussed below, landscape-level adaptive management strategies that include active management of forest habitat should be encouraged (Wright and Agee 2004, Lee and Irwin 2005, Carey 2007, Keeton *et al.* 2007, Littell *et al.* 2008). Millar *et al.* (2007) suggest a conceptual framework for managing forested ecosystems in a way that helps ecosystems accommodate changes adaptively. These "adaptation" strategies include: (1) resistance options (to forestall impacts and protect highly valued resources), (2) resilience options (to improve the capacity of ecosystems to return to desired conditions after disturbance), and (3) response options (to facilitate transition of ecosystems from current to new conditions). This framework has value in planning actions to help spotted owls accommodate future climate changes and is discussed in more detail below.

Part of the Service-wide priority for responding to climate change is to conduct species and habitat vulnerability assessments, an analytical tool for determining how climate change will affect a species, habitat, or ecosystem and for developing strategies to safeguard these resources (USFWS 2009). Methodologies have been developed in recent years to conduct vulnerability assessments, some of which may be useful for determining appropriate recovery actions, given the climate change effects on the spotted owl and its habitat (Stein 2010).

Recovery implementation for spotted owls should also, wherever feasible, look for opportunities where managing for spotted owl habitat also meets other societal priorities concerning climate change. For example, the highest densities of forest biomass carbon storage in North America occur in the conifer forests of the Pacific Northwest (Sundquist *et al.* 2009, Keith *et al.* 2010). Older forests with longer rotations may be more effective at sequestering carbon than younger, more intensively managed tree plantations (Schulze *et al.* 2000, Luyssaert 2008), but all forest lands may have value for the purpose of carbon sequestration. Effectiveness in this goal may depend on very specific prescriptions and locales. Preliminary research funded by the Service indicates that forests in Oregon have tremendous potential for carbon sequestration on State forest lands in the Coast Range (Davies *et al*. 2011), and nearby lands likely have similar potential. Likewise, managing for carbon sequestration means it is also necessary to manage forest biomass and the risks of stand replacing wildfire (Canadell and Raupach 2008). As of this writing it is unclear what role, if any, Federal and State forest lands will ultimately play in mitigating climate change, but some policy analysts have begun to frame this issue (see Depro *et al.* 2008).

Therefore, to be consistent with the Secretarial Order as well as other Service initiatives (*e.g.*, Landscape Conservation Cooperatives), we are recommending researchers emphasize ecological and economic overlap between recovery actions for spotted owls and action to mitigation climate change. For example, more research should be conducted on the relative compatibility or conflict between thinning a forest to reduce fire risk, its impact on long-term spotted owl habitat quality, and the action's mitigation of climate change impacts. Although thinning activity removes carbon from the forest system in the short-term, it may reduce the risk of a subsequent carbon release through fire or disease outbreak, and it also encourages carbon being concentrated in fewer, larger trees that approximate old-growth structure of pre-fire suppression forests (Hurteau *et al.* 2008). The validity of such a concept is not in dispute among mainstream scientists but, as discussed elsewhere in this document, there is significant disagreement regarding where, when, and how to implement such management measures to optimize the potential for positive outcomes.

- ***Recovery Action 5 – Consistent with Executive Order 3226, as amended, the Service will consider, analyze and incorporate as appropriate potential climate change impacts in long-range planning, setting priorities for scientific research and investigations, and/or when making major decisions affecting the spotted owl.***

Spotted Owls and Ecological Forestry

As documented above, there is a strong scientific consensus that Pacific Northwest forests will be – and already are – undergoing significant changes from current conditions due to past management practices, shifting disturbance patterns, and changing climate influences. There is a variety of scientific opinion regarding the extent to which land managers can manage or positively influence these changes (Millar *et al.* 2007, Reinhardt *et al.* 2008), and how such shifts may affect spotted owls (see, *e.g.*, Hanson *et al.* 2009, 2010 and Spies *et al.* 2010b). To address this uncertainty, we propose applying "active forest management" as part of a spotted owl recovery strategy that includes "ecological forestry and restoration" as described by Franklin *et al.* (2007), Carey (2007), Johnson and Franklin (2009), Long (2009), and Spies *et al.* (2010a), among others. We recommend that land managers consider implementing forest restoration activities where the best available science suggests ecosystems and spotted owls would benefit in the long-term.

We recognize that this recommendation may be controversial. As described below, some forest areas need or would benefit from restoration treatments, whereas others are at less risk or the science is less clear about how to treat certain areas. We make this recommendation to apply ecological forestry and restoration in many parts of the spotted owl's range because:

- Climate change is rapidly altering forest ecosystems within the range of the spotted owl with some unpredictable or potentially undesirable outcomes (Lenihan *et al.* 2008, Littell *et al.* 2010, Shafer *et al.* 2010, Spies *et al.* 2010a);
- The Service, forest managers, and policy makers must take reasonable but proactive steps to conserve forest ecosystems and spotted owls in the face

of past management and future uncertainty (Agee 2002, Carey 2007, Gaines *et al.* 2010); and

- There is a scientific and social consensus emerging that land managers must restore more sustainable (resistant and resilient) ecological processes to forests at various landscape scales (Hessburg *et al.* 2004, Millar *et al.* 2007, Long 2009, Moritz *et al.* 2011).

First, it is worth noting that this recommendation is consistent with a primary goal of the NWFP – the conservation of ecological processes (FEMAT 1993, App. VIII) – and thus should be addressed within the existing planning and adaptive management framework currently in place for Federal lands in the range of the spotted owl. The concept of "conservation of ecological processes" has long been an underlying principle of "ecosystem management" and should be familiar to most land managers in the Pacific Northwest. Ricklefs *et al.* (1984) proposed this concept to include basic ecological cycles on large landscapes, such as the soil formation cycle and the hydrological cycle, with the understanding that fish and wildlife resources are integral to these cycles. That is, conserve the ecological processes and you conserve fish and wildlife. In the 1980s and 1990s, ecosystem management emerged as a dominant theme in managing large landscapes across varied ownerships. Some examples include management of the Greater Yellowstone Ecosystem, the Florida Everglades, the coastal sage scrub of Southern California and the forests of the Pacific Northwest with the NWFP. The NWFP explicitly includes this goal of conserving natural processes (FEMAT 1993, App. VIII).

Natural disturbance processes – wildfire, disease, insect outbreaks and windthrow – are important forces that influence spotted owl habitat. The scientific study and emulation of these processes has emerged as a "dominant paradigm in North American forest management" (Long 2009). Much of this work has occurred in the Pacific Northwest and has direct applicability to forest management in the range of the spotted owl (*e.g.*, Franklin *et al.* 2002, Perera *et al.* 2004, Hessburg *et al.* 2004, Wright and Agee 2004, Nitschke 2005, Drever *et al.* 2006, Noss *et al.* 2006, Carey 2007, Franklin *et al.* 2007, O'Hara 2009, Johnson and Franklin 2009, Long 2009, Odion *et al.* 2010, Swanson *et al.* 2010). A good synopsis of disturbance-based management for forested systems is provided by North and Keeton (2008:366):

> "Disturbance-based forest management is a conceptual approach where the central premise might be summarized as 'manipulation of forest ecosystems should work within the limits established by natural disturbance patterns prior to extensive human alteration of the landscape' (Seymour and Hunter 1999). Although such an objective seems like a simple extension of traditional silviculture, it fundamentally differs from past fine-filter approaches that have manipulated forests for specific objectives such as timber production, water yield, or endangered species habitat. Some critics have argued that this approach leaves managers without clear guidelines because the scale and processes of ecosystems are poorly defined, making it difficult to directly emulate the ecological effects of natural disturbances.

> Disturbance-based management, however, readily acknowledges these uncertainties. It emphasizes a cautious approach, targeted at those specific management objectives, such as provision of complex habitat structures, reduced harvesting impacts, and landscape connectivity that can be achieved. Although this approach will require changes in how management success is evaluated, disturbance-based management is likely to minimize adverse impacts on complex ecological processes that knit together the forest landscape."

The Service continues to recommend that active forest management and disturbance-based principles be applied throughout the range of the spotted owl with the goal of maintaining or restoring forest ecosystem structure, composition and processes so they are sustainable and resilient under current and future climate conditions in order to provide for long-term conservation of the species. The majority of published studies support this general approach for Pacific Northwest forests, although there is some disagreement regarding how best to achieve it. We received widely varying recommendations for meeting this goal from knowledgeable scientists. Most of this variance in opinion is due to the scientific uncertainty in: (1) accurately describing the ecological "reference condition" or the "natural range of variability" in historical ecological processes, such as fire and insect outbreaks across the varied forest landscape within the range of the spotted owl (*e.g.*, see Hessburg *et al.* 2005, and Keane *et al.* 2002, 2009); and (2) confidently predicting future ecological outcomes on this landscape due to rapid, climate-driven changes in these natural processes, with little precedent in the historical (or prehistoric) record (Drever *et al.* 2006, Millar *et al.* 2007, Long 2009, Littell *et al.* 2010).

These are very real problems that should be addressed with more research (Strittholt *et al.* 2006, Kennedy and Wimberly 2009). In the meantime, addressing this uncertainty in a careful but active manner is the challenge of this Revised Recovery Plan and of forest management in general. The Service agrees with those climate scientists and forest researchers who propose that decision makers must deploy a suite of reactive and proactive approaches to cope with the impacts of climate change on forest lands, while taking into account both short- and long-term timeframes and differing landscape scales (Millar *et al.* 2007, Joyce *et al.* 2008, Reinhardt *et al.* 2008, Blate *et al.* 2009, Gaines *et al.* 2010, Spies *et al.* 2010a, Moritz *et al.* 2011). This strategy should incorporate the concept of "adaptation" into forest management decisions (Drever *et al.* 2006, Joyce *et al.* 2008, Long 2009, Littell *et al.* 2010). Adaptation options include: (1) resisting change; (2) promoting resilience to change; and (3) allowing forest ecosystems to respond to change (Millar *et al.* 2007, Joyce *et al.* 2008, Blate *et al.* 2009, Littell *et al.* 2010).

Resistance strategies are usually deployed to protect high-value resources, such as human structures or very rare habitats. They can be expensive and labor intensive, and include actions such as fire suppression across large and rugged landscapes. Resilience-enhancing adaptations include managing within the bounds of natural disturbance processes by emulating these processes through prescriptive actions (Peterson *et al.* 1998, Franklin *et al.* 2002, Drever *et al.* 2006, Joyce *et al.* 2008). This approach will likely lead to the restoration and maintenance of forest ecosystems which are resilient to a wide range of environmental challenges or scenarios (Long 2009). Allowing forest ecosystems to change as resilience thresholds are crossed means minimizing dramatic and abrupt transitions from one ecosystem condition to another (*e.g.*, forest to shrubland), thereby also minimizing disruptions to important ecological processes (*e.g.*, species dispersal, hydrological cycle, etc.) (Hessburg *et al.* 2005, Blate *et al.* 2009).

Maintaining or improving ecosystem resilience in the face of climate change should be a fundamental goal of forest land managers (Hessburg *et al.* 2005, Reinhardt *et al.* 2008, Lawler 2009, Littell *et al.* 2010). "Resilient forests are those that not only accommodate gradual changes related to climate but tend to return toward a prior condition after disturbance either naturally or with management assistance" (Millar *et al.* 2007). Managing for resilient forests should also be considered a fundamental recovery goal for spotted owls. Federal land managers should apply ecological forestry principles where long-term spotted owl recovery will benefit, even if short-term impacts to spotted owls may occur (Franklin *et al.* 2006) to improve the resiliency of the landscape in light of threats to spotted owl habitat from climate change and other disturbances. For example, managers should promote spatial heterogeneity within patches and local and regional landscapes, restore lost species and structural diversity (including hardwoods) within the historical range of variability, and restore ecological processes to historical levels and intensities (Franklin *et al.* 2002, 2007, Drever *et al.* 2006, Long 2009). This includes early-successional ecosystems on some forest sites (Swanson *et al.* 2010, Perry *et al.* 2011). Some of these management actions may degrade spotted owl habitat in local areas in the short-term (Franklin *et al.* 2006, Spies *et al.* 2006, 2010a), but may be beneficial to spotted owls in the long-term if they reduce future losses of ecosystem structure or better incorporate future disturbance events to improve overall forest ecosystem resilience to climate change (Roloff *et al.* 2005, Ager *et al.* 2007a, Spies *et al.* 2010a).

Of course, trade-offs that affect spotted owl recovery will need to be assessed on the ground, on a case-by-case basis with careful consideration given to the specific geographical and temporal context of a proposed action. There is no "one right prescription." Specific patch-level prescriptions are impossible to make in this Revised Recovery Plan given the tremendous variety in conditions and land management goals across the species' range. Each forest is unique (Agee 2002), and landscape and site-specific assessments need to be made (Lee and Irwin 2005). Prescriptive management goals to address climate change concerns vary across the spectrum of forest types, landscapes, and ownership (Millar *et al.* 2007). When considering a potential restoration treatment project, it will be necessary for land managers working with the Service and other interested stakeholders to weigh the potential tradeoffs between short-term impacts to spotted owl habitat versus longer-term ecosystem restoration outcomes. While our understanding of short- and long-term effects of ecosystem restoration actions on spotted owls is limited at this time, research on effects of more traditional forest management practices on spotted owls and their prey has been conducted and is discussed below. These studies provide data that should inform development of restoration projects to develop desired future conditions while best maintaining existing spotted owls on the landscape. In addition, projects with these types of effects on Federal land will undergo section 7 consultation to assess the impact to the spotted owl.

Effects of Forest Management Practices on Spotted Owls

Before applying ecological forestry principles and implementing the recommendations in this Plan, it is necessary to summarize the scientific understanding of how various forest management practices affect spotted owls. Historically, many of the timber management practices used in the Pacific Northwest have had detrimental consequences for spotted owls. Clearcuts, shelterwoods and heavy commercial thinning operations have typically converted spotted owl habitat to non-habitat. Several peer-reviewed publications (Forsman *et al.* 1984, Zabel *et al.* 1992, Buchanan *et al.*1995, Hicks *et al.* 1999, Meiman *et al.* 2003), three master's theses (Solis 1983, Sisco 1990, King 1993) and a number of reports (Anthony and Wagner 1999, Irwin *et al.* 2005, Irwin *et al.* 2008, Irwin *et al.* 2010) specifically addressed effects of timber harvest (primarily thinning operations) on spotted owls, and results of these studies were summarized by Hansen and Mazurek (2010). In most of these studies, one to two spotted owls were affected by thinning projects, and data on thinning effects were collected incidental to larger research objectives. Furthermore, timber harvest activities in these studies were generally not designed or intended to develop future spotted owl habitat.

Among those studies that reported spotted owl responses to thinning or other timber harvest activities, four studies (Forsman *et al.* 1984, King 1993, Hicks *et al.* 1999, Meiman *et al.* 2003) found spotted owls were displaced by contemporary harvest near the nest or activity center. Based on observations of nine spotted owl territories where harvest occurred during the study, Forsman *et al.* (1984) suggested that negative effects (decreased reproduction, site abandonment) of thinning or selective harvest were most likely associated with higher-intensity thinning, timber harvest close to the nest area and when the affected owl site had low amounts of alternative habitat available. Similarly, Meiman *et al.* (2003) reported that a male spotted owl expanded his home range and shifted foraging and roosting away from a thinning operation located close to the nest tree. Consequently, they recommended harvest operations not be conducted near spotted owl nest sites. While harvest activities tend to decrease use by spotted owls during and immediately following the action, spotted owl use of previously logged forest (selectively logged or thinned) was demonstrated in a number of cases: four of these 12 studies reported nesting attempts, five reported roosting, and nine described foraging activities in stands that had been thinned or selectively logged one to five decades earlier (Hansen and Mazurek 2010). Given the small number of spotted owls studied, the information provided in these studies is insufficient for drawing firm conclusions about the effects of thinning prescriptions on spotted owls.

Another important consideration is the effect of vegetation management on spotted owl prey species, including northern flying squirrels, dusky-footed woodrats, bushy-tailed woodrats and other small mammals. The northern flying squirrel's relationships with forest seral stages, forest structure and land management have been a topic of considerable research and debate. Some studies have found that densities of flying squirrels are highest in old forests (Carey *et al.* 1992, Carey 1995), whereas others have suggested that the species is a generalist with respect to seral stage or stand age (Rosenberg and Anthony 1992, Waters and Zabel 1995, Ransome and Sullivan 1997). Studies of the effects of timber harvest on northern flying squirrels have generally found negative responses to thinning, although results have varied across studies. Several studies have suggested that forest thinning can temporarily (*e.g.*, up to 20 years) reduce the availability of truffles, which are a key food resource for northern flying squirrels and other small mammals on which spotted owls depend (Waters *et al.* 1994, Colgan *et al.* 1999, Luoma *et al.* 2003, Meyer *et al.* 2005). However, studies in British Columbia did not find any significant short-term differences in densities, movements or reproduction of flying squirrels in young, commercially-thinned stands versus unthinned young stands (Ransome and Sullivan 2002, Ransome *et al.* 2004). Carey (2000) found lower abundances of flying squirrels in recently-thinned (within 10 years) stands in Washington than in stands that were clear-cut 50 years prior to the study, with retention of both live and dead trees. He attributed his results to the apparently negative effects of commercial thinning on canopy connectivity, downed wood and truffle communities in the area. Wilson (2010) also reported most thinning is likely to suppress flying squirrel populations for several decades, but the long-term benefits of variable-density thinning for squirrels are likely to be positive. He emphasized that developing the next layer of trees is critical if the goal is to accelerate late-seral conditions and promote prey for spotted owl, and complex structure favorable to squirrels may be achieved sooner in younger stands where there is a shorter vertical distance between the ground and the bottom of the canopy.

Mixed results have also been reported in studies that examined effects of thinning on woodrats. Dusky-footed woodrats occur in a variety of conditions, including both old, structurally complex forests and younger seral stages, and are often associated with streams (Raphael 1987, Carey *et al.* 1992, 1999, Williams *et al.* 1992, Sakai and Noon 1993, Anthony *et al.* 2003, Hamm and Diller 2009). Research has suggested that thinning or associated practices (*e.g.*, burning slash piles) could be detrimental to dusky-footed woodrats if it reduces hardwoods, shrubs or downed wood, yet treatments could ultimately benefit woodrats if they result in growth of shrubs or hardwoods (Williams *et al.* 1992, Innes *et al.* 2007). Bushy-tailed woodrats may be more limited by abiotic features, such as the availability of suitable rocky areas for den sites (Smith 1997) or the presence of streams (Carey *et al.* 1992, 1999). Similar to dusky-footed woodrats, forms of thinning that reduce availability of snags, downed wood or mistletoe could negatively impact bushy-tailed woodrat populations (Lehmkuhl *et al.* 2006a). A study of dusky-footed woodrats in the redwood region of California, however, did not find an association between abundances of woodrats and different intensities of commercial thinning (Hamm and Diller 2009).

Results from these studies suggest that active management projects should explicitly evaluate the short-term impacts to spotted owls and their prey while considering the long-term ecological benefits of such projects, especially in spotted owl core-use areas. Spotted owl home ranges generally have a greater proportion of older forest within the core-use area and more diverse forest conditions on the periphery of their ranges (Swindle *et al.* 1999). The studies referenced above primarily described effects of commercial timber harvest; management designed under an ecological forestry framework should avoid existing high value habitat, if possible, while meeting long-term restoration goals. Within provincial home ranges but outside core-use areas, opportunities exist to conduct vegetation management to enhance development of late-successional characteristics or meet other restoration goals in a manner compatible with retaining resident spotted owls. Restoration activities conducted near spotted owl sites should first focus on areas of younger forest less likely to be used by spotted owls and less likely to develop late-successional forest characteristics without vegetation management. Vegetation management should be designed to include a mix of disturbed and undisturbed areas, retention of woody debris and development of understory structural diversity to maintain small mammal populations across the landscape.

At regional landscape scales, managers should consider how spotted owls fit into a larger ecological framework. Additional factors including historical disturbance regimes and different forest vegetation communities need to be considered. The following section addresses these regional differences in more detail. As ecological forestry is considered and applied in the Pacific Northwest, forest ecosystem management goals will differ between moist and dry forests, and between northern interior portions of the range versus coastal areas in California (Spies *et al.* 2006, Strittholt *et al.* 2006, Mitchell *et al.* 2009). The following sections provide some principles for land managers to consider in these differing forests within the spotted owl's range.

Habitat Management in Moist Forests

A primary spotted owl recovery goal of this Revised Recovery Plan for moist forests is to conserve older stands that are either occupied or contain high-value spotted owl habitat; this recovery goal is discussed in greater detail later under Recovery Action 10 and Recovery Action 32. On Federal lands these recommendations apply to reserved and non-reserved land allocations.

Managers of the moist forest landscapes recognize that emulating natural disturbance patterns at large landscape levels will be very difficult (Wimberly *et al.* 2004). In contrast to dry forests, short-term fire risk is generally lower in the moist forests that are the dominant condition on the west side of the Cascade Range, and disturbance-based management for forests and spotted owls here should be different. Silvicultural treatments are generally not needed to maintain existing old-growth forests on moist sites (Wimberly *et al.* 2004, Johnson and Franklin 2009). Efforts to alter either fuel loading or potential fire behavior in these sites could have undesirable ecological consequences (Johnson and Franklin 2009, Mitchell *et al.* 2009). Potential management in older forests, either for climate-related management or spotted owl recovery, must explicitly weigh the relative pros and cons of such activities.

However, this recommendation should be reassessed regularly as new scientific information emerges regarding climate change. For example, Littell *et al.* (2010) suggest climate-driven fire risk may increase on the west-side in moist forests, and Shafer *et al.* (2010) conclude that fire activity is expected to increases in all forest types in Oregon. Although these model predictions are still highly variable, the recommendations of mainstream climate scientists (Littell *et al.* 2010, Shafer *et al.* 2010) should be incorporated into longer-term planning. Wimberly *et al.* (2004) give some recommendations to consider in the Oregon Coast Range that address historical fire regimes and disturbance patterns.

Even with uncertain model predictions, there are younger or less diverse moist forest areas outside of old-growth stands where active management could promote ecological goals, including spotted owl recovery. The most current evaluations suggest climate change in the Pacific Northwest is affecting processes in addition to wildfire, including insect and disease outbreaks and changes in species composition (Latta *et al.* 2010, Littell *et al.* 2010, Spies *et al.* 2010a). Therefore, ecological forestry and active management in the range of the spotted owl should address issues in addition to wildfire dynamics. For example, where past management practices have decreased age-class diversity and altered the structure of forest patches, targeted vegetation treatments could simultaneously reduce fuel loads and increase canopy and age-class diversity (Franklin *et al.* 2002, 2006, Wimberly *et al.* 2004, Littell *et al.* 2010). Likewise, there may be post-disturbance opportunities to restore more natural, early successional forest conditions that provide more ecological benefits to spotted owls (and other native forest species) than do traditional clearcuts and young, even-aged stands (Swanson *et al.* 2010).

Long-term spotted owl recovery could benefit from forest management where the basic goals are to restore or maintain ecological processes and resilience. Therefore, we recommend application of disturbance-based principles to such decisions (Franklin *et al.* 2002, 2006, 2007, Drever *et al.* 2006, Noon and Blakesley 2006, Carey 2007, Long 2009, Swanson *et al.* 2010). For example, some treatments may accelerate the development of spotted owl nesting habitat (Wimberly *et al.* 2004, Andrews *et al.* 2005), even if it temporarily degrades existing dispersal habitat (Franklin *et al.* 2006). This issue needs more applied research, and land management experiments should target this need. There are areas in moist LSRs where stands average 50 years or older that are uniform and not likely to achieve desired complexity or resilience on their own, yet may develop structural complexity more quickly with treatment (Bailey and Tappeiner 1998, Latham and Tappeiner 2002, Carey 2003). These areas should be considered for restoration treatments designed to encourage development of late-successional structural complexity and promote resilience in the face of expected climate-driven changes (Johnson and Franklin 2009). Much of this activity can, and should, be carried out in all Federal land classifications consistent with the NWFP Standards and Guidelines. In some cases, it may be appropriate to seek exemptions to the 80-year old threshold for silvicultural activities in LSRs if a clear conclusion can be reached that spotted owl recovery and/or ecosystem restoration goals would be met. Research and monitoring on the specific effects of such treatments on spotted owls and their prey is needed and should evaluate effects on both spotted owl recovery as well as broader forest management goals.

In general, to advance long-term spotted owl recovery and ecosystem restoration in moist forests in the face of climate change and past management practices, we recommend the following principles be applied by land managers:

1. Conserve older stands that have occupied or high-value spotted owl habitat as described in Recovery Actions 10 and 32. On Federal lands this recommendation applies to all land-use allocations outside of Congressionally Reserved Areas.
2. Management emphasis needs to be placed on meeting spotted owl recovery goals and long-term ecosystem restoration and conservation. When there is a conflict between these goals, (*e.g.*, short-term adverse impact but expected long-term benefit), managers should make tradeoffs explicit and seek Service input if necessary. Use a sliding scale to prioritize landscapes (*e.g.*, watersheds, stands, etc.) for treatment.
3. Continue to manage for large, continuous blocks of late-successional forest.
4. Regeneration harvest, if carried out, should apply ecological forestry principles as recommended by Franklin *et al.* (2002, 2007), Drever *et al.* (2006), Johnson and Franklin (2009), Swanson *et al.* (2010), and others cited above.
5. Use pilot projects and applied management to test or demonstrate techniques and principles (Noon and Blakesley 2006). In the near term, to reduce conflict and potential inconsistencies with existing Federal land management plans, locate such pilot projects wherever possible in Matrix and Adaptive Management Areas. However, we continue to recommend that such actions be considered in LSRs if a determination is made that treatments would meet broader ecosystem restoration goals.

- ***Recovery Action 6: In moist forests managed for spotted owl habitat, land managers should implement silvicultural techniques in plantations, overstocked stands and modified younger stands to accelerate the development of structural complexity and biological diversity that will benefit spotted owl recovery.***

Implement LSR treatments per the Standards and Guides of the NWFP. In addition, LSR thinning in plantations older than 80 years of age should occur in cases where long-term beneficial effects to spotted owls will be realized from enhancing within-stand structural diversity. The treatment should emphasize the retention of the oldest and largest trees in the stands or any trees with characteristics that create stand diversity (*e.g.*, bole and limb deformities) and should focus on structural diversity in the mid- to upper- story layers, but not at the expense of large snags or existing species diversity. Cases where facilitating a thinning operation necessitates felling existing remnant trees over 120 years old should be rare. We recommend the use of fungal inoculation, mechanical methods, or other tools as needed to create snags. The Service is available to participate in local or regional efforts to provide guidance on these sorts of prescriptions. Any LSR thinning in plantations greater than 80 years old, if appropriate, should occur where nesting and roosting habitat is needed within LSRs to bolster spotted owl populations and should be considered within the interagency structure of the Level 1 teams.

Likewise, in areas with regeneration harvest in moist forest Matrix lands, any harvest should be designed using ecological forestry principles that emphasize retention of larger and older trees, snags and downed wood of varying size and decay classes, and live trees with decay and deformities (see Swanson *et al.* 2010). Unlike traditional regeneration harvests, applying these measures retain important habitat features while also encouraging eventual development of late-successional conditions.

Habitat Management in Dry Forests

Although the dry forest portion of the spotted owl's range hosts a minority of the overall population, management of spotted owl habitat in these drier areas is an extremely complex undertaking. Changing climate conditions, dynamic ecological processes, and a variety of past and current management practices render broad management generalizations impractical. Recommendations for spotted owl recovery in this area also need to be considered alongside other land management goals – sometimes competing, sometimes complimentary – such as fuels management and invasive species control. In some cases, failure to intervene or restore forest conditions may lead to dense stands heavy with fuels and in danger of stand-replacing fires and insect and disease outbreaks. As a consequence, the dry forest discussion below provides substantial detail on spotted owl ecology in such areas, including a more specific treatment of the effects of climate, fire, and insect and disease outbreaks on spotted owl habitat.

In general, we recommend that dynamic, disturbance-prone forests of the eastern Cascades, California Cascades and Klamath Provinces should be actively managed in a way that reconciles the overlapping goals of spotted owl conservation, responding to climate change and restoring dry forest ecological structure, composition and processes, including wildfire and other disturbances (Noss *et al.* 2006, Spies *et al.* 2006, 2010a, Agee and Skinner 2005, Healey *et al.* 2008, Mitchell *et al.* 2009). Vegetation management of fire-prone forests can retain spotted owl habitat on the landscape by altering fire behavior and severity (Reinhardt *et al.* 2008, Haugo *et al.* 2010, Wiedinmyer and Hurteau 2010) and, if carefully and strategically applied, it could be part of a larger disturbance management regime for landscapes that attempts to reintegrate the relationship between forest vegetation and disturbance regimes, while also anticipating likely shifts in future ecosystem processes due to climate (Gartner *et al.* 2008, Noss *et al.* 2006, Lawler 2009, Mitchell *et al.* 2009, Littell *et al.* 2010, Swanson *et al.* 2010, Moritz *et al.* 2011). Such an approach is more likely to achieve ecologically and socially acceptable outcomes, and could enable transitions to more acceptable disturbance regimes, even if it includes more frequent but less severe wildfires (Allen *et al.* 2002, Wright and Agee 2004, Hessburg *et al.* 2005, 2007, Strittholt *et al.* 2006, Reinhardt *et al.* 2008). Some areas, such as dry portions of the Klamath Province, have a different fire ecology than areas in the East Cascades and may not be subject to the same generalizations (Odion *et al.* 2004, 2010, Skinner *et al.* 2006, Hanson *et al.* 2009, 2010); this should be evaluated at a finer scale by recovery implementation teams and interested land managers.

Specific silvicultural practices that promote forest resilience and that can be applied to various forest types are given by Franklin *et al.* (2002, 2006, 2007), Hessburg *et al.* (2004, 2005, 2007), and Drever *et al.* (2006). Short-term decisions to increase forest ecosystem adaptations to climate-driven drought stresses may include vegetation management around older individual trees to reduce competition for moisture (Wright and Agee 2004, Agee and Skinner 2005, Reinhardt *et al.* 2008, Johnson and Franklin 2009, Haugo *et al.* 2010, Littell *et al.* 2010). Longer-term strategies may include protecting or restoring multiple examples of ecosystems and promoting heterogeneity among and within forest stands with the potential for natural adaptation to future (and unpredictable) climate changes (Hessburg *et al.* 2005, Kennedy and Wimberly 2009, Blate *et al.* 2009). In many areas, fire could be encouraged to perform its ecological role of introducing and maintaining landscape diversity (DellaSala *et al.* 2004, Reinhardt *et al.* 2008, Odion *et al.* 2010), although it may be desirable to manage fire severity or return intervals through vegetation management at various temporal and landscape scales (Agee and Skinner 2005, Haugo *et al.* 2010, Littell *et al.* 2010, Spies *et al.* 2010a, Moritz *et al.* 2011).

There is an ongoing debate, as captured in Hanson *et al.* (2009, 2010) and Spies *et al.* (2010b), regarding the relative merits of active management in dry forest landscapes and the potential positive and negative impacts to spotted owls (Spies *et al.* 2006). This debate focuses on uncertainty and seems to be one of degree rather than fundamental difference in long-term conservation goals. We would like to build on areas of agreement for spotted owl recovery, but we recognize that many of these recommendations are controversial due to political and socio-economic reasons (*e.g.*, see Spies *et al.* 2010a). However, given the need for action in the face of uncertainty (Agee 2002, Roloff *et al.* 2005, Carey 2007, Millar *et al.* 2007, Reinhardt *et al.* 2008, Littel *et al.* 2010, Mote *et al.* 2010, Shafer *et al.* 2010), we continue to recommend that land managers implement a program of landscape-scale, science-based adaptive restoration treatments in disturbance-prone forests that will reconcile the goals of conserving and encouraging spotted owl habitat while better enabling forests to: (1) recover from past management measures, and (2) respond positively to climate change with resilience (Spies *et al.* 2006, 2010a,b, Millar *et al.* 2007, Reinhardt *et al.* 2008, Haugo *et al.* 2010, Keane *et al.* 2009, North *et al.* 2010, Littell *et al.* 2010, Stephens *et al.* 2010). This should provide more high quality spotted owl habitat sooner and for longer into the future which will greatly benefit spotted owl recovery in the long-term. Several authors provide clear recommendations for how to consider reconciling spotted owl habitat management with vegetation management in the eastern Cascades (Lehmkuhl *et al.* 2007, Buchanan 2009, Gaines *et al.* 2010, USDA 2010).

Disturbance Regimes of Dry Forests Within the Range of the Spotted Owl

Ecological disturbance regimes derive from complex interactions among vegetation, climate, topography, and other biotic and abiotic factors that vary over space and time. Fire and other disturbances have been fundamentally important to shaping landscape patterns and processes in the dry forest systems (Hessburg *et al.* 2000a, 2005, 2007, Dale *et al.* 2001, Hessburg and Agee 2003, Skinner *et al.* 2006, Skinner and Taylor 2006, Perry *et al.* 2011). Fire regimes have been described for the Eastern Washington Cascades, Eastern Oregon Cascades, California Cascades, and Klamath Provinces (Hessburg *et al.* 2000a, 2005, 2007, Hessburg and Agee 2003, SEI 2008, Skinner *et al.* 2006, Skinner and Taylor 2006, Perry *et al.* 2011), though there is not agreement on some regime descriptions (Hanson *et al.* 2009, 2010, Spies *et al.* 2010b).

Additional research has advanced our understanding of the occurrence of low, mixed, and high-severity fires in dry forest fire regimes typically considered as low severity only (*e.g.,* see Baker *et al.* 2007, Hessburg *et al.* 2007, Beaty and Taylor 2008, Brown *et al.* 2008, Collins and Stephens 2010, Perry *et al.* 2011). In dry forests of the eastern Cascades of Washington, for example, surface-fire dominated mixed severity fires were found to be more prominent historically than previously thought (Hessburg *et al.* 2007), rendering more spatial and temporal variability in landscape patterns of disturbed and recovering vegetation. Kennedy and Wimberly (2009) found similar results for the Deschutes National Forest in the eastern Cascades of Oregon. Consequently, dry forest landscapes historically comprised a complex arrangement of fire regimes and patch sizes (Hessburg *et al.* 2005, 2007, Skinner *et al.* 2006, Skinner and Taylor 2006, Perry *et al.* 2011), creating spatial and temporal patterns and variability in vegetation and fuels that reinforced self-similar patterns (Turner and Romme 1994, Peterson 2002, Hessburg and Agee 2003, Bigler *et al.* 2005, Skinner *et al.* 2006, North and Keeton 2008, Moritz *et al.* 2011). This temporal and spatial variability in vegetation and fuels has been substantially altered by human activities and are key features that must be included in restoring dry forest ecosystems.

Past Management Actions

Over the past two centuries, Euro-American settlement has substantially transformed the inland northwest of the U.S. Anthropogenic activities that have altered the landscape include timber harvesting, mining, livestock grazing, fur trapping, constructing roads and rail lines, development of towns and settlements, agricultural conversion, fire suppression and fire exclusion. These activities have so altered the patterns of vegetation and fuels, and subsequent disturbance regimes, that contemporary landscapes no longer function as they did historically (Hessburg *et al.* 2000a, 2005, Hessburg and Agee 2003, Skinner *et al.* 2006, Skinner and Taylor 2006).

Fire exclusion, combined with the removal of fire-tolerant structures (*e.g.,* large, fire-tolerant tree species such as ponderosa pine, western larch, and Douglas-fir), have reduced the resiliency of the landscape to fire and other disturbances, at least in those forest types outside of the wetter, higher severity fire regime types (Agee 1993, Hessburg *et al.* 2000a, Hessburg and Agee 2003). In the eastern Cascades of Washington and Oregon, forest types that historically had understories of grass and shrubs have shifted to shade-tolerant conifer understories which are denser and less tolerant of fire than historic understories. This has resulted in an overall increase in the area of fire-intolerant forest-types at the expense of fire-tolerant forest types (Hessburg *et al.* 2000a, Hessburg and Agee 2003). Additionally, these understories compete with fire-tolerant tree species for limited water, thus exacerbating drought stress on the structural components that will be important in restoring dry forest ecosystems. These understories result in an altered fuel bed that exhibits increased flame length, fireline intensity and rate of spread over historic understories, putting any remnant fire-tolerant structural features at greater risk of loss to fire (Hessburg *et al.* 2000a).

In addition to the stand structure, the spatial distribution of these stands also influences fire activity across the landscape. The spatial distribution of fire intolerant-stands among the fire-tolerant stands has been fundamentally altered through past management. Past management has homogenized the patchy vegetative network and reduced the complexity that was more prevalent during the pre-settlement era (Skinner 1995, Hessburg and Agee 2003, Hessburg *et al.* 2007, Kennedy and Wimberly 2009). Therefore, rather than existing as patches of fire-intolerant vegetation types being spatially separated, they have become more contiguous, and are more prone to conducting fire, insects, and diseases across large swaths of the landscape (Hessburg *et al.* 2005). This homogenized landscape may be altering the size and intensity of today's fires and further altering landscape functionality (*e.g.,* Everett *et al.* 2000). This alteration in the disturbance regime further affects forest structure and composition. Not only do these landscapes not exhibit the structure or function that they historically had (Hessburg and Agee 2003, Naficy *et al.* 2010), the shift from fire and drought-tolerant species to shade-tolerant species is a shift in the opposite direction in terms of forest types that will be most resilient to projected future climates (Haugo *et al.* 2010).

Projected Effects of Climate Change in Dry Forest Ecosystems

The implications of climate change on dry forest ecosystems are multi-faceted. The effects and interrelationships are complex and not fully understood. A comprehensive treatment of this topic is beyond the scope of the recovery plan.

Instead, we lay out some of the possible implications of climate change on ecosystem structures and processes that are relevant to dry forest management, and restoration and spotted owl recovery.

Mean temperatures have increased in the Pacific Northwest and northern California. Models project an even more substantial increase than what occurred over the twentieth century (Cayan *et al.* 2008, Mote and Salathe 2010). Seasonally, most models predict the greatest increases during the summer rather than winter months (Cayan *et al.* 2008, Mote *et al.* 2010). Regional models that further consider local geographical features show an increased warming above global model predictions. For example, the loss of snowpack in the Cascades is projected to increase temperatures above those projected in the global models, likely due to the increased heat absorption caused by snowpack loss. This results in many areas of the Cascade Range showing greater rates of winter and spring warming, which is expected to hasten the loss of snowpack and further increase drought stress on trees (Salathe *et al.* 2008), as well as lengthen the fire season (Westerling *et al.* 2006).

The magnitude and direction of changes in mean annual precipitation in the Pacific Northwest and northern California are less clear than for temperature (Cayan *et al.* 2008, Westerling and Bryant 2008, Mote and Salathe 2010). This region is located in a transition zone between projected increased precipitation in the southern portion of North America and projected decreased precipitation in the northern part of the continent (Mote and Salathe 2010). Model projections for northern California range from slight increases in precipitation to decreases of 10-20 percent, with no noticeable change in seasonal precipitation (Cayan *et al.* 2008). In the Pacific Northwest, models are ambiguous in their projections of annual precipitation trends. Seasonal predictions are less ambiguous, however, with most predicting increased winter precipitation and decreased summer precipitation (Mote and Salathe 2010), though regional models project local differences (Salathe *et al.* 2008). Even if increases in annual precipitation should occur, summer water deficits in the Pacific Northwest are projected to increase by 2-3 times due to increased temperatures and decreased summer precipitation (Littell *et al.* 2010). Some projections call for decreases in the amount, frequency, and intensity of precipitation in drier parts of the world, including the western U.S., potentially increasing the vulnerability to drought (Sun *et al.* 2007), while in northern California, some models call for a slight increase in the number and magnitude of large precipitation events (Cayan *et al.* 2008). Due to increasing temperatures throughout the west, more precipitation is expected to fall as rain rather than snow, reducing snow accumulation. Snowpacks are already declining (Stewart *et al.* 2005) and showing decreased water content throughout western North America (Mote *et al.* 2005). Warmer temperatures are expected to result in snow continuing to melt earlier than in the past (Mote *et al.* 2005, Cayan *et al.* 2008), further increasing drought stress on dry forests.

Changes to the range and composition of current vegetation species are expected as local climates transform and become more favorable for some species and less favorable for others (van Mantgem *et al.* 2009, Allen *et al.* 2010, Haugo *et al.* 2010, Littell *et al.* 2010, Shafer *et al.* 2010). For example, Littell *et al.* (2010) predict a 32 percent increase in the area of forests in Washington that will be severely water-limited by the 2020s, with further increases of 12 percent by 2040 and another 12 percent by 2080. Specific to the range of the spotted owl, this effect is most likely to occur in the eastern Cascades in the northern part of the state. As a result, shifts in the range of Douglas-fir and several pine species are expected (Littell *et al.* 2010). A statewide analysis of forests in California indicates evergreen forests will decline while mixed evergreen forests will increase under all climate scenarios modeled (Lenihan *et al.* 2008). Total forest cover is expected to increase by 23 percent statewide in California under the cooler and wetter climate scenarios, whereas forest cover is projected to decrease by 3 and 25 percent under the warmer and drier models used (Lenihan *et al.* 2008). Where climate becomes less suitable for tree species, particularly in areas that become drier, these tree species are likely to decline in growth and become more vulnerable to mortality agents such as fire or insects that may result in large-scale mortality (Littell *et al.* 2010).

Increased mortality rates of trees have already been attributed to drought and heat stress caused by increasing temperatures (van Mantgem *et al.* 2009, Allen *et al.* 2010). Mortality is expected to increase further as temperatures warm and drought stress increases, even in systems that are not water limited (Allen *et al.* 2010). Water limitation is expected to increase across a significant portion of the eastern Cascades of Washington (Littell *et al.* 2010). The degree to which trees may succumb to drought stress is not entirely clear, however, when one considers other effects brought on by climate change. The increase in atmospheric CO_2 is expected to have a fertilization effect on tree growth, allowing them to more efficiently use water and reduce their susceptibility to drought stress (Huang *et al.* 2007). However, this efficiency may not be sustainable in the long-term (Huang *et al.* 2007, Lindroth 2010). For example, CO_2-enhanced growth may diminish over time as other nutrients become limited; specifically, as nitrogen demand and its subsequent storage in plant biomass increase, its availability to plant growth is expected to decrease, resulting in systems becoming nitrogen limited (Huang *et al.* 2007, Lindroth 2010). Others project that warmer temperatures will eventually increase water stress and evaporative demand, regardless of precipitation amount or water use efficiency (Nielson *et al.* 2006, Barber *et al.* 2000).

The effect of changing disturbance regimes such as fire and insects will likely be more abrupt and rapid than the changes in vegetation composition, distribution, and productivity in response to climate change (Littell *et al.* 2010). Interactions among these disturbances can alter forest structure and function more rapidly than what is predicted to occur through modeling of vegetation redistribution or disturbance alone. In periods of rapid climate change during the Holocene, fire was often the catalyst for changing vegetation (Whitlock *et al.* 2003). How climate change affects fire regimes will vary with the energy or water limitations of the varying ecosystems (Littell *et al.* 2009). In energy-limited wildfire regimes (*e.g.,* ecosystems with abundant fuels, such as productive forests), increasing temperatures are likely to substantially increase fire risk, regardless of precipitation; conversely, in moisture-limited regimes (*e.g.,* particularly dry ecosystems with limited fuels such as grass and shrublands), changes in both temperature and precipitation will influence their fire risk (Westerling and Bryant 2008). Predicting specifics of disturbance processes is difficult not only because of the uncertainties in the climate models, but also the synergistic interactions among disturbance agents (*e.g.,* Simard *et al.* 2011). In addition, there are other variables not easily modeled that will likely affect disturbance processes under future climate scenarios (Fried *et al.* 2004, Spracklen *et al.* 2009, Littell *et al.* 2010). These include changes in vegetation composition and distribution, as well as changes in ignitions caused by changing climate or by human activity. For example, while mountain pine beetle attacks are projected to be more successful, it is not known how changes in the range of beetles and host trees may affect this success. If vegetation range changes occur rapidly as a result of increased fire, a subsequent spatial heterogeneity across the landscape could substantially reduce the risk of beetle outbreaks (Littell *et al.* 2010).

Multi-year climatic patterns tied to sea surface temperatures in the Pacific Ocean have been linked to fire activity within the Pacific Northwest. Specifically, the El Niño-Southern Oscillation (ENSO) results in an alteration of temperature and precipitation patterns that cycle, on average, every four years, though annual cycles occur (Mote *et al.* 2010). The Pacific Decadal Oscillation (PDO) is a manifestation of ENSO which cycles between cool and warm phases every 20-30 years (Mantua *et al.* 1997). Prior to the onset of fire exclusion in the 20th century, increased fire activity has been associated with warm phases of the PDO (Hessl *et al.* 2004, Heyerdahl *et al.* 2008). Gedalof *et al.* (2005), however, found no difference in fire activity in the latter half of the 20th century between warm and cool phases of the PDO, but they did find a relationship with smaller scale annual and inter-annual variability in the PDO. The PDO entered a warm phase in 1977 (Mantua *et al.* 1997), and it may now be reversing into a cooler phase (JPL 2008), or it may be losing its decadal persistence (Mote *et al.* 2010, NOAA 2011). Given past associations between fire activity and PDO, it could be argued that the next several decades will result in a decrease in fire activity in the Pacific Northwest. However, making such an inference of cause and effect should be done with caution (Hessl *et al.* 2004). The onset of fire exclusion in the 20th century may confound associations of fire activity with PDO (Mote *et al.* 1999). Furthermore, our understanding of how ENSO and PDO will respond to climate change and our ability to extrapolate their influence on disturbance regimes is poor (McKenzie *et al.* 2004).

Though there is uncertainty with how climate change may specifically alter fire regimes, McKenzie *et al.* (2004) proposed several inferences that can be made given our understanding of fire-climate interactions and our understanding of vegetation response to fire. The first inference is that warmer and drier summers will produce more frequent and extensive fires. Second is that reduced snowpack and earlier snowmelt will likely extend the time span of moisture deficits in water-limited systems. Finally, drought stress on plants will increase as a result of the drier conditions and longer moisture deficits, increasing their vulnerability to other multiple disturbances such as fire and insects; these disturbances often have a synergistic effect.

Evidence is already accumulating to support some of the inferences made by McKenzie *et al.* (2004). The frequency of large (>400 hectares) wildfires and the total area burned by these fires has substantially increased in the western U.S. (Westerling *et al.* 2006), despite active fire suppression. Westerling *et al.* (2006) links this trend to an increase in spring and summer temperatures and earlier spring snowmelts, both of which can result in earlier and longer fire seasons. Given the link between climate and wildfire activity, the authors underscore the urgency to ecologically restore forests that have undergone substantial alterations from past land uses. Specific to California and the Pacific Northwest, an analysis of wildland fires between 1984-2005 showed a significant trend of increasing average fire size, and what appears to be a trend towards an increasing proportion of area burned as a result of large fires (Schwind 2008). Trends in burn severity were less conclusive.

Various authors have projected increases in fire potential in response to projected climate changes, both globally (*e.g.,* Liu *et al.* 2010) as well as in areas encompassing parts or all of the spotted owl range. Littell *et al.* (2010) predicted for Washington that by the 2080s, there will be two to three times as much area burned as what burned between 1916 and 2006; specific to the forested ecosystems of the eastern Cascades, Littell *et al.* (2010) predict a near doubling by the 2080s of the mean area burned between 1980 and 2006 (from 63,000 to 124,000 ha). Westerling and Bryant (2008) projected a 15-90 percent increase in fire in northern California by 2070-2099. Though unquantified, an increase in fire activity is expected in all forest types in Oregon (Shafer *et al.* 2010). Spracklen *et al.* (2009) projected that Pacific Northwest forests will experience some of the greatest increases in mean annual area burned in the western U.S., with a projected increase of 78% by 2050 over that burned between 1996-2005. Whitlock *et al.* (2003) suggest that fire frequency or severity may increase under climate projections. However, in areas where changing climate is expected to reduce combustible vegetation, fire activity could decrease (Westerling and Bryant 2008, Krawchuk *et al.* 2009).

Frequent and extensive outbreaks of native forest insects, such as bark beetles and spruce budworm, have occurred historically in the western U.S. (*e.g.,* Amman and Cole 1983, Brookes *et al.* 1987, Swetnam and Lynch 1989, Hessburg *et al.* 1994). However, anthropogenic influences through past management and fire suppression have altered the landscape vegetation patterns, subsequently altering the timing, duration and magnitude of outbreaks (Swetnam and Lynch 1989, Hessburg *et al.* 1994). Climate change is predicted to further exacerbate the situation by redistributing forest insects as well as intensifying all aspects of forest insect outbreak behavior (Logan *et al.* 2003). Temperatures drive the life history of insects and determine their geographic range. As highly mobile species living in a warmer world, insects are expected to readily expand their range and invade new habitats (Logan *et al.* 2003). Increased CO2 levels may further favor sap-feeding insect species such as bark beetles (Whittaker 1999). Yet predicting specific responses is difficult because climate relationships with some forest insect outbreaks are poorly understood (*e.g.*, see Swetnam and Lynch 1993 regarding spruce budworm).

Recent bark beetle outbreaks have exceeded the magnitude of outbreaks documented during the prior 125 years in parts of the U.S. (Raffa *et al.* 2008). It appears that human activities have influenced recent increases in bark beetle activity (Logan and Powell 2001, Logan *et al.* 2003). Changing climate, particularly increased temperature and drought, combined with management that has favored continuous, uninterrupted distributions of host tree species (*e.g.,* Douglas-fir and true fir species), tend to foster outbreaks (Hicke and Jenkins 2008, Raffa *et al.* 2008). Unusually hot and dry weather is already responsible for increased insect outbreaks in forests in several North American localities, from pinyon pine in the southwest U.S. (Breshears *et al.* 2005) to lodgepole pine forests in British Columbia where the beetle outbreak is larger than any recorded in Canada (Carroll *et al.* 2004 as cited in Whitehead *et al.* 2006, Taylor *et al.* 2006). In addition, increased stand densities of lodgepole pine have increased their susceptibility to bark beetle outbreaks throughout the western U.S. (Hicke and Jenkins 2008). There is evidence of irruptive thresholds being crossed by insects in Alaska and British Columbia, whereby the outbreak continues in a self-sustaining mode even after the extreme drought conditions that initiated the attack have subsided (Raffa *et al.* 2008). However, not all outbreaks appear to be exceeding known historical magnitudes. In Colorado for example, mountain pine beetle activity does not exceed historical activity levels, although the insects are moving outside of their known historical range and into higher elevation (Romme *et al.* 2006); the authors, however, point out that it is difficult to know if this movement is truly outside of their historical range given the lack of historical data on beetle distributions.

With respect to forest pathogens, Kliejunas *et al.* (2009) summarize the literature on the relationship between climate change and tree diseases in western North America. They note that while there is great uncertainty with how specific pathogens will respond to climate change, general inferences can be made, all of which can vary by ecosystem and specific climate conditions. Similar to forest insects, pathogen distributions are expected to change, including invasion of new areas by nonnative pathogens. The epidemiology of plant diseases is also expected to change, complicating the prediction of disease outbreaks. The rate that pathogens evolve and overcome host resistance may increase in a rapidly changing climate. With increasing temperatures, we should expect an increase in overwintering survival of pathogens, as well as an increase in disease severity. Predicted drought stress on many host species will increase their vulnerability to, and exacerbate the effect of, many pathogens. Finally, with the exception of extremely dry conditions, climate change may alter fungal pathogens that could have a profound change on rates of wood decay, shortening the length of time valuable legacies like down wood can be retained in the ecosystem (Yin 1999).

Interactions between disturbance processes also need to be considered, but are not well understood. For example, the fuel composition created by mountain pine beetle outbreaks in lodgepole pine is thought to facilitate the stand-replacing fires favorable to lodgepole reproduction (Logan and Powell 2001). However, the evidence is mixed as to whether insect mortality increases the risk or severity of fire (Fleming *et al.* 2002, Bebi *et al.* 2003, Hummel and Agee 2003, Lynch *et al.* 2006, Parker *et al.* 2006, Romme *et al.* 2006, Kulakowski and Veblen 2007, Jenkins *et al.* 2008, Simard *et al.* 2011). Some studies recorded situations where probability or severity of burns was higher in beetle-killed stands than in control stands (Bigler *et al.* 2005, Lynch *et al.* 2006). Others found no difference in severity or probability of fires occurring in beetle-killed stands compared to control stands (Bebi *et al.* 2003, Lynch *et al.* 2006, Kulakowski and Veblen 2007). Furthermore, high-severity fires that did occur were consistent with the typical fire regime of affected forests, even without the insect outbreaks (see Romme *et al.* 2006). Still other research has found that the likelihood of active crown fire was actually reduced in beetle killed stands than in control stands, potentially due to decreases in the canopy fuels caused by beetle mortality (Simard *et al.* 2011). Finally, Bigler *et al.* (2005) observed that while beetle outbreaks may have contributed to fire severity, other contributors such as pre-fire stand structure and composition were more of an influence.

At a minimum, insect outbreaks substantially alter the fuel complex and ultimate vegetative composition within a stand (Jenkins *et al.* 2008), and such alteration can potentially affect fire activity. Insect mortality does more to affect fire behavior than just increase the dead fuel load. The removal of overstory canopy can decrease the surface fuel moistures, alter understories, and allow for greater wind speeds through the stand, which can affect fire behavior. These changes in stand structure and composition may be more influential drivers of fire risk and severity than the actual direct increase in fuels caused by beetle outbreaks (Bigler *et al.* 2005, Lynch *et al.* 2006). These factors change through time and will influence the behavior of fires that enter the stand at any given time. In short, the relationships between insects and fire are complex with no simple, single conclusion that can be drawn (Romme *et al.* 2006).

In summary, the implications of climate change on dry forest ecosystems are broad and multi-faceted. Though models are not all in agreement, it appears likely that there will be at least some level of summer water deficit, even if overall precipitation increases. This increase in water limitation increases the risk of fire activity and creates drought stress on trees, making them more susceptible to insect attacks. Interactions among these disturbances can have synergistic effects. The existing condition of increased stand densities and decreased landscape heterogeneity further exacerbates the vulnerability of these systems to disturbance, as well the potential magnitude and intensity of the event itself, particularly in those fire regimes that were predominately of mixed- and low-severity (Schoennagel *et al.* 2004, Keeton *et al.* 2007). Ecosystem functions that are already altered due to past management will be further altered with projected climate change.

Effects of Fire on Spotted Owl Habitat

Research on all three spotted owl subspecies indicates variability in the degree to which spotted owls use post-fire sites, depending on fire severity and the function of the site for spotted owls (*i.e.*, nesting, roosting, or foraging). A few studies have looked at spotted owl occupancy of nesting territories and survival rates in burned areas. In southwest Oregon, lower occupancy and survival rates of northern spotted owls were found in burned areas compared to unburned areas, but the results were confounded by prior management of the area and harvest after the fire (Clark 2007, Clark *et al.* 2011). Jenness *et al.* (2004) found decreased occupancy of Mexican spotted owls in burned areas compared to unburned areas, although the authors considered the relationship statistically weak. Roberts *et al.* (2011) found no difference in occupancy of California spotted owls between burned and unburned areas, although their burned areas were predominately of low and moderate severity. Bond *et al.* (2002) compared survival rates of all three subspecies of spotted owls in burned sites with overall survival estimates recorded in the literature and found them to be similar.

Spotted owl reproduction and nesting have been observed in burned landscapes and in core areas in which some portion was burned by high-severity fire (*i.e.,* fires with typically 70-100% overstory mortality). It is not known whether there is a maximum amount of high severity fire within a nesting core that would preclude nesting of spotted owls, and there have been no long-term studies to determine how long spotted owls may remain in a burned-over area. Specific to the actual nest tree, Bond *et al.* (2009) did not find any of their four nest trees located in a high severity burn. Nest trees, however, have been observed in patches with low to moderate severity burn (Gaines *et al.* 1997, Clark 2007, Bond *et al.* 2009). For spotted owls nesting in burned areas, reproductive rates are generally similar to unburned areas (Gaines *et al.* 1997, Bond *et al.* 2002, Clark 2007).

While spotted owls have been observed roosting in forests experiencing the full range of fire severity, most roosting owls were associated with low or moderate severity burns (Clark 2007, Bond *et al.* 2009). Specifically, Bond *et al.* (2009) found spotted owls selecting low severity burns for roosting and avoiding high severity burns. In addition, roost sites from which stand measurements were taken had high levels of canopy closure (*i.e.,* greater than 60 percent) and a large tree component, regardless of burn severity (Clark 2007, Bond *et al.* 2009). Spotted owls have been observed foraging in forest areas that experienced fire events of all severities, and seemed especially attracted to edges where burned forest met unburned stands (Clark 2007, Bond *et al.* 2009). This is consistent with other observations of spotted owl habitat use in the Klamath Province, where increased edge between old-growth forest and other vegetation types were important habitat components (Franklin *et al.* 2000). Clark (2007) found that spotted owls did not use large patches of high severity burns, and Bevis *et al.* (1997) found spotted owls shifting their use away from areas burned at a higher severity to those burned at a lower severity; however, the results in both studies may be confounded due to post-fire logging that occurred in the burn areas. Bond *et al.* (2009) found owls selecting burned areas, including high-severity burns, over unburned areas for foraging when those areas were within 1.5 kilometers of a nest or roost site. Bond *et al.* (2009) postulated that selecting burned patches over unburned patches for foraging may be due to increased presence of prey, such as the dusky-footed woodrat, a species associated with open stands and increased shrub and herbaceous cover.

It is unknown whether spotted owl selection of high-severity burns for foraging would prevail in that portion of its range where dusky-footed woodrats are not available (eastern Washington Cascades and most of eastern Oregon Cascades). In these areas, northern flying squirrels are the principle prey species (Forsman *et al.* 2001, 2004, Sztukowski and Courtney 2004) and are more closely tied to closed canopy forest (Lehmkuhl *et al.* 2006a, b). It is difficult to tease out the relationship between prey abundance and prey selection by spotted owls, but studies suggest that variability in diet among spotted owls may be due to spatial variation in prey abundance (Forsman *et al.* 2001, 2004, Roberts and van Wagtendonk 2006). The degree that other prey species are available to spotted owls in post-burn areas outside of the range of the dusky-footed woodrat may affect their use of post-fire landscapes in this area.

There is evidence of spotted owls occupying territories that have been burned by fires of all severities. The limited data on spotted owl use of burned areas seems to indicate that different fire severities may provide for different functions. For example, spotted owls appear to select high severity burns for foraging, but avoid roosting or nesting in these sites. However, there are multiple confounding factors and uncertainties in the data on this topic which limit the strength of the conclusions that can be drawn. Few studies occur in areas where post-fire logging has not taken place, which confounds conclusions regarding non-use of burned areas. Studies that looked at habitat use by radio-marked spotted owls either have low sample sizes or suffer from other confounding effects. For example, Clark (2007) had the largest sample size of radio-marked spotted owls (n=26), but interpretation is confounded by prior management history as well as logging that occurred in the burned area post-fire. The largest sample size of radio-marked spotted owls monitored in burned areas that were not harvested post-fire was seven (Bond *et al.* 2009).

There are no long-term studies to look at how spotted owl habitat use of these sites changes through time since the burn; so far, habitat use studies have all occurred within four years of the fire. Survey information on spotted owls is not always adequate to allow rigorous comparison of spotted owl occupancy in the burn area before and after fire. Likewise, when adequate occupancy data is available pre-fire, the fate of spotted owls tied to sites that are deemed unoccupied after fire are often unknown; whether these spotted owls died in the fire, abandoned the area, or shifted their use to alternate sites within or adjacent to the burned area is rarely known. It is not clear whether spotted owls outside the range of the dusky-footed woodrat, a species tied to habitats consistent with the early seral conditions created by fire, would show similar use of burned areas as those spotted owls in areas where this prey species is available. Finally, we have a poor understanding of how spotted owl occupancy and habitat use are affected by the geographic scale of the disturbance, as well as the spatial arrangement and amount of unburned patches and patches exhibiting different burn severities within a home range. We can conclude that fires are a change agent for spotted owl habitat, but there are still many unknowns regarding how much fire benefits or adversely affects spotted owl habitat.

Restoring Dry Forest Ecosystems

Dry forest ecosystems exhibit tremendous complexity in structure and process, as well as in the relationships among and within biotic and abiotic components. Historically it was topography and disturbance regimes such as insects and fire that shaped the distribution and composition of vegetation across the landscape, with patches of shade-tolerant and fire-intolerant conifers spatially isolated from one another in the drier forest types. The disturbance regimes, along with the vegetation structure, composition and distribution have been substantially altered since Euro-American settlement. As a consequence, dry forest systems no longer function as they once did (Hessburg *et al.* 2005). There is not agreement on some regime descriptions within the range of the spotted owl (*e.g.*, Hanson *et al.* 2009, 2010, Spies *et al.* 2010b), and our understanding of fire regimes in certain dry forest types is changing (*e.g.*, Hessburg *et al.* 2007, Perry *et al.* 2011). Complicating the matter is the ongoing climate change that will likely increase the stressors on these systems. We may accurately predict some ecosystem changes and not others, but we can be confident that dry forest ecosystems will change in the face of projected climate change. Consequently, there are risks in any management decision we make, whether it be action or no action, active or passive management (Agee and Skinner 2005). Any actions we take should move dry forest systems on a path that will develop and retain the resiliency in the ecosystem to adequately respond to whatever changes do occur. The key to developing that resiliency is to restore the inherent forest structure and composition and to reintegrate the relationship between forest vegetation and the disturbance regimes.

As noted earlier in this document, our intent in this Revised Recovery Plan is to embed spotted owl conservation and recovery within broader dry forest ecosystem restoration efforts to increase the likelihood spotted owl habitat will remain on the landscape longer and develop as part of this fire adapted community instead of being consumed by uncharacteristic wildfires. Herein we borrow from original objectives described in SEI (2008). Our first objective is to develop and maintain adequate spotted owl habitat in the near term to allow spotted owls to persist in the face of threats from barred owl expansion and habitat alterations from fire and other disturbances. The second objective is to restore landscapes that are resilient to fire and other disturbances in the near term, and more resilient to alterations projected to occur with ongoing climate change. The final objective is to restore function of a variety of ecological services provided by late-successional and old forests. It is not our intent, nor do we believe it would be consistent with the above objectives, to do landscape-wide treatments for the purpose of excluding disturbance events such as fires, including high-severity fires. On the contrary, we are looking to support the disturbance regimes inherent to these systems and believe our management should be consistent with the counsel of Hessburg *et al.* (2007:21):

> "Restoring resilient forest ecosystems will necessitate managing for more natural patterns and patch size distributions of forest structure, composition, fuels, and fire regime area, not simply a

> reduction of fuels and thinning of trees to favor low severity fires."

We define resiliency as the "ability of a system to absorb change and variation without flipping into a different state where the variables and processes controlling structure and behavior suddenly change (Holling 1996:734-735)." Key to managing systems for resilience are to keep options open, view events in a regional rather than local context, and to manage for heterogeneity (Holling 1973). Furthermore, managers need to acknowledge our limited understanding and assume that unexpected events will happen. Therefore, managing for resilience does not require the need for precision in predicting future events, "but only a qualitative capacity to devise systems that can absorb and accommodate future events in whatever unexpected form they may take" (Holling 1973:21).

To accommodate future disturbances and restore ecosystem resiliency, we believe it is essential to restore ecosystem structure, composition and processes. Restoring ecosystem structures that provide resiliency will necessitate maintaining and restoring the biological legacies that typically persist through disturbance events and influence the recovery process in the post-disturbance landscape (Franklin *et al.* 2000). With respect to the dry forest landscapes, structural legacies include not only the large trees that tend to be fire tolerant, but the snags and downed wood that were created as a result of the disturbance event. Structural legacies serve valuable functions such as reproductive structures that facilitate plant propagation, modifying microclimates, or improving connectivity through the disturbed area (Franklin *et al.* 2007).

Restoring ecosystem composition that provides resiliency will necessitate managing for vegetative heterogeneity both within and among stands. Compositional, as well as structural heterogeneity, are influenced by tree growth and decline, competition among plants and the resulting mortality, as well as small-scale disturbances (Franklin *et al.* 2002, 2007). Heterogeneity in the patterns of vegetation composition and structure are key features of resilient forests (*e.g.,* Stephens *et al.* 2008). Complex arrangements and spatial patterns of vegetation produce a similar variability in fire behavior and effect, maintaining ecosystem heterogeneity (Stephens *et al.* 2010).

Restoring ecosystem processes that provide resiliency will aid in developing the vegetation structures, composition, patterns, and distributions advocated above. This would include managing for high-severity disturbance events in the appropriate landscape context. High severity fires, for example, provide valuable habitat for fire-dependent species (*e.g.,* Hutto 2008), as well as important seral conditions that contribute to biodiversity (Swanson *et al.* 2010). Conversely, specific locations on the landscape may be identified where it is desirable to manage the vegetation so that fire severity is reduced (*e.g.,* in wildland urban interface or in areas where human activities have increased available fuel (see Odion *et al.* 2004), or in areas where it is desirable to reduce the risk to valued structural legacies).

We believe restoring ecosystem processes will contribute to developing and maintaining ecosystem structure and heterogeneity, increasing the resiliency to disturbance events and ongoing climate change (Schoennagel *et al.* 2004, Fettig *et al.* 2007, Hessburg *et al.* 2007, Klenner *et al.* 2008, Stephens *et al.* 2008, 2010). Restoring these features would further allow the disturbance processes to play their inherent role in maintaining these features (Noss *et al.* 2006). The following treatment principles were derived from multiple sources (SEI 2008, Gaines *et al.* 2010, Hanson *et al.* 2010). We believe them to be consistent with the stated objectives above, and will be important to accommodating future disturbances and restoring ecosystem resiliency. These principles should be part of any dry forest restoration treatment:

1. Emphasize vegetation management treatments outside of spotted owl core areas or high value habitat where consistent with overall landscape project goals. The proportion of Federal land in the dry forest provinces that is currently spotted owl habitat ranges from 18 percent in the Eastern Washington Cascades to 42 percent in the Oregon Klamath Province (Davis and Lint 2005, Davis and Dugger in press). Thus, there are many opportunities to restore ecosystem components in areas that will have little direct effects on spotted owls. Where treatments will occur within spotted owl core areas or high value habitat, we recommend monitoring owl response to treatments or apply treatments as part of an adaptive management process to improve our understanding of how these activities affect spotted owls.
2. Design and implement restoration treatments at the landscape level. Treatments need to be placed in context with the surrounding landscape to be most effective and to accommodate the inherent disturbance regime (see USDA 2010).
3. Retain and restore key structural components, including large and old trees, large snags and downed logs. Retaining these structural features will conserve habitat, legacy, seed stock, and genetic values. In addition, vegetation management to reduce moisture competition and improve the vigor of these older trees will also be necessary. An emphasis should also be placed on retaining tree species that are fire and drought tolerant in those vegetation types that exhibit fire regimes typically of low or mixed severity or typically dominated by predominately a surface -fires regime. However, older trees likely present before fire exclusion should also be retained, regardless of their fire tolerance.
4. Retain and restore heterogeneity within stands (*i.e.,* manage for fine-scale mosaic within stands). This includes both vertical and horizontal diversity.
5. Retain and restore heterogeneity among stands (*i.e.,* manage for meso-scale mosaics across a landscape). Retain patches of denser, moister forests that are good quality spotted owl habitat, as appropriate, within the landscapes where fire may be more frequent but less severe, consistent with historic variability or modeled future variability, and

where its occurrence maintains and provides for desired levels of species and structural diversity.

6. Manage roads to address fire risk.
7. Use wildfires to meet vegetation management objectives where appropriate.

Some form of vegetation management will be necessary to address many of the restoration principles described above. This can be done through a variety of methods, including mechanical removal such as thinning, prescribed burning, or using naturally ignited fires burning within a specified prescription to meet ecological objectives (*i.e.*, wildland fire for resource use). There are risks associated with these treatments in their potential to disturb soils, affect long-term productivity, and increase the risk of exotic plant invasions. Managers need to account for and minimize these risks as they plan and implement restoration treatments. There is also limited information on the effects of these types of treatments on spotted owls; the few studies that have looked at effects of thinning on spotted owls were limited to prescriptions designed to increase stand productivity and decrease stand complexity rather than improve stand structure for spotted owl. To fill this knowledge gap, restoration treatments implemented inside spotted owl core areas or high value habitat should be initiated under a monitoring or adaptive management study to test their effects on spotted owl occupancy, demographic performance and habitat use.

Restoring the large and old fire-tolerant trees and structure requires more than simply retaining them where they are found. In places where fire exclusion or past management has increased the density of surrounding trees, the densities of these smaller trees will need to be reduced to decrease the competition for water and resultant susceptibility to drought stress and insect attack (Thomas *et al.* 2006). Reducing the stand basal area around residual target trees, including large trees present prior to settlement, can be effective in improving the vigor of several tree species (Larsson *et al.* 1983, Feeney *et al.* 1998, Kolb *et al.* 1998, Latham and Tappeiner 2002). This increased vigor helps individual trees to withstand drought stress and better ward off attacks from sap-feeding insects such as bark beetles (Amman and Logan 1998, Schmid and Mata 2005, Fettig *et al.* 2007), but only if done before an outbreak begins (Shore *et al.* 2006, Romme *et al.* 2006). Thinning to improve tree vigor may not be as effective in reducing a stand's susceptibility to defoliating insects, such as western spruce budworm (Muzika and Liebhold 2000), but it may reduce insect densities and ultimate stand damage if the treatment is focused on reducing the tree host species within the stand (Swetnam and Lynch 1993, Su *et al.* 1996).

Mountain pine beetles, at least in lodgepole pine stands, tend to prefer larger trees (Safranyik and Carroll 2006). Their preference for tree size is less clear in ponderosa pine stands (Olsen *et al.* 1996, Negron and Popp 2004). Thus, while thinning lodgepole stands may improve tree vigor and resistance, the larger remnant trees may increase the likelihood of beetle colonization in the stand, particularly once an outbreak begins (Mitchell and Preisler 1991, Preisler and Mitchell 1993). This risk needs to be considered when managing vegetation to reduce risk of insect attack. Finally, when treating vegetation to reduce susceptibility to insect attack, care needs to be taken to ensure treatments do not increase risk of attack through injury (Jenkins *et al.* 2008).

Vegetation management for the purpose of altering fuels to modify fire behavior at specific locations can be effective (Omi and Martinson 2002, Pollet and Omi 2002, Martinson *et al.* 2003). This assumes, however, that surface fuels generated from the stand treatment were reduced or removed. Otherwise, severities can actually be higher with treatment (Weatherspoon and Skinner 1995, Raymond and Peterson 2005, Prichard *et al.* 2010). In addition, retaining structures that are fire resistant (*e.g.*, retaining the largest trees) will improve effectiveness (Omi and Martinson 2002, Agee and Skinner 2005). Fire severity, however, results from a complex interaction of fuels (including composition and moisture), topography (including slope percent , elevation, and aspect), and fire weather (including wind and temperature). Variations in each of these components and interactions among them will influence fire behavior and its resultant burn severity. Understanding how these components interact within local fire regimes is important to implementing effective restoration treatments. For example, thinning and underburning have resulted in lower fire severities than those observed in untreated stands across a variety of geographical areas and vegetation types (*e.g.,* Pollet and Omi 2002). However, the mixed evergreen forests of the Klamath Province may exhibit stand development pathways that result in different fire susceptibilities (see Perry *et al.* 2011). For example, lower fire severities were observed in stands with longer fire-free periods as well as in untreated stands with closed canopies or with larger, more mature forest conditions, when compared to treated stands (Weatherspoon and Skinner 1995, Odion *et al.* 2004, Alexander *et al.* 2006, Thompson and Spies 2009). Severities of past fires may be a major determinant of future fire severity; for example, in the Klamath Province, stands burned by high severity fires in the previous one or two decades have been observed to reburn at high severity (Odion *et al.* 2010, Thompson *et al.* 2007, Thompson and Spies 2010). Aspect and slope have been tied to fire severity is some areas (*e.g.*, Alexander *et al.* 2006) but not others (*e.g.*, Turner *et al.* 1999). Fire severity within a given patch may be affected by the surrounding landscape (*e.g.* Weatherspoon and Skinner 1995). Finally, extreme fire weather events can overwhelm a stand's resistance to fire, resulting in high severity burns regardless of the topography, fuel condition or prior management (Martinson *et al.* 2003, Skinner *et al.* 2006). Thus, treatments to reduce fire severity need to be strategically located and designed with specific objectives and a clear understanding of how the local landscape responds to the many variables that influence fire severity.

Fuel treatments have other limitations that need to be considered in their application. Treatments require maintenance if they are to remain effective (Agee and Skinner 2005, Reinhardt *et al.* 2008). In addition, treatments that are not maintained may actually result in fire behavior that is more deleterious than expected without treatment (Ager *et al.* 2007b). Finally, given the stochastic nature of fires, without extremely large-scale treatments that may be neither economically nor socially feasible, there is a low probability of fires intercepting fuel breaks (Rhodes and Baker 2008). However, modeling indicates that strategic placement can improve treatment leverage (*i.e.,* increase the ratio of acres experiencing reduced fire severity to acres treated) (*e.g.,* Loehle 2004, Schmidt *et al.* 2008). Fuel treatments need to be strategically located with clear objectives. They should not be used for the purpose of "fireproofing" the forest. Rather, they should be designed to increase the acceptability of wildfire through reducing fire behavior and severity in local areas, rather than simply to reduce fire occurrence, size, or amount of burned area per se (Reinhardt *et al.* 2008).

Vegetation management treatments that are strategically located in a landscape context are encouraged to restore structural elements, restore heterogeneity within and among stands, and which increase resiliency to future fires and other disturbance events. A necessity of any vegetation management treatment, regardless of its purpose, is to ensure that slash and other residual fuels generated as part of the project are adequately treated so as not to increase fire severity or risk (Agee and Skinner 2005). Treatments should allow us to incorporate future disturbance events as a means to restore and maintain desired ecosystem components and heterogeneity (Noss *et al.* 2006, Reinhardt *et al.* 2008). Prescribed fire may be a means to reintroduce fire as an ecosystem process, but will likely need to be implemented at scales much greater than what has been done in the past to be effective (Baker 1994, Taylor 2000); such a scale may not be socially or politically acceptable at this time (Stephens and Ruth 2005, Schulte *et al.* 2006). Developing wildfire management plans to allow the use of wildfires to meet vegetation management objectives is another tool that the Service encourages.

Need for Active Management

The characterization of fire risk in the dry forest provinces within the range of the spotted owl has recently been argued in the scientific literature (Hanson *et al.* 2009, 2010, Spies *et al.* 2010b). In short, Hanson *et al.* (2009) concluded that, given the low risk of high-severity fire in these provinces, there is time to conduct needed research to fill key information gaps before committing to a large-scale strategy of active management. We acknowledge the value that some high-severity fires may provide to spotted owls in areas where these effects have been studied, though there are many limitations with the existing data to make strong conclusions. We also agree with the authors that an adaptive management framework should be in place so that we can learn from our management efforts as we go forth, and have included an adaptive management discussion in this plan. However, given the highly altered condition of the existing dry forest ecosystem and the effects of ongoing climate change on the currently compromised functions, we believe restoration of dry forest ecosystem structures and processes must begin now and cannot wait for all key information gaps to be filled.

As an example, the Gotchen Risk Reduction and Restoration Project was designed to reduce fire risk and promote forest health in the Gotchen LSR and the surrounding landscape of the Eastern Washington Cascades on the Gifford

Pinchot National Forest. Forest health in the area had declined dramatically due to a history of selective timber harvest, fire suppression, and widespread tree mortality caused by insects and diseases (USFS 2003). The project included over 2,200 acres of strategic thinning and fuels treatments to reduce the risk of catastrophic wildfire including some degradation of spotted owl habitat deemed necessary to achieve the objectives of the project. Treatment areas included over 1,000 acres of suitable spotted owl habitat, but direct impacts to spotted owls were minimized by avoiding treatments near known spotted owl nest sites.

There are some questions under adaptive management that may be answered within the next several years, the results of which can be applied to future management decisions (*e.g.,* how do spotted owls use areas treated with specific vegetation management prescriptions intended to promote structural features conducive to spotted owl habitat?). Other questions, particularly population-based questions such as how spotted owls respond to disturbance processes, may take decades before clear conclusions can be drawn from those studies. The risk in waiting this long before pursuing restoration activities is a continued loss of valued ecological structures (*e.g.,* large, fire-tolerant trees) to increased drought stress that is projected with future climate change, as well as continued decoupling of vegetation patterns from disturbance processes. In the immediate future, we need to pursue restoration activities that are strategic and that focus on restoring and maintaining ecosystem structure, composition, patterns and processes with an eye towards maintaining resiliency in the face of future climate change.

We also stress this cannot be done successfully without an aggressive adaptive management framework to learn from treatments. Land managers should use pilot projects and active management to test or demonstrate techniques and principles (Noon and Blakesley 2006). In the near term, to reduce conflict and potential inconsistencies with existing Federal land management plans, we recommend locating such projects wherever possible in Matrix and Adaptive Management Areas. However, we continue to recommend that such actions be considered in LSRs as well (Gaines *et al.* 2010). An example of a site-specific plan that could be emulated in other areas is the Okanogan-Wenatchee National Forest Restoration Strategy (USDA 2010). This strategy applies many of the concepts described in this Plan to meet the overlapping goals of spotted owl recovery and ecosystem management.

Conclusions Regarding Dry Forest Management

Given the complexity of the disturbance regimes in dry forest systems, response of spotted owls to these disturbances, and the projected influence that climate change will play on these regimes, this Revised Recovery Plan recognizes that active management of vegetation within the dry forest landscape is needed to restore ecosystem resiliency consistent with spotted owl conservation objectives. Restoration of forest ecosystems that are resilient to the endemic disturbance regimes and adaptive to impending climate change is a primary goal of any dry forest recovery strategy and needs to include some form of active management to achieve that objective. Our knowledge is far from complete, and management to restore these systems will be challenging. These knowledge gaps need to be addressed through a well-defined adaptive management approach that reduces biological risk to the spotted owl and provides information to inform future management decisions.

The 2008 Plan called for establishing an interagency, science-based Dry forest Landscape Work Group (DFLWG) as a recovery implementation team to assist the Service in designing a strategy for managing the Klamath Provinces, the Eastern Washington Cascades, Eastern Oregon Cascades, and California Cascades Provinces. Shortly after publication of the 2008 Plan, the Service created another recovery implementation team, the Klamath Province Work Group to address dry forest issues in the Klamath Provinces, leaving the DFLWG to cover the Cascades portion of the dry forest landscape (To more clearly identify the geographic responsibility of the DFLWG, we are renaming it the Dry Cascades Work Group as part of this recovery plan). Both of these work groups were tasked with helping identify landscape-scale approaches to managing these areas based on the restoration of ecosystem processes.

- ***Recovery Action 7: Create an interagency Dry Cascades Work Group that is available to assist land managers in developing and evaluating landscape-level recovery strategies for the Eastern Washington, Eastern Oregon, and California Cascades Provinces, including monitoring and adaptive management actions.***

The DFLWG has been working to evaluate and develop landscape approaches to restoring forest ecosystem structure and processes in support of spotted owl recovery. The work group members represented a broad array of expertise in different technical fields from different geographical areas. Researchers and practitioners comprised the work group, and members brought forward different interpretations of the research in dry forest systems. After this plan is finalized, the Service will appoint a new recovery implementation team, the Dry Cascades Work Group, using a similar diverse array of expertise to continue this work and find areas of agreement upon which a strategy for the dry Cascades provinces can be developed.

This implementation team will be available to help local land management units with the design and development of new prescriptions and treatments for fuel reduction and other dry forest management strategies through training, workshops or other information transfer methods. It may also be asked to develop an integrated strategy for all the Eastern Washington, Eastern Oregon, and California Cascades Provinces. This may include:

1. Recommending relevant research.
2. Standardizing, to the extent possible, new recommendations for prescriptions and treatments for fuel reduction and other dry forest management to facilitate regional comparisons by meta-analysis and to maximize the scientific and management value of studies.

3. Standardizing, to the extent possible, experimental designs to assist with comparability across the region and to ensure statistically valid results.
4. Assisting in the development or evaluation of plans that include landscape specific habitat objectives, treatment strategies, and projected outcomes.
5. Developing monitoring techniques and coordinating effort. Given the uncertainties concerning sustaining spotted owl habitat in dry forest landscapes, monitoring is imperative. Characteristics that may be important to monitor in any dry forest landscape managed for spotted owl habitat include:
   - Total spotted owl habitat area and condition;
   - Dispersal habitat and condition;
   - Effectiveness of spatial isolation on spotted owl habitat clusters;
   - Pattern, amount, and timing of management activities and natural disturbances;
   - Preferred timing of follow-up treatments by area;
   - Patch recruitment potential and timing as replacement spotted owl habitat relative to fledging success; interactions with barred owls; and stand-level prey response to treatments, including habitat elements that support prey (mistletoe, snags, downed wood, forage lichens, truffle abundance);
   - Spotted owl response to habitat and dispersal areas; and
   - Occupancy breeding pairs or single spotted owls

- ***Recovery Action 8: In Eastern Washington, Eastern Oregon and California Cascades Provinces, analyze existing data on spotted owl occupancy pre- and post-fire and establish a consistent database to track owl occupancy response to fires across the dry Cascades provinces.***

Data currently exist that may aid our understanding of spotted owl occupancy of sites after a fire. Most National Forest units in these provinces annually monitor known spotted owl sites for occupancy, and they have accumulated occupancy data sets in burned and unburned areas. Members of the DFLWG have begun compiling and analyzing existing data on occupancy rates of spotted owls in burned and unburned sites, as well as fire extent and severity in the burned sites, to determine how fire influences occupancy rates of spotted owls. We anticipate the DCWG will continue this effort. Existing data on pre- and post-fire vegetation structure is also being analyzed to determine possible connections between pre-fire estimates of fuel loads, fire severity, and subsequent spotted owl occupancy to inform risk analysis efforts. These data should be entered into a database to track future data on spotted owl occupancy and fires. Data collection standards should be established to aid comparison of data among the provinces to aid in comparison across the provinces, though these standards will be subject to change if methodology improvements become available. This synthesis and analysis will inform land managers about how fuel loads in and adjacent to spotted owl habitats can be managed.

- ***Recovery Action 9: Create an interagency Klamath Province Work Group that is available to assist land managers in developing and evaluating landscape-level recovery strategies for the Oregon and California Klamath physiographic province, which include monitoring and adaptive management actions.***

The KPWG was formed as a recovery implementation team as a result of Recovery Action 8 in the 2008 Recovery Plan, and has been operating since 2008. During the course of several meetings and workshops in 2008 and 2009, the KPWG established a multi-step approach for evaluation of potential alternative conservation strategies for spotted owls in the Klamath Province, a combined view of the Oregon and California Klamath Provinces. The primary steps included: (1) conduct a thorough review of the literature, spotted owl data sets, and spatial information and synthesize into a report describing spotted owl habitat in the Klamath Province, and the role of fire in developing, maintaining, modifying, and removing spotted owl habitat at multiple scales; (2) use spatially-explicit predictive models, developed and validated using current spotted owl location data from the Klamath Province, to identify areas of high-value spotted owl habitat based on forest composition and structure, climate variables, and topographic features; and (3) integrate spotted owl habitat models with models of fire occurrence and severity patterns to identify and prioritize areas for habitat protection, habitat restoration, and fuels treatment. This implementation team will be available to help land management units with the design and development of new prescriptions and treatments for fuel reduction and other dry forest management strategies through training, workshops or other information transfer methods.

Spotted Owl Habitat Conservation on All Landscapes

This Revised Recovery Plan recommends building on the principles established in the NWFP to conserve and restore more occupied and high-value spotted owl habitat, including increased conservation of habitat on some Federal "Matrix" lands and the evaluation of potential contributions from State and private lands.

This Plan does not propose a new or revised mapped habitat reserve network and continues to recommend reliance upon the LSRs of the NWFP throughout the range of the spotted owl. In addition, the Service sought remand of the 2008 spotted owl critical habitat designation in a recent court case and will consider revisions to the designation, with a final rule to be published by the end of 2012. Critical habitat designation defines and maps those geographical areas essential to the conservation of the species. Particularly in light of the fact that a revised designation based on the latest and best available information is imminent, the

Service believes it is appropriate to use the critical habitat rulemaking process to identify any essential habitat areas for the spotted owl in addition to the LSR system.

Because of the value to spotted owls, it is likely that much of the LSR network that was originally established in the NWFP process will continue to serve as the foundation for the spotted owl recovery on Federal lands. We expect that recommendations made in this Revised Recovery Plan concerning active management of spotted owl habitat, if applied by land managers, will be beneficial to spotted owl conservation and thus may not be considered as having a significant adverse effect on the spotted owl or its critical habitat in the long-term. Final decisions concerning these and other issues will be made as part of the critical habitat revision and section 7 consultation processes.

Conserving Occupied and High Value Spotted Owl Habitat

The three main threats to the spotted owl are competition from barred owls, past habitat loss, and current habitat loss (USFWS 2008b). Despite the habitat protections of the NWFP, the most recent demographic analysis (Forsman *et al.* 2011) indicates that spotted owl populations are declining on 7 of the 11 active demographic study areas at about 3 percent annually range-wide. Scientific peer reviewers and Forsman *et al*. (2011) recommended that we address this downward demographic trend by protecting known spotted owl sites in addition to the retention of structurally-complex forest habitat.

The Service recommends conserving occupied spotted owl sites throughout the range, especially those containing the habitat conditions to support successful reproduction. This recommendation is especially important in the short-term, until spotted owl population trends improve (Forsman *et al.* 2011).

Conservation of important spotted owl habitat depends on the application of a two-tiered approach to forest land management decisions as follows:

1. Conserve spotted owl sites and high-value spotted owl habitat where possible in addition to Federal conservation blocks to provide additional demographic support to the spotted owl population (see Recovery Action 10, below).
    a. This recommendation includes currently occupied as well as historically occupied sites (collectively "spotted owl sites," see Appendix G: Glossary of Terms).
    b. Work with land managers and spotted owl field scientists to develop prescriptions and approaches to implement this recommendation. At a minimum, this prescription should retain sufficient NRF habitat within the provincial core-use area and within the provincial home range to support breeding, feeding and sheltering.

2. Maintain and restore the older and more structurally complex multi-layered conifer forests on all lands (see Recovery Action 32 under Listing factor E).

It is clear that these two recommendations overlap. It is our hope that their application on Federal, State, and private lands will more effectively address the threats of competition with and displacement by barred owls, as well as the impacts of past and current habitat loss.

This recommendation can be justified at several scales. At the scale of a spotted owl territory, several studies have shown a positive association between spotted owl fitness and spotted owl habitat or a mosaic of habitat types (Franklin *et al.* 2000, Dugger *et al.* 2005, Olson *et al.* 2004). Additionally, Dugger *et al.* (in press) found an inverse relationship between the amount of old forest within the core area and spotted owl extinction rates from territories. At the population scale, Forsman *et al.* (2011) found a positive relationship between recruitment of spotted owls into the overall population and the percent cover of spotted owl NRF habitat within study areas. This multi-scale research suggests retention of spotted owl habitat within spotted owl territories positively affects demographic rates. Because spotted owls on established territories are likely to be more successful if they remain in those locations (Franklin *et al.* 2000), managing to retain spotted owls at existing sites should be the most effective approach to bolstering the demographic contribution of a habitat conservation network and the highest priority for land managers. Retention of long-term occupancy and reproduction at established spotted owl sites will require a coordinated and cooperative effort to craft management approaches tailored to regional, provincial or local conditions.

- ***Recovery Action 10 - Conserve spotted owl sites and high value spotted owl habitat to provide additional demographic support to the spotted owl population.***

For Federal lands, create an interagency scientific team to use the latest and best available habitat modeling information and other data to identify these high value areas. This recovery implementation team will make recommendations for areas to conserve and manage based upon the following criteria and considerations:

- Use of habitat modeling to better identify high value habitat, including consideration of abiotic factors that influence spotted owl usage.

- Use of demographic monitoring and survey data, if available, to inform other measures of value, such as maintaining population distribution in underrepresented areas or to reflect the most current habitat conditions.

- How retention of specific areas may affect probability of persistence of the spotted owl population at the province scale. Use this evaluation to establish "thresholds" for recommendations of which areas to conserve or not.

- Consideration of related barred owl impacts, influence, and management decisions and the likely success of such management actions in those areas.

The intent of this recovery action is to protect, enhance and develop habitat in the quantity and distribution necessary to provide for the long-term recovery of spotted owls. The Service will use the results of this effort to inform subsequent recommendations or decisions regarding the quantity and spatial configuration of habitat necessary to support the recovery of spotted owls. The spatial depiction informed by the habitat modeling efforts will better identify areas where land managers should consider protecting, enhancing and developing habitat to support recovery of spotted owls and, where appropriate, will seek additional public review and comment (*e.g.*, as part of proposed critical habitat). Where the modeling output and/or examination on the ground indicate that forest stands could and should be enhanced or developed through vegetation management activities to improve long-term habitat conditions, or to create improved habitat for spotted owls, larger habitat patches, or increased connectivity between patches, they should generally be encouraged even if they result in short-term impacts to existing spotted owls. However, such a process should occur where a determination is made that these longer term goals outweigh short-term impacts.

Interim Guidance

In the interim time period while the above team process is formalized and carried out, we recommend the following process be followed.

When planning management activities, Federal and non-federal land managers should work with the Service to prioritize known and historic spotted owl sites for conservation and/or maintenance of existing levels of habitat. The prioritization factors to consider are reproductive status and site condition.

The site conservation priorities for reproductive status are:

- Known sites with reproductive pairs;
- Known sites with pairs;
- Known sites with resident singles; and
- Historic sites with reproductive pairs, pairs, and resident singles, respectively.

The priority for site condition is sites currently with ≥40% in the provincial home range (*e.g.*, 1.3 mile radius) and ≥50% habitat within the core home range (*e.g.*, 0.5 mile radius). This prioritization provides a guide to evaluate the relative impacts of management actions, and conservation of sites that provide the most support to spotted owl demography.

When implementing this interim process, land managers and the Service should utilize professional judgment as to the best available site-specific data (collectively across years, if appropriate). These data may be contained in agency databases, land manager files, or other sources. Managers can also decide to conduct surveys to document current status.

Land managers should prioritize vegetation management and silvicultural treatments intended to enhance habitat conditions based on:

- Status as follows:
  - Unoccupied stands
  - Miscellaneous observations sites
  - Historic sites and;
  - Known sites – resident singles;
  - Known sites – resident pairs.
- Known sites with ≤40% in the provincial home range and ≤50% habitat within the core home range
- Ability to affect meaningful structural change in ≤30 years. Land managers should generally avoid activities that would reduce nesting, roosting and foraging habitat within provincial home ranges (*e.g.*, 1.3 mile radius) of reproductive pairs. Activities which address threats from stochastic disturbance (*e.g.*, insect, disease, wildfire, etc.) by restoration action will generally be consistent with the intent of RA 10 even if short-term effects to spotted owls would occur.

In unsurveyed spotted owl habitat, the agencies and the Service should work cooperatively through the Endangered Species Act consultation process to minimize impacts to potential spotted owl sites. It is likely to be most beneficial to address these areas as early in the planning process as possible. Non-federal land managers should seek technical assistance from the FWS as appropriate.

It is not uncommon for an occupied spotted owl site to be unoccupied in subsequent years, only to be re-occupied by the same or different spotted owls two, three or even more years later (Dugger *et al.* 2009). While temporarily unoccupied, these sites provide conservation value to the species by providing habitat that can be used by spotted owls on nearby sites while also providing viable locations on which future pairs or territorial singles can establish territories. Where unique circumstances or questions arise (*e.g.,* multiple activity centers, etc.), the Service is available to assist land managers with applying this recovery action.

As a general rule, forest management activities that are likely to diminish a home range's capability to support spotted owl occupancy, survival and reproduction in the long-term should be discouraged. However, we recognize that land managers have a variety of forest management obligations and that spotted owls may not be the sole driver in these decisions. Here, active forest management may be necessary to maintain or improve ecological conditions. We support projects whose intent is to provide long-term benefits to forest resiliency and restore natural forest dynamic process, when this management is implemented in a landscape context and with carefully applied prescriptions to promote long-term forest health. Examples of active management projects include forest stand restoration, fire risk reduction, treatment of insect infestations and disease and the restoration of high quality early seral habitat as described by Swanson *et al.* (2010). It is recognized that these projects may have both short and/or long-term effects to spotted owls and that treatments will be designed to minimize impacts as much as possible in keeping with project's intent.

Given natural events such as fire, wind storms, and insect damage, not all habitat-capable lands in a spotted owl home range are likely to contain spotted owl habitat at any one time. The amount and distribution of existing habitat within a home range may determine which management options will have greater or lesser impacts to the ability of spotted owls to occupy and reproduce in those areas. This, in turn, may affect the flexibility for land managers to implement traditional timber harvests while meeting the intent of this recovery action.

In the drier and southern portions of the range, managing for dense older forest mixed with some younger or more structurally diverse stands may also be appropriate (Franklin *et al.* 2000, Olson *et al.* 2004, but see Dugger *et al.* 2005). The Service recognizes there is tremendous variation across the species' range in such habitat conditions, and therefore, we expect to work closely with the BLM, FS and other land managers to define how to best meet the intent of this recommendation.

There is a wide breadth of spotted owl occupancy data throughout the species' range. Where spotted owl occupancy data are unavailable (*e.g*., unsurveyed habitat), land managers have a variety of tools to assist in determining where likely occupied habitat is and how to implement this recovery action, including assumption of occupancy (a common practice during section 7 consultation), surveys, spotted owl modeling results, forest stand data, etc.

Monitoring data, interagency teams, and adaptive management feedback will be useful tools in future revisions of this recovery action and its implementation, and may result in more refined approaches to implementation of this recovery action in the future. In cases where active management is conducted, assessing the effectiveness of treatments within spotted owl home ranges will provide land managers valuable feedback on how to design future projects and approaches within spotted owl home ranges. Land managers and researchers have numerous tools available to assess project efficacy, including spotted owl surveys, habitat mapping, prey analysis and modeling results. When opportunities arise, integration of monitoring in an adaptive management framework would be particularly valuable. The utility of each tool is largely dependent on the pre-project data available for comparison.

Research directly evaluating spotted owl responses to vegetation management including thinning, fuels reduction, and management intended to restore ecosystem functions is needed to address: (1) whether vegetation treatments result in development of desired habitat conditions; (2) whether treatments designed to create spotted owl habitat are used by spotted owls as NRF habitat conditions develop; (3) whether thinning operations designed to create future spotted owl habitat result in site abandonment during or after the operation and what types of vegetation management operations will allow spotted owls to persist on existing territories (minimize short-term negative effects); and (4) whether fuel reduction treatments can be done in a manner consistent with retaining occupied spotted owl sites and developing future spotted owl habitat on the landscape.

- ***Recovery Action 11: When vegetation management treatments are proposed to restore or enhance habitat for spotted owls (e.g., thinnings, restoration projects, prescribed fire, etc.), consider designing and conducting experiments to better understand how these different actions influence the development of spotted owl habitat, spotted owl prey abundance and distribution, and spotted owl demographic performance at local and regional scales.***

Additional research that identifies both short-term and long-term responses of prey populations (northern flying squirrels, woodrats, and other small mammals) to thinning treatments is also needed. Such forest management experiments should recognize the management activities known to negatively affect spotted owls discussed earlier and seek to expand our understanding of practices that will improve conditions for spotted owls and their prey.

We encourage collaborative efforts among State and Federal agencies, research scientists, and other interested parties where possible. In order to address the questions presented above, both intensive field research projects and larger, retrospective analyses that examine how different forest practices influence development of spotted owl habitat over time are needed.

Post-fire Logging

Decisions to harvest timber after wildfires often are based on financial considerations, human safety, a desire to modify the composition and resource production of forests, and a desire to "clean up the forest" (Foster and Orwig 2006, Noss and Lindenmayer 2006, Lindenmayer *et al.* 2008). Possible beneficial ecological effects of post-fire timber harvest include: decreased erosion due to placement of debris on the forest floor which intercepts surface water flow; decreased buildup of insect pests due to dead tree removal; decreased magnitude and extent of lethal soil temperatures around burning coarse woody debris; and, in stands where harvest-generated slash is treated, decreased fire risk due to removal of snags (McIver and Starr 2000, Lindenmayer *et al.* 2008, Monsanto and Agee 2008, Peterson *et al.* 2009). However, support is lacking for the contention that reduction of fuels from post-fire harvest reduces the intensity of subsequent fires (McIver and Starr 2000), and planting of trees after post-fire harvest can have the opposite effect. For example, forests in southwest Oregon that were logged and planted after a 1987 fire burned more severely in a 2002 fire than areas that were not logged or planted due, evidently, to high fuel conditions in conifer plantations (Thompson *et al.* 2007).

Detrimental ecological effects of post-fire timber harvest include: increased erosion and sedimentation, especially due to construction of new roads; damage to soils and nutrient-cycling processes due to compaction and displacement of soils; reduction in soil-nutrient levels; removal of snags and, in many cases, live trees (both of which are habitat for spotted owls and their prey); decreased regeneration of trees; shortening in duration of early-successional ecosystems; increased spread of weeds from vehicles; damage to recolonizing vegetation; reduction in hiding cover and downed woody material used by spotted owl prey; altered composition of plant species; increased short-term fire risk when harvest generated slash is not treated and medium-term fire risk due to creation of conifer plantations; reduction in shading; increase in soil and stream temperatures; and alterations of patterns of landscape heterogeneity (Perry *et al.* 1989, McIver and Starr 2000, Beschta *et al.* 2004, Karr *et al.* 2004, Donato *et al.* 2006, Lindenmayer and Noss 2006, Reeves *et al.* 2006, Russell *et al.* 2006, Thompson *et al.* 2007, Lindenmayer *et al.* 2008, Johnson and Franklin 2009, Peterson *et al.* 2009, Swanson *et al.* 2010). Soil damage and erosion are higher with traditional harvesting systems (*e.g.*, tractors) than they are with advanced systems (*e.g.*, helicopters) (Klock 1975, Peterson *et al.* 2009). After the 1988 Yellowstone fire, rates of soil loss were greatest where litter cover was minimal, percent silt content was high, and postfire logging had been conducted (Marston and Haire 1990 in McIver and Starr 2000). Moreover, post-fire timber harvest activities "undermine many of the ecosystem benefits of major disturbances" (Lindenmayer *et al.* 2004:1303) and frequently "ignore important ecological lessons, especially the role of disturbances in diversifying and rejuvenating landscapes" (DellaSala *et al.* 2006:51). To avoid crisis-mode decision-making and to minimize these detrimental effects, ecologically-informed policies based on pre-fire management direction should be developed before fires occur (Lindenmayer *et al.* 2008, Johnson and Franklin 2009).

Results from the three radio-telemetry studies of spotted owls in post-fire landscapes indicate that spotted owls use forest stands that have been burned, but generally do not use stands that have been burned and logged. For example, California spotted owls tracked 4 years post-fire in burned, unlogged stands: (1) had 30 percent of their nonbreeding-season roost locations within the fire's perimeter (Bond *et al.* 2010); (2) selected low-severity burned forests for roosting during the breeding season (Bond *et al.* 2009); and (3) selected low-, medium-, and high-severity burned forests for foraging within 1.5 km of the nest or roost site, with the strongest selection for high-severity burned forest (Bond *et al.* 2009). However, for spotted owls in stands that had been harvested post-fire: (1) infrequent foraging in stands burned with low-, medium-, and high-severity fires was restricted to areas with live trees such as those in riparian areas (Clark 2007), and (2) use shifted away from burned stands during 3 years post-fire (King *et al.* 1998). Comprehensive analyses quantifying how spatial configuration of forest type, burn intensity, and post-fire logging affects spotted owl demographic and occupancy rates will provide critical information for maintaining habitat during fuels-management activities.

Consistent with restoration goals, post-fire management in these areas should promote the development of habitat elements that support spotted owls and their prey, especially those which require the most time to develop or recover (*e.g.*, large trees, snags, downed wood). Such management should include retention of large trees and defective trees, rehabilitation of roads and firelines, and planting of native species (Beschta *et al.* 2004, Hutto 2006, Peterson *et al.* 2009). We anticipate many cases where the best approach to retain these features involves few or no management activities. Forests affected by medium- and low-severity fires are still often used by spotted owls and should be managed accordingly. Many researchers supported the need to maintain habitat for spotted owl prey. For example, Lemkuhl *et al.* (2006) confirmed the importance of maintaining snags, downed wood, canopy cover, and mistletoe to support populations of spotted owl prey species. Gomez *et al.* (2005) noted the importance of fungal sporocarps which were positively associated with large downed wood retained on site post-harvest. Carey *et al.* (1991) and Carey(1995) noted the importance of at least 10 to 15 percent cover of downed wood to benefit prey. The costs and benefits of post-fire harvest to the development of habitat for spotted owls and their prey should be evaluated by interagency teams (*e.g.*, Level 1 teams) during the consultation process.

- ***Recovery Action 12: In lands where management is focused on development of spotted owl habitat, post-fire silvicultural activities should concentrate on conserving and restoring habitat elements that take a long time to develop (e.g., large trees, medium and large snags, downed wood).*** Examples of areas where we believe this recovery action would greatly benefit future spotted owl habitat development include such fire-affected areas as the Biscuit fire, the Davis fire and the B&B complex.

Habitat Definitions

While some area-specific definitions of habitat have been developed in parts of the spotted owl's range, identification of existing spotted owl habitat and the management of lands to provide new habitat in the future would benefit greatly from a range-wide set of province-specific definitions of spotted owl habitat (*e.g.,* high-quality, nesting/roosting, foraging, dispersal). Variation in habitat structure and use across the spotted owl's range drives the need for province-specific definitions. The definitions should use forest composition and structure vernacular so that spotted owl habitat can be described in forest-management terms, and may also incorporate spatial and abiotic features that help determine where spotted owls use these types of stands. As part of our habitat modeling process (Appendix C), we solicited information from spotted owl experts on the regional biotic and abiotic factors that dictated where on the landscape spotted owls nested and roosted, and on regional definitions of spotted owl foraging habitat. These data will provide a good starting point for this effort.

- ***Recovery Action 13: Standardize province-specific habitat definitions across the range of the spotted owl using a collaborative process.***

Tribal Lands

The Service received comments from a number of American Indian Tribes on the draft Revised Recovery Plan indicating concerns that Tribal lands were not recognized separately from other non-federal lands. It was not the Service's intent to imply that Tribal lands are the same as other non-federal lands. The Revised Recovery Plan is not intended to affect the American Indian Tribal governments' rights to manage their lands. We understand Tribal lands are managed in accordance with Tribal goals and objectives, within the framework of applicable laws.

The Service recognizes the special government-to-government relationship between the Federal government of the United States and American Indian Tribal governments derived from the Constitution of the United States, treaties, Supreme Court doctrine, and Federal statutes. The Service acknowledges American Indian Tribal governments as sovereign nations with inherent powers of self-governance.

The Service also recognizes American Indian Tribes have long worked to conserve and monitor spotted owls on their lands. The efforts of many Tribes have contributed to spotted owl conservation and maintained the Tribal cultural values of the spotted owl and its habitat. Many Tribal lands have been managed with a holistic perspective, including reserves and modified silvicultural practices, and therefore can be islands of high quality habitat that support many species as well as healthy ecosystems. The Service is proud of our many positive government-to-government collaborations with American Indian Tribes and the benefits to fish and wildlife conservation.

The Service is committed to engaging in regular and meaningful consultation and collaboration with American Indian Tribal governments to determine what cooperative and voluntary measures Tribes may take to support spotted owl recovery actions and address other recovery needs and opportunities for spotted owls, recognizing the special status of Tribal lands. Consistent with existing laws and policies, and to honor this spirit of consultation and collaboration, the Service will give full consideration to tribal recovery plans, habitat and modeling data, and other conservation efforts.

All of the Service's actions, including our consultation and collaboration, will take place on a government-to-government basis and be consistent with applicable executive and secretarial orders, memoranda, and policies, including Executive Order 13175, "Consultation and Coordination with Indian Tribal Governments" (11/6/2000); Secretarial Order 3206, "American Indian Tribal Rights, Federal-Tribal Responsibilities, and the Endangered Species Act" (6/5/97); Presidential Memorandum (11/5/09); the U.S. Fish and Wildlife Service's Native American Policy (6/28/94), and the Endangered Species Act.

The Service may enter Memoranda of Understanding with Tribes for (a) mutually agreeable species conservation efforts, (b) utilizing Tribal habitat and modeling data regarding the presence of threatened, endangered, or candidate species on Tribal lands, and (c) processes to discuss and resolve matters regarding each government's spotted owl recovery efforts and obligations.

State and Private Lands

This Revised Recovery Plan acknowledges the role State and private lands can contribute toward recovering the spotted owl. The relative importance of this role to spotted owl recovery should be assessed. In 1994, in its biological opinion on the NWFP, the Service concluded that the NWFP met or exceeded the standards expected for the Federal contribution to recovery of the spotted owl. The Service also concluded in that opinion that overall recovery of the species would be further evaluated to determine recovery needs on non-federal lands. Since 1994, Federal lands have provided the majority of contribution to spotted owl recovery, and in many portions of the range it provides the sole contribution. However, there are portions of the range where habitat on Federal lands are lacking or of low quality or where there is little Federal ownership, and State and private lands may be able to improve recovery potential in key areas.

Given the continued decline of the species, the apparent increase in severity of the threat from barred owls, and information indicating a recent loss of genetic diversity for the species, we recommend conserving occupied sites and unoccupied, high-value spotted owl habitat on State and private lands wherever possible. This recommendation is primarily driven by the concern associated with displacement of spotted owls by barred owls, the need to retain good quality habitat to allow for displaced or recruited spotted owls to reoccupy such habitat, and the need to retain a spotted owl distribution across the range where Federal lands are lacking. Examples of these areas include portions of southwestern Washington, northwestern Oregon (potentially including parts of the Tillamook and Clatsop State Forests), and northeastern California.
Because spotted owls on established territories are likely to be more successful if they remain in those locations (Franklin *et al.* 2000), managing to retain spotted owls at existing sites should be the most effective approach to conserving spotted owls. Retention of long-term occupancy and reproduction at established spotted owl sites will require a coordinated and cooperative effort to craft management approaches tailored to regional, provincial or local conditions.

This Revised Recovery Plan acknowledges the important role State and private lands can play toward implementing a coordinated and cooperative effort to recover the spotted owl. The relative importance of this role to spotted owl recovery can be addressed in a variety of ways. Using the rangewide habitat modeling framework will help identify areas where State and private lands can make the best contribution to spotted owl recovery. The Service will continue to work with these landowners to use a variety of voluntary incentives and approaches that will help contribute to spotted owl recovery through protection and development of unoccupied, high-quality habitat.

During the past 20 years, the Service has worked cooperatively with non-federal landowners to minimize negative impacts to spotted owls and to encourage conservation of spotted owl habitat. The Service has worked with a number of different applicants to implement habitat conservation plans (HCPs) and safe harbor agreements (SHAs) that minimize and mitigate impacts or provide for a net conservation benefit. Lands covered under section 10 of the ESA provide for the conservation of key habitat areas and occupied sites.

Although HCPs are not required to advance the recovery of listed species, voluntary recovery actions included in an HCP can promote recovery. These plans generally are designed to provide: (1) high-quality habitat and retain spotted owl sites; or (2) foraging and dispersal opportunities to make important contributions to spotted owl recovery. SHAs must provide a net conservation benefit to the species, while allowing the landowner to return to baseline habitat conditions after a pre-defined period of time. The net conservation benefits are often direct contributions to recovery, even if of a limited temporal nature. We recommend these efforts be continued and expanded in certain portions of the range to retain and recruit spotted owl habitat on State and private lands in areas with a lack of proximal high-quality habitat on Federal lands and where future distribution of spotted owls would improve long-term recovery potential. These areas include, but are not limited to, southwest Washington, northwest Oregon and the north coast of California.

This Revised Recovery Plan also identifies several recovery actions meant to encourage State and private landowners to work voluntarily toward recovery through economic incentives. There are a number of established and emerging incentive-based options that currently exist for non-federal landowners, including conservation banking and carbon sequestration that could provide valuable spotted owl habitat maintenance or restoration. Spotted owls could receive either directed or indirect benefits from ecosystem services market incentives.

- ***Recovery Action 14: Encourage applicants to develop Habitat Conservation Plans and Safe Harbor Agreements that are consistent with the recovery objectives.***

Habitat conservation plans and safe harbor agreements are important tools that non-federal landowners can voluntarily use to assist in the recovery of the spotted owl. On July 27, 2010, the Service finalized a SHA for small woodlot owners in Oregon that will enroll up to 50,000 acres of non-federal lands within the State over a total of 50 years. The primary goal of this SHA is to increase the time between harvests (*i.e.*, defer harvest), and to lightly to moderately thin younger forest stands that are currently not habitat to increase tree diameter size and stand diversity (*e.g.*, species, canopy layers, presence of snags).

- ***Recovery Action 15: The Service will solicit individual recommendations from stakeholders to develop a comprehensive set of tools and business and economic incentives that facilitate creative opportunities for non-federal landowners to engage in management strategies consistent with the recovery objectives.***

Many non-federal landowners and land managers in the region have adjusted their management strategies to emphasize short harvest rotations (*e.g.*, 40 to 50 years) and the processing of comparatively small diameter trees. Incentives should be identified and developed as a means to reward landowners and land managers for implementing "ecological forestry" practices (Franklin *et al.* 2007) designed to recruit and retain higher-quality spotted owl habitat. Such incentives may include extending tax credits for recovery–related activities that are carried out under the Farm Bill to timber production, development of State or Federal subsidies for lands that meet carbon sequestration and habitat development goals, or conservation banks that facilitate mitigation for actions that impact the spotted owl. Many of the emerging ecosystem services incentives could allow landowners to receive financial compensation for providing co-benefits that include growing higher-quality spotted owl habitat. Implementation of the incentives program could be coupled with the SHA process to provide regulatory protection for landowners who create or enhance spotted owl habitat. Aspects of this recovery action may also be implemented more efficiently at the individual state levels as described under Listing Factor D.

- ***Recovery Action 16: Federal, State, and local managers should consider long-term maintenance of local forest management infrastructure as a priority in planning and land management decisions.***

This Revised Recovery Plan documents the need for active forest management and restoration in many parts of the spotted owl's range to meet long-term ecological goals, especially in dry forest areas, which will benefit spotted owl recovery. Meeting this need will require local capability to treat, remove, and process various types of forest biomass under a variety of logistical and economic conditions.

Timber-based economies and communities in the western United States have experienced significant changes during the last half-century. Some declines in workforce can be attributed to changes in environmental regulation at the Federal, State, and local levels during this time period. However, changing domestic and international markets, competition, industry automation, and depleted supply of older timber have all combined to create a sometimes volatile and unpredictable economic environment for local timber-based economies. Many of these economic changes were well underway prior to the listing of the spotted owl and have occurred outside of the spotted owl's range as well (Raettig and Christensen 1999, Conway and Wells 1994, Power 2006).

Several representatives from smaller timber companies and rural communities have stated that the ability to implement forest restoration projects in the future will suffer because of a continued decline in local workforce, expertise, equipment, and milling or processing capacity (Storm 2007, Mason and Lippke 2009, Carrier 2010). The Service recognizes this concern and recommends it be evaluated at the State and local scales.

Although it is beyond the scope of this Revised Plan to address these broader economic issues, it is in the general interest of long-term forest health -- and therefore spotted owl recovery -- to maintain a local ability to implement forest management and restoration projects on public lands. Therefore, it is appropriate for agency land managers to take into account this need when designing, prioritizing, and locating projects. Stewardship contracting by the BLM and the USFS may be applicable to this goal (Newberry 2011).

LISTING FACTOR B: OVERUTILIZATION FOR COMMERCIAL, SCIENTIFIC, OR EDUCATIONAL PURPOSES

There is no known threat to the spotted owl relative to this listing factor, so no recovery criteria or recovery actions are identified specific to this listing factor.

LISTING FACTOR C: DISEASE OR PREDATION

Although there is no known imminent threat to the spotted owl from disease or predation (so no recovery criteria are identified specific to this listing factor) it is important to continue to monitor for diseases and pathogens so that appropriate action can be taken if necessary.

Diseases

Sudden oak death

Sudden oak death is a potential threat to spotted owl habitat (Courtney *et al.* 2004). This disease is caused by a non-native, recently introduced, fungus-like pathogen, *Phytopthora ramorum*. This pathogen has killed hundreds of thousands of oak and tanoak trees along the California coast (from southern Humboldt County to Monterey County) and hundreds of tanoak trees on the southern Oregon coast (southwestern Curry County) (Goheen *et al.* 2006).

According to Goheen *et al.* (2006:1):

> “The pathogen has a wide host range including Douglas-fir, grand fir, coast redwood, and many other tree and shrub species common in Oregon and Washington forests. Tree mortality, branch and shoot dieback, and leaf spots result from infection depending on host species and location. *Phytopthora ramorum* spreads aerially by wind and wind-driven rain and

> moves within forest canopies and tree tops to stems and shrubs and from understory shrubs to overstory trees. The pathogen survives in infected plant material, litter, soil, and water. It is moved long distances in nursery stock.…State and Federal personnel regularly survey forests and nurseries in the Pacific Northwest to detect the disease."

Due to its potential impact on forest dynamics and alteration of key prey and spotted owl habitat components (*e.g.,* hardwood trees, canopy closure, and nest tree mortality), sudden oak death poses a potential threat to spotted owls, especially in the southern portion of the spotted owl's range (Courtney *et al.* 2004).

Avian disease

At this time, no avian diseases are significantly affecting spotted owls. It is unknown whether avian diseases such as West Nile virus (WNV), avian flu, or avian malaria (Ishak *et al.* 2008) will significantly affect spotted owls. Carrying out the following monitoring action would alert us if any disease becomes a threat.

- ***Recovery Action 17: Monitor for sudden oak death and avian diseases (e.g., WNV, avian flu, Plasmodium spp.) and address as necessary.***

Monitoring is necessary to assess the degree to which sudden oak death affects spotted owl habitat and whether any avian disease becomes a threat. If one or more pathogens or diseases pose a threat to spotted owls or their habitat, specific responses would need to be developed and implemented.

Predation

Known predators of spotted owls are limited to great horned owls (Forsman *et al.* 1984), and, possibly, barred owls (Leskiw and Gutiérrez 1998). Other suspected predators include northern goshawks, red-tailed hawks, and other raptors (Courtney *et al.* 2004). Occasional predation of spotted owls by these raptors is not considered to be a threat to spotted owl populations, so no criteria or actions are identified. Actions relative to the threat from barred owls are presented in Listing Factor E.

LISTING FACTOR D: INADEQUACY OF EXISTING REGULATORY MECHANISMS

One of the original reasons for listing the spotted owl was the inadequacy of the applicable regulatory mechanisms as they existed in 1990. Although there were regulatory mechanisms in place at the time, they offered variable levels of protection to spotted owls and, to a lesser extent, spotted owl habitat. Since 1994, the NWFP has been implemented on Federal lands throughout the range of the spotted owl. On Federal lands, the Service continues to support the implementation of the NWFP and its associated Standards and Guidelines, as well as the implementation of the recovery actions in this Revised Recovery Plan. This section focuses primarily on the State regulations that cover the approximately 21 million acres of private- and State-owned forest lands in Washington, Oregon and California (see Table III-1).

State and private lands are regulated under various State authorities, and timber harvest within each state is governed by rules that provide varying degrees of protection of spotted owls or their habitat. In Washington, logging practices on State, State trust, and private lands are regulated by the Washington State Department of Natural Resources. In Oregon, the State Forest Practices Act regulates State and private lands. In California, the Forest Practice Rules and timber harvest plan review process on State and private lands substitute for an Environmental Impact Review under the California Environmental Quality Act of 1970. The California Department of Forestry and Fire Protection (CAL FIRE) is responsible for review and approval of timber harvest plans. See below for a more comprehensive treatment of each state.

Since the listing of the spotted owl, there have been some regulatory changes that have reduced the rate of habitat decline on State and private lands. However, in light of the continued decline of the species, the apparent increase in severity of the threat from barred owls, and information indicating a recent loss of genetic diversity for the species, this Revised Recovery Plan identifies a more important recovery role for State and private lands. The Service recommends the States evaluate existing spotted owl conservation efforts and consider changes where appropriate to contribute to recovery goals; specific geographical areas of interest include northeastern California, northwestern Oregon and southwestern Washington. This evaluation should consider the feasibility of restoring and conserving spotted owl habitat on non-federal lands where they can contribute to spotted owl recovery. The Service is available to assist States in evaluating the importance of spotted owl conservation efforts on State and private lands.

In addition, the Service suggests the States evaluate existing regulations affecting spotted owls and make changes where necessary and appropriate to meet recovery goals. We acknowledge the potential economic impacts such changes might have in certain parts of the spotted owl range, and we make several recommendations below to address these concerns.

Washington. In 1996, the State Forest Practices Board (Board) adopted Forest Practices Rules (Washington Forest Practices Board 1996, Washington Administrative Code 222) that would contribute to protection of spotted owls on strategic areas of non-federal lands. Adoption of the Forest Practices Rules was based in part on recommendations from a Science Advisory Group that identified important non-federal lands and recommended roles for those lands in spotted owl conservation (Hanson *et al.* 1993, Buchanan *et al.* 1994). The 1996 rule package was developed by a stakeholder policy group and then reviewed, modified, and approved by the Board.

The Board is currently working to develop an updated, long-term strategy to protect the spotted owl and its habitat on private and state forest lands. In 2008, the Forest Practices Board convened a Northern Spotted Owl Policy Working Group (Working Group). The Working Group's consensus recommendations were presented to the Board in February 2010. The Board accepted the Working Group consensus recommendations and directed Washington State Department of Natural Resources to form a Northern Spotted Owl Implementation Team (Washington NSO Implementation Team).

One of the Working Group's recommendations resulted in a rule change that reduces the likelihood that potentially important habitat near a spotted owl site center is lost through timber harvest while the Board completes its long-term conservation strategy. This rule change adds an evaluation by a three-member Spotted Owl Conservation Advisory Group whenever a site center is subject to possible decertification (and therefore loss of regulatory protections provided by the Forest Practices Rules). The purpose of this evaluation is to determine whether habitat at the site center should be maintained, regardless of the site center's occupancy status, while the Board is completing its long-term strategy.

The Board also directed the Washington NSO Implementation Team to develop a work plan, including prioritization, and directed the team to coordinate with the Federal agencies with regard to the Barred Owl control experiments. The Board also directed the Washington NSO Implementation Team to formally convene a technical team to assess spatial and temporal allocation of conservation efforts on non-federal lands using best available science.

- ***Recovery Action 18: The Washington State Forest Practices Board (Board) should use the final recovery plan and the habitat modeling tool to inform the process currently underway to identify areas on non-federal lands in Washington that can make strategic contributions to spotted owl conservation over time. The Service encourages timely completion of the Board's efforts and will be available to assist as necessary.***

Oregon. The Oregon Forest Practices Act provides for protection of 70-acre core areas around recently surveyed sites occupied by an adult pair of spotted owls capable of breeding (as determined by protocol surveys), but it does not provide for protection of resident single sites, nor of spotted owl habitat beyond these areas (ODF 2006). The Forest Practices Act does not require spotted owl surveys to identify potential nesting-pair or resident-single sites. The interim protection goals for spotted owl nesting sites initially adopted under the Forest Practices Act at the time of listing have yet to be finalized. There is a process under the Forest Practices Act (*see* Oregon Administrative Rule 629-680) to update resource (*i.e.,* spotted owl) site protection measures. Every two years the Oregon Department of Forestry reports to the Board of Forestry regarding any recommended changes to the resource site protection rules and to identify any research needed to further evaluate the protection levels. This on-going review has not been used to finalize the spotted owl resource site protection rules or to monitor their impact on spotted owls.

- ***Recovery Action 19: The Service will request the cooperation of Oregon Department of Forestry in a scientific evaluation of: (1) the potential role of State and private lands in Oregon to contribute to spotted owl recovery; and (2) the effectiveness of current Oregon Forest Practices in conserving spotted owl habitat and meeting the recovery goals identified in this Revised Recovery Plan. Based on this scientific evaluation, the Service will work with the Oregon Department of Forestry and other individual stakeholders to provide specific recommendations for how best to address spotted owl conservation needs on Oregon's non-federal lands.***

Such an analysis is beyond the scope of this Revised Recovery Plan and should be initiated as a cooperative effort between the Service and Oregon Department of Forestry. Among the issues this evaluation should address are the adequacy of the 70-acre core approach for spotted owl pair nest sites in contributing to recovery needs, an assessment of long-term residency and productivity of spotted owls in these territories, the potential application of the habitat modeling tool (Appendix C) to identify areas of high current or potential recovery value, and the potential application of these results to future land management decisions (*e.g.*, critical habitat revisions, HCPs, etc.).

Similar to the Washington Forest Practices Board's Northern Spotted Owl Policy Working Group, this group should identify voluntary and regulatory incentives that may improve spotted owl conservation on State and private lands, as well as areas where economic and other goals may be achieved while also benefiting spotted owls. The state-led Washington group provides a strong model for critically examining the contribution of State forestry regulations to spotted owl recovery.

This Oregon effort should focus on the identification of opportunities to address spotted owl recovery needs on State and private lands and an assessment of the various economic and social trade-offs necessary to meet this goal. Some specific issues this Oregon group should address are:

- potential recommendations to revise Forest Practice regulations, if appropriate and necessary;
- identification of specific opportunities to apply complimentary management goals that meet multiple economic, social, and ecological objectives compatible with spotted owl recovery, such as carbon sequestration, fuels treatment, silviculture, water quality, and recreation;
- coordination between the Oregon Department of Forestry and the Service to receive routine summaries of forest operations; and
- identification of financial and non-regulatory incentives to non-federal land managers that may encourage implementation of recovery actions on these lands (see Recovery Action 15).

California. State Forest Practice Rules, which govern timber harvest on private lands, were amended in 1990 to require surveys for spotted owls in nesting, roosting and foraging habitat and to provide habitat protection measures around activity centers (CFPR 2011, 14 CCR§§ 919.9 (a)-(g)). Under the Forest Practice Rules, a timber harvest plan cannot be approved if it is likely to result in incidental take of federally-listed species, unless the take is authorized by a Federal HCP (CFPR 2011, 14 CCR§§ 898.2(d) and (f)). The California Department of Fish and Game (CDFG) initially reviewed all Timber Harvest Plans (THPs) to ensure that take of State- and federally-listed species was not likely to occur. The Service currently provides technical assistance to CAL FIRE in its THP review of federally-listed species.

- ***Recovery Action 20: The Service will request the cooperation of CAL FIRE and individual stakeholders in an evaluation of: (1) the potential recovery role of spotted owl sites and high-quality habitat on non-federal lands in California, and (2) evaluation and implementation of appropriate conservation tools (e.g., carbon sequestration, Habitat Conservation Plans, Safe Harbor Agreements) to assist with supporting spotted owl recovery actions outlined in this Recovery Plan.***

Working with the State and stakeholders in this manner would create an opportunity to identify more locally-specific information to assist with outlining the potential contribution of private lands to spotted owl recovery. This sort of collaboration would also be an appropriate mechanism to identify and create voluntary and regulatory incentives that may improve spotted owl conservation on non-federal lands that integrate with existing State regulatory and incentive programs.

- ***Recovery Action 21: The Service will provide technical assistance to the California Board of Forestry and Fire Protection and CAL FIRE to develop scientifically based and contemporary Forest Practice Rules to provide for the breeding, feeding and sheltering of spotted owls.***

Currently, the State of California considers it a crime to "take, possess, or destroy" birds of prey, including all owl species (California Fish and Game Code: CA FISH & G § 3500 – 3857). While some barred owl removal has occurred in California forest lands under special permits, this statute could hinder the ability to reduce the effects of barred owls on spotted owls in the southern portion of the range.

- ***Recovery Action 22: If barred owl removal is determined to be effective, work with the State of California to explore options for managing barred owls using lethal means.***

Table III-1. Summary of the forestry rules that provide spotted owl protections for California, Oregon and Washington

State	NSO Surveys Required	Habitat Requirements				Noise Disturbance Restrictions			NSO Forest Rules last updated	Exceptions
		Which spotted owl sites	Size-Location	Habitat	Duration	Zone size	Duration	Restricted Disturbance Includes		
California[1]	Yes	All	Within 0.7–1.3 miles of center	Within 500 ft. of nest timber operations limited during breeding season and must retain functional nesting habitat[2]	All year as long as determined by CAL FIRE to be a site	500 ft.	Breeding season[3]	All timber harvest operations except planting and surveying	2009 – allowed designation of independent biological consultants to fulfill evaluation role for likelihood of take	CFPRs allow for deviations with FWS review and other sec. 7 and 10
				500-1000 ft. retain functional roosting habitat[2]						
				500 acres spotted owl habitat in 0.7 -mile radius						
				1336 acres spotted owl habitat in 1.3- mile radius						
Oregon	No	All	Nest site[4] is within 500 ft. of timber operations	70-acre no cut Core around nest with the outer edge of the Core no less than 300 ft. distance from the nest	Life of circle	0.25 mile	Critical period[5]	Timber operations except log hauling, reforestation, road maintenance, research and monitoring, ground application of chemicals, aerial applications that do not require multiple passes, and burning	2006	
Washington	No	SOSEA	Within 0.7 miles of site center	retain all suitable habitat [6,7]	Life of circle	0.25 mile	Nesting season[8]	Felling and bucking, yarding, slash disposal, prescribed burning, road construction, and other such activities (operation of heavy equipment and blasting)	1996	For landowners whose forest land ownership within the SOSEA is ≤500 acres and where the activity is
			Within home range of 1.8-2.7 mile radius	retain 40% of suitable habitat [6,7]						
		Non-SOSEA	70 acres around known nest site	retain best 70 acres[7]	Nesting season[8] only					

										>0.7 mile of the NSO site center and sec. 7, 10 and some State planning regulations

1. California Forest Practice Rules (CFPRs) rely on the Service's Guidelines as presented here.
2. Nest-Roost habitat in California is generally defined as 60-90% canopy closure, multi-layered/species canopy with trees >30 inches diameter, trees with deformities, woody debris on ground and open space below canopy to allow spotted owls to fly.
3. Breeding season for Coastal California is defined as February 1-July 30, Interior as February 1-August 31.
4. Nest site requires a pair of spotted owls.
5. The critical period in Oregon is defined as March 30 to September 30.
6. Suitable habitat in Washington is defined as: forest stands which meet the description of old forest habitat, sub-mature habitat or young forest marginal habitat per Washington Forest Practices Regulations (Washington Forest Practices Board 1996).
7. These thresholds are used as guidance in SEPA review and do not necessarily preclude harvest.
8. Nesting season in Washington is defined as March 1 to August 31.

LISTING FACTOR E: OTHER NATURAL OR MANMADE FACTORS AFFECTING ITS CONTINUED EXISTENCE

Barred Owl

The three main threats to the spotted owl are competition from barred owls, past habitat loss, and current habitat loss. Barred owls reportedly have reduced spotted owl site occupancy, reproduction, and survival (see Appendix B). Limited experimental evidence, correlational studies, and copious anecdotal information all strongly suggest barred owls compete with spotted owls for nesting sites, roosting sites, and food, and possibly predate spotted owls. The threat posed by barred owls to spotted owl recovery is better understood now than when the spotted owl was listed. Because the abundance of barred owls continues to increase, the effectiveness in addressing this threat depends on action as soon as possible.

Because the abundance of barred owls continues to increase, the effectiveness in addressing this threat depends on action as soon as possible.

There are substantial information gaps regarding ecological interactions between spotted owls and barred owls, and how those interactions may be managed to meet the Recovery Criteria. Recovery actions should provide the information needed to identify effective management approaches and guide the implementation of appropriate management strategies. Many of the following actions should be done concurrently; Figure III-1 shows how these Actions may inform one another. The Service is the primary agent to oversee implementation of any strategy for the management of barred owls.

Coordination among all agencies and non-governmental organizations that can contribute to research on ecological interactions between spotted owls and barred owls is needed to prioritize research topics, maximize funding opportunities, minimize redundancies, increase efficiency, identify potential management strategies, and communicate with decision-makers. Included as Recovery Action 21 in the 2008 Recovery Plan, the Barred Owl Work Group was appointed as a Recovery Implementation Team to implement the 2008 Recovery Plan and has provided coordination on numerous analyses, topics and issues. Currently, representatives from 10 Federal, State and non-governmental agencies and organizations comprise the Work Group helping to implement its technical and scientific functions.

This Barred Owl Work Group is chaired by the Service and guided by its charter, along with the Northern Spotted Owl Implementation Team (NSOIT). The Barred Owl Work Group has guided, and will continue to guide, implementation of numerous recovery actions addressing the barred owl threat to spotted owls.

- ***Recovery Action 23: Analyze existing data sets from the demographic study areas relative to the effects of barred owls on spotted owl site occupancy, reproduction, and survival.***

Through implementation of this recovery action, many of the long-term demographic data sets have been studied, resulting in white papers and pending publications. Additional analysis of these data has provided a greater understanding of the effects of barred owls on spotted owl detection rates, survival, site occupancy and the role of habitat in site occupancy. The Barred Owl Work Group will continue to work with the Principal Investigators of the demographic studies to mine data as appropriate.

- ***Recovery Action 24: Establish protocols to detect barred owls and document barred owl site status and reproduction.***

Protocols to detect barred owls and document important population information, including pair status and reproduction, provide vital data needed to help manage barred owls to reduce their threat to spotted owls. A subgroup of the Barred Owl Work Group was formed in 2008 to develop a barred owl-specific survey protocol. The subgroup developed a draft protocol in 2009 with the purpose of providing a high likelihood of determining barred owl presence for research studies. During the 2009 field season, the draft protocol was tested in several areas with the objectives of determining barred owl detection rates and the survey effort needed to adequately detect barred owls. These data have been analyzed allowing the subgroup to refine the protocol based on the field tests.

- ***Recovery Action 25: Ensure that protocols adequately detect spotted owls in areas with barred owls.***

The presence of barred owls has been shown to decrease the detectability of spotted owls. Consequently, the Barred Owl Work Group enlisted scientific support and analysis from many individual spotted owl researchers from the Federal, State and private sectors across the range of the spotted owl. Additional analysis of data from demographic study areas focused on addressing the questions of: 1) what are the per visit detection rates of spotted owls with and without barred owls, and 2) what are the site occupancy rates of spotted owls at historical spotted owl sites? These efforts have led to several white papers and pending publications. A draft revised spotted owl survey protocol was released for use and comment during the 2010 field season along with direction on how to transition from the 1992 protocol. Field testing of, and commenting on, several provisions of the draft protocol will occur during the next several field seasons leading to finalization of a survey protocol.

- ***Recovery Action 26: Analyze resource partitioning of sympatric barred owls and spotted owls.***

Radio-telemetry studies of sympatric spotted and barred owls help to: determine how the two species use their habitat and resources, including prey, in various areas; identify characteristics of habitats used by spotted owls in areas with substantial barred owl populations; and determine how habitat use by barred owls and spotted owls changes as barred owl numbers increase.

In anticipation of the need for this information, several research projects were initiated in 2007 and led by USGS, PNW, OSU and private industry researchers. This research is focused on interspecific competition and niche partitioning by spotted owls and barred owls. Results from the research are either incorporated in Appendix B or soon will be released in peer-reviewed publications. This information will provide the opportunity for adaptive management of this Revised Recovery Plan when it becomes available.

- ***Recovery Action 27: Create and implement an outreach strategy to educate the public about the threat of barred owls to spotted owls.***

Outreach and education are important components in addressing the barred owl threat, and we continue to look for opportunities to provide this. For example, since completion of the 2008 Recovery Plan, a Barred Owl Stakeholder Group has been formed. The Barred Owl Stakeholder Group, comprised of nearly 40 private and public stakeholders with interest in spotted owl and barred owl issues, met twice in 2009 with members of the barred owl work group and a professional ethicist to discuss the ethical considerations associated with permitting the experimental removal of barred owls and provided their individual feedback on the issue. The results of these discussions are part of the pre-scoping process, and are being considered, along with the results of public scoping, in the development of the draft EIS for issuance of a permit for barred owl removal to ensure we are aware of all potential issues. We will be conducting extensive outreach as part of the NEPA process for issuance of the Migratory Bird Treaty Act permit for the experimental removal of barred owls.

It is crucial that the general public be kept informed concerning this difficult aspect of spotted owl recovery and the potential consequences of not addressing this threat. Public outreach could include production and distribution of brochures, kiosk displays, press releases, and public meetings relative to research and management options.

- ***Recovery Action 28: Expedite permitting of experimental removal of barred owls.***

The concern regarding the current and future negative effects of barred owls on the recovery of spotted owls is considerable, and immediate research is needed. State and Federal permitting of scientifically sound research on removal experiments will be necessary to answer the question of the impacts of barred owls on spotted owls.

- ***Recovery Action 29: Design and implement large-scale control experiments to assess the effects of barred owl removal on spotted owl site occupancy, reproduction, and survival.***

We believe removal of barred owls would provide benefits to spotted owls in the vicinity of the removal and may have larger population effects. Given the rapidity and severity of the increasing threat from barred owls, barred owl removal should be initiated as soon as possible in the form of well-designed removal experiments. These experiments will have the potential to substantially expand our knowledge of the ecological interactions between spotted owls and barred owls (Dugger *et al.* in press) and the effectiveness of barred owl removal in recovering spotted owls. Removal experiments should be conducted in various parts of the spotted owl's range, including a range of barred owl/spotted owl densities, to provide the most useful scientific information.

In the fall of 2009 the Service initiated an Environmental Impact Statement for a proposed experimental removal of barred owls to determine if the removal benefits spotted owls. Public scoping was completed in January 2010 and a draft Environmental Impact Statement is in process.

- ***Recovery Action 30: Manage to reduce the negative effects of barred owls on spotted owls so that Recovery Criterion 1 can be met.***

Implement the results of research to adaptively manage the effects of barred owls to meet Recovery Criterion 1. Management could include silvicultural treatments for stand structure and composition (*e.g.*, habitat management for spotted owl prey), local or large-scale control of barred owl populations, and/or other activities at present unforeseen but informed by research results.

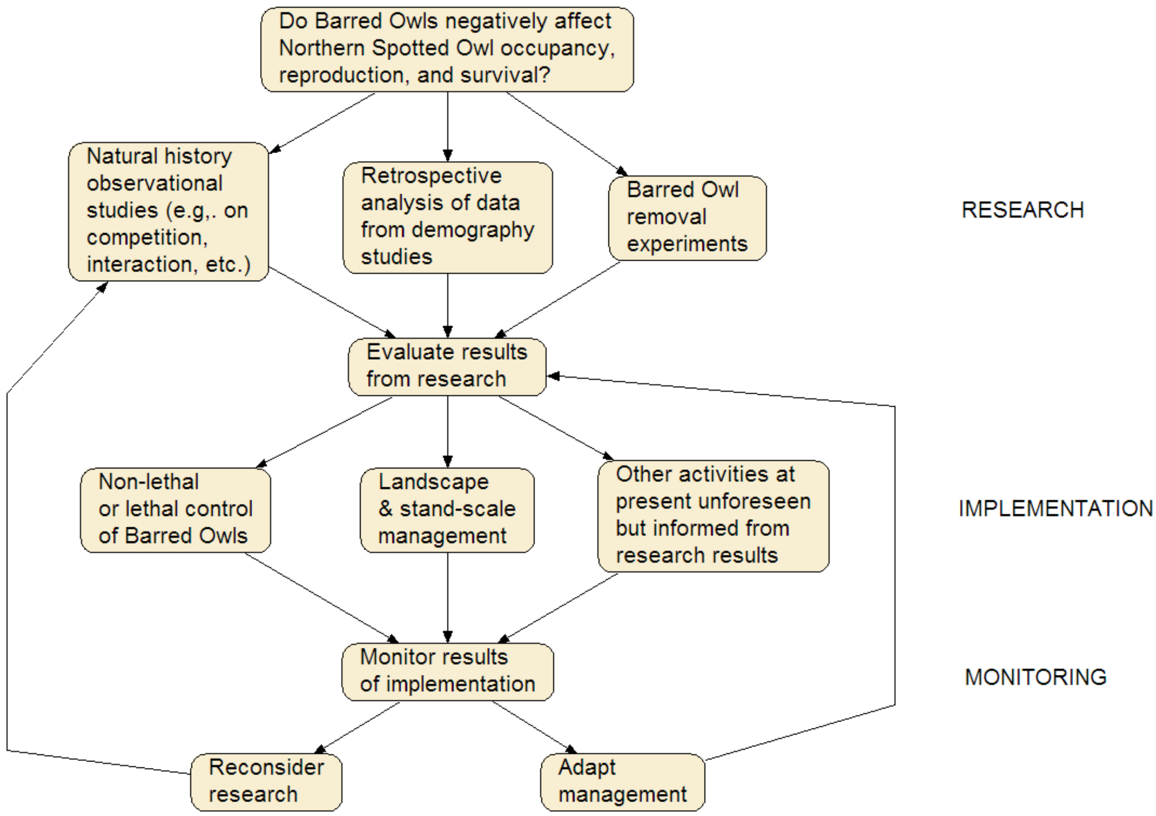


Figure III-1. Flowchart of barred owl Recovery Actions.

Conducting natural history studies (Figure III-1) is ongoing. Retrospective analysis of data from past and ongoing studies involves evaluating past data sets from demography study areas by adding barred owl covariates to test whether presence of barred owls affected detection rates, occupancy, reproduction, and survival of spotted owls (Dugger *et al.* 2009, Forsman *et al.* 2011, Dugger *et al.* in press). Many actions (*e.g.*, additional analysis of data, improving detection protocols for both species', outreach, identification of key spotted owl areas) have already begun. Preliminary findings from barred owl removal experiments could be realized in 1-3 years, whereas estimates of spotted owl vital rates may require more time. Evaluation of results from research is ongoing, and includes research already completed. Identification of management strategies should be based on research results, considerations for different geographic areas, costs, and changes in risk-levels to spotted owls over time. This may lead to the removal of barred owls through non-lethal or lethal methods. If research indicates local or large-scale maintenance removal of barred owl populations is needed, then public outreach, coordination among agencies, Migratory Bird Treaty Act permitting, and NEPA compliance would be required. Evaluation of results from research also may result in landscape and stand-scale management of spotted owl habitat and/or other activities unforeseen at present.

- ***Recovery Action 31: Develop mechanisms for landowners and land managers to support barred owl management using a collaborative process.***

Incentives, such as easily implemented safe harbor agreements or habitat conservation plans, can decrease a private landowner's concern regarding barred owl management that may result in an increase of spotted owls, as well as the associated issues that come with a listed species under the ESA.

- ***Recovery Action 32: Because spotted owl recovery requires well distributed, older and more structurally complex multi-layered conifer forests on Federal and non-federal lands across its range, land managers should work with the Service as described below to maintain and restore such habitat while allowing for other threats, such as fire and insects, to be addressed by restoration management actions. These high-quality spotted owl habitat stands are characterized as having large diameter trees, high amounts of canopy cover, and decadence components such as broken-topped live trees, mistletoe, cavities, large snags, and fallen trees.***

Maintaining or restoring forests with high-quality habitat will provide additional support for reducing key threats faced by spotted owls. Protecting these forests should provide spotted owls high-quality refugia habitat from the negative competitive interactions with barred owls that are likely occurring where the two species' home ranges overlap. Maintaining or restoring these forests should allow time to determine both the competitive effects of barred owls on spotted owls and the effectiveness of barred owl removal measures. Forest stands or patches meeting the described conditions are a subset of NRF habitat and actual stand conditions vary across the range. These stands or patches may be relatively small but important in a local area, may not be easily discernable using remote sensing techniques, and likely require project-level analysis and field verification to identify.

This recommendation can be justified at several scales and is supported by the best available research. At the scale of a spotted owl territory, Dugger *et al.* (in press) found an inverse relationship between the amount of old forest within the core area and spotted owl extinction rates from territories. At the population scale, Forsman *et al.* (2011) found a positive relationship between recruitment of spotted owls into the overall population and the percent cover of spotted owl NRF habitat within study areas. Both of these studies provide scientific support for the value to spotted owls of retaining structurally complex stands on the landscape.

Because the characteristics of the stands or patches targeted by this recovery action vary widely across the range of the species, the Service believes implementation and/or mapping of this recovery action is best left to interagency teams with localized expertise. To facilitate implementation of this recovery action on Federal lands, local, interagency Level 1 teams should continue to identify RA 32 stands or patches when necessary and evaluate the effects of proposed management activities in these areas on spotted owls, with assistance from management (Level 2) and Regional Technical Specialists, as needed. This approach will continue to ensure that interagency localized expertise will be utilized in identifying and managing Recovery Action 32 stands or patches and will be the result of interagency cooperation. Non-federal landowners are welcome to utilize the tools developed during the cooperative Federal process. The Service is available to assist non-federal landowners with the implementation of this recovery action.

On-the-ground application of this action has been, and continues to be, implemented on the west side of the Cascades on Federal lands as part of the level 1 team consultation process since shortly after the 2008 Recovery Plan was finalized. Our recent experience reinforces that the BLM and FS are aware of the conservation value of this recovery action and have been proactive and collaborative in the application of Recovery Action 32.

In dry forest areas, actively manage habitat to meet the overlapping goals of spotted owl recovery, restoration of dry forest structure, composition and process including fire, insects and disease. Managers should refer to earlier discussions in this Plan for specific recommendations about landscape scale, science based adaptive restoration treatments to meet Recovery Action 32 goals. Land managers that utilize and document the application of these recommendations in their project planning are consistent with the intent of Recovery Action 32. An existing example of a site-specific plan that could be emulated at the National Forest, BLM District, or project level in other dry forest areas is the Okanogan-Wenatchee National Forest Restoration Strategy (USDA 2010).

The Dry Cascades and the Klamath Province Work Groups will both assist the Service with implementation of this recovery plan by developing multiple province-specific management strategies. Given the dynamic disturbance regimes of these provinces, the strategies developed by these two work groups may address the goals of this recovery action differently than outlined above when finalized. If these strategies require amendments to this Revised Recovery Plan the Service will provide an additional opportunity for public comment.

This recovery action may be temporary in nature, until such time as the competitive pressures of the barred owl on the spotted owl can be reduced to an extent that retention of these stands or patches is not necessary for spotted owl recovery. The 5-year review process will help inform assessments of reduction of threats posed by barred owls. If the 5-year review finds this recommendation unnecessary we will amend this Revised Recovery Plan as needed.

Post-delisting Monitoring

Once the spotted owl is delisted the Service is required to continue to monitor its population for at least 5 years to ensure it does not require the protections of the ESA after those protections have been lifted. Currently, spotted owl populations are monitored through the demographic study areas described in Appendix A under **Population Trends and Distribution**.

Recovery Criterion 4 – Post-delisting Monitoring**:** To monitor the continued stability of the recovered spotted owl, a post-delisting monitoring plan has been developed and is ready for implementation with the States of Washington, Oregon, and California (ESA 4(g)(1)).

- ***Recovery Action 33: Develop a post-delisting monitoring plan ready for implementation with the States of Washington, Oregon, and California (ESA 4(g)(1)).*** Such a plan is necessary to meet the requirements of the ESA.

IV. IMPLEMENTATION SCHEDULE AND COST ESTIMATES

Recovery plans are intended to assist the Service and other stakeholders in planning and implementing actions to recover or protect threatened or endangered species. The following implementation schedule identifies priority number, duration, potential stakeholders, responsible agencies, and estimated costs for the recovery actions described in this Revised Recovery Plan. It is a guide for planning and meeting the objectives discussed in this Revised Recovery Plan.

Due to the uncertainties associated with the effects of barred owl interactions, results from ongoing and new research, and habitat changes that may occur as a result of climate change, the actions needed to stabilize and begin to recover the spotted owl may change over time. The Service and other implementers of this Revised Recovery Plan will have to employ an active adaptive management strategy to achieve results and focus on the most important actions for recovery. This Revised Recovery Plan will be amended as necessary.

The implementation schedule and cost estimate (Table IV-1) outlines recovery actions and their estimated costs for the first 5 years of this recovery program; total costs are estimated for the entire 30-year period. The costs are broad estimates and identify foreseeable expenditures that could be made to implement the specific recovery actions. Actual expenditures by identified agencies and other partners will be contingent upon appropriations and other budgetary constraints.

The actions identified in the implementation schedule are those that, in our opinion, should bring about the recovery of this species. However, these actions are subject to modification as dictated by new findings, changes in the species' status, and the completion of other recovery actions. The priority for each action is assigned as follows:

Priority 1: An action that must be taken to prevent extinction or prevent the species from declining irreversibly in the foreseeable future.

Priority 2: An action that must be taken to prevent a significant decline in the species' population/habitat quality or some other significant negative impact short of extinction.

Priority 3: All other actions deemed necessary to meet the recovery objectives.

The column "Action Duration" indicates whether the action is one of five types. (1) Discrete actions are shown by the number of years estimated to complete the action. (2) Continuous actions are to be implemented every year once begun. (3) Ongoing actions are currently being implemented and will continue until the action is no longer necessary. (4) Intermittent actions are to be implemented as needed. (5) "TBD" (to be determined) actions are those for which the duration was not possible to estimate.

While the ESA assigns a strong leadership role to the Service for the recovery of listed species, it also recognizes the importance of other Federal agencies, States, and other stakeholders in the recovery process. The "responsible parties" identified in the implementation schedule are those partners who can make significant contributions to specific recovery tasks and who may voluntarily participate in any aspect of recovery actions listed. In some cases, the most logical lead agency has been identified with an asterisk. The identification of agencies and other stakeholders in the implementation schedule does not constitute any additional legal responsibilities beyond existing authorities. However, parties willing to participate may benefit by being able to show in their own budgets that their funding request is for a recovery action identified in an approved recovery plan and is therefore considered a necessary action for the overall coordinated effort to recover the spotted owl. Also, section 7(a)(1) of the ESA directs all Federal agencies to use their authorities in furtherance of the purposes of the ESA by carrying out programs, such as these recovery actions, for the conservation of threatened and endangered species.

We listed the agencies and other parties that we believe are the primary stakeholders in the recovery process, and have the authority, expertise, responsibility, or expressed interest to implement a specific recovery action. However, the list of possible stakeholders is not limited to the parties below; other stakeholders are invited to participate.

There are four assumptions associated with these cost estimates:

1. Estimates include Federal government reimbursement of travel and per-diem costs of non-governmental employees to participate in recovery actions.
2. Responsible parties include both organizations that carry out the activity and organizations that fund the activity.
3. The cost of each Action is estimated independently, unless otherwise noted.
4. The opportunity cost of managing these lands for spotted owls instead of other uses is not included in this analysis.

For most of the actions identified in this Revised Recovery Plan, there is no way of deriving a precise cost estimate. A variety of assumptions were used to produce these estimates. For actions that called for meetings or formation of work groups, we assumed the cost of meetings based on the cost of a single Recovery Team meeting. For research and monitoring related actions, current similar research or monitoring projects were used as surrogates to estimate these costs. In some cases, researchers were asked to estimate the cost of a particular study or monitoring program. The cost estimates shown include certain actions that have no new costs (*e.g.*, certain agencies or organizations are already staffed and committed to participating in some of the actions identified).

Several actions call for habitat alteration to benefit the spotted owl. These comprise two categories: actions calling for modification of existing practices to benefit the spotted owl, and actions calling for specific types of management. For modifications of existing practices, the cost of adjusting the action during planning was estimated, rather than the actual entire cost of implementing the project since the "existing practices" cost would already be incurred by the land manager. For the actions that call for specific management, actual estimates for conducting a given type of management were used, but the cost attributable to spotted owl recovery was set at 10 percent of this total cost as an estimate of the added cost to the agencies of implementing such actions. To complete the estimates for some habitat-related actions, base numbers were obtained using the costs and accomplishments of the FS and BLM within the range of the spotted owl.

The costs are broad estimates and identify foreseeable expenditures that could be made to implement the specific recovery actions. Actual expenditures by identified agencies and other partners will be contingent upon appropriations and other budgetary constraints. There are no recovery actions for Listing Factor B.

In Table IV-1, "Land managers" means non-federal land managers, "Landowners" means non-federal landowners, and "States" means State governments of Washington, Oregon, and California. For some recovery actions the interagency Northern Spotted Owl Implementation Team is identified as a responsible party. In these cases it is likely the Northern Spotted Owl Implementation Team will coordinate within their agencies to complete these actions as opposed to the Northern Spotted Owl Implementation Team itself actually carrying out the activity.

Table IV-1. Implementation schedule and cost estimates.

Action No.	Priority No.	Action Description	Action Duration	Resp. Parties (* = lead)	FY Cost Estimate (in $1,000s)					
					30-yr Total	2011	2012	2013	2014	2015
1	1	Establish FWS spotted owl implementation structure	Continuous	FWS	180	6	6	6	6	6
2	3	Monitor population trend	Ongoing	FWS, FS, BLM*, NPS, NSOIT	69,000	2,300	2,300	2,300	2,300	2,300
3	3	Monitor occupancy through surveys or modeling	Start TBD, intermittent thereafter	NSOIT	7,500	0	0	0	0	0
Listing Factor A: The present or threatened destruction, modification, or curtailment of the species' habitat or range										
4	1	Utilize habitat modeling framework for Recovery measures	Continuous	FWS*, BLM, FS, States, NPS	140	80	60	0	0	0
5	2	FWS to consider and incorporate climate change impacts on spotted owls into planning	Continuous	FWS*	350	20	20	20	20	20
6	1	West side: Manage to accelerate structural complexity	Continuous	FS, BLM, FWS	1,750	150	150	100	50	50
7	1	Create Dry Cascades Work Group (DCWG)	Up to 10 years	FWS*, FS, BLM	230	35	35	20	20	20
8	3	Fire and occupancy data analysis	3 years	DCWG	60	25	25	10	0	0
9	1	Create Klamath Province Work Group (KPWG)	Up to 10 years	FWS*, FS,BLM	200	20	20	20	20	20
10	1	Conserve spotted owl sites and high value habitat for demographic support	Continuous	FS, BLM, FWS	1,600	100	100	50	50	50

Table IV-1. Implementation schedule and cost estimates.

Action No.	Priority No.	Action Description	Action Duration	Resp. Parties (* = lead)	FY Cost Estimate (in $1,000s)					
					30-yr Total	2011	2012	2013	2014	2015
11	3	Design and conduct experiments concerning habitat, prey and spotted owl fitness and thinning	Intermittent to Continuous	FS, BLM, FWS, NPS, WDNR, ODF, CAL FIRE, CDFG, landowners	1,500	50	50	50	50	50
12	2	Post-fire management in lands managed for spotted owl habitat development	Continuous	FWS, FS, BLM	0	0	0	0	0	0
13	3	Standardize habitat definitions	2 years	NSOIT, FS, BLM	200	100	100	0	0	0
14	3	Encourage development of HCPs and SHAs that are consistent with spotted owl recovery	Continuous	FWS	1,500	50	50	50	50	50
15	3	Solicit recommendations for non-federal landowner incentives	Continuous	FWS	1,500	50	50	50	50	50
16	2	Long-term maintenance of forest management infrastructure	Continuous	FS, BLM, FWS, States, Counties	0	0	0	0	0	0
Listing Factor C: Disease or predation										
17	3	Monitor and address diseases	Continuous	NSOIT	300	10	10	10	10	10
Listing Factor D: Inadequacy of existing regulatory mechanisms										
18	2	WA State Forest Practices Board evaluation of strategic non-federal spotted owl contributions	3 years	WA State Forest Practices Board*, WA Dept. of Natural Resources, WA Dept.	450	150	150	150	0	0

Table IV-1. Implementation schedule and cost estimates.

Action No.	Priority No.	Action Description	Action Duration	Resp. Parties (* = lead)	FY Cost Estimate (in $1,000s)					
					30-yr Total	2011	2012	2013	2014	2015
				of Fish and Wildlife						
19	2	Cooperate with ODF on scientific evaluation of potential role of State and private lands, and the effectiveness of Oregon Forest Practices rules	5 years	ODF*, FWS	450	100	100	100	100	50
20	2	Work with CAL FIRE on recovery role on non-federal lands and evaluation/implementation of conservation tools	Continuous	CAL FIRE*, FWS	730	10	80	80	80	20
21	2	FWS work with CAL FIRE to provide Forest Practice Rules for spotted owls	3 years	CAL FIRE, FWS	310	0	100	100	100	0
22	2	If necessary, work with State of California on options to allow lethal control of barred owls	4 years	State of Cal*, FWS	200	50	50	50	50	0
Listing Factor E: Other natural or manmade factors affecting its continued existence										
23	2	Analyze existing data sets for effects of barred owls	5 years	BOWG*, FWS, FS, BLM, NPS	250	50	50	50	50	50
24	2	Establish protocols to detect barred owls	2 years	BOWG*, FWS, FS, BLM, NPS	150	75	75	0	0	0
25	2	Ensure protocols adequately detect spotted owls	3 years	BOWG*, FWS, BLM, FS, NPS, States, landowners	300	100	100	100	0	0

Table IV-1. Implementation schedule and cost estimates.

Action No.	Priority No.	Action Description	Action Duration	Resp. Parties (* = lead)	FY Cost Estimate (in $1,000s)					
					30-yr Total	2011	2012	2013	2014	2015
26	2	Analyze resource partitioning	5 years	BOWG*, USGS, FS, FWS, NPS, BLM	1,820	190	510	440	440	120
27	2	Implement public outreach strategy	Continuous	BOWG*, FWS	48	15	5	1	1	1
28	1	Expedite permitting of experimental removals	3 years	FWS*, States	45	0	0	0	15	15
29	1	Conduct experimental removal studies	10 years	BOWG*, TBD	3,000	0	0	600	600	600
30	1	Manage negative effects of barred owls	Start time 4 years away, continuous once started	BOWG*, FS, BLM, NPS, States, FWS, landowners	31,860	0	0	0	1,180	1,180
31	2	Develop mechanisms to support barred owl management	2 years to develop; intermittent as needed	BOWG*, FWS, FS, BLM, NPS, States, landowners	360	40	40	20	0	20
32	1	Maintain high-quality habitat across all landscapes	Continuous	FWS, BLM, FS, States	1040	100	100	30	30	30
33	3	Develop delisting monitoring plan	1 year; initiation TBD	FWS	30	0	0	0	0	0
Estimated total cost for all actions for 30 years: $127.1. million										

Appendix A. Background

This section of the Revised Recovery Plan is designed to provide information necessary to understand the Revised Recovery Plan's strategy, goals, objectives, and criteria for the spotted owl. While it is not an exhaustive review, information on the spotted owl's status, basic ecology, demography, and past and current threats is included. Detailed accounts of the taxonomy, ecology, and reproductive characteristics of the spotted owl were presented in the 1987 and 1990 Status Reviews (USFWS 1987, 1990a), 1989 Status Review Supplement (USFWS 1989), Interagency Scientific Committee Report (Thomas *et al.* 1990), Forest Ecosystem Management Assessment Team (FEMAT) Report (USDA *et al.* 1993), final rule designating the spotted owl as a threatened species (USFWS 1990b), scientific evaluation of the status of the spotted owl (Courtney *et al.* 2004), and several key monographs (*e.g.*, Forsman *et al.* 2004, Anthony *et al.* 2006).

Species Description and Taxonomy

The spotted owl is a medium-sized owl and is the largest of the three subspecies of spotted owls (Gutiérrez *et al.* 1995). It is approximately 46 to 48 centimeters (18 inches to 19 inches) long and the sexes are dimorphic, with males averaging about 13 percent smaller than females. The mean mass of 971 males taken during 1,108 captures was 580.4 grams (1.28 pounds) (range = 430.0 to 690.0 grams) (0.95 pound to 1.52 pounds), and the mean mass of 874 females taken during 1,016 captures was 664.5 grams (1.46 pounds) (range = 490.0 to 885.0 grams) (1.1 pounds to 1.95 pounds) (P. Loschl and E. Forsman pers. comm. 2006). The spotted owl is dark brown with a barred tail and white spots on its head and breast, and it has dark brown eyes surrounded by prominent facial disks. Four age classes can be distinguished on the basis of plumage characteristics (Forsman 1981, Moen *et al.* 1991). The spotted owl superficially resembles the barred owl, a species with which it occasionally hybridizes (Kelly and Forsman 2004). Hybrids exhibit physical and vocal characteristics of both species (Hamer *et al.* 1994).

The northern spotted owl is one of three subspecies of spotted owls recognized by the American Ornithologists' Union. The taxonomic separation of these three subspecies is supported by genetic (Barrowclough and Gutiérrez 1990, Barrowclough *et al.* 1999, Haig *et al.* 2004), morphological (Gutiérrez *et al.* 1995), and biogeographic information (Barrowclough and Gutiérrez 1990). The distribution of the Mexican subspecies (*S. o. lucida*) is separate from those of the northern and California (*S. o. occidentalis*) subspecies (Gutiérrez *et al.* 1995). Recent studies analyzing mitochondrial DNA sequences (Haig *et al.* 2004, Chi *et al.* 2005, Barrowclough *et al.* 2005) and microsatellites (Henke *et al.* 2005) confirmed the validity of the current subspecies designations for northern and California spotted owls. The narrow hybrid zone between these two subspecies, which is located in the southern Cascades and northern Sierra Nevadas, appears to be stable (Barrowclough *et al.* 2005).

Population Trends and Distribution

There are no estimates of the size of the spotted owl population prior to settlement by Europeans. Spotted owls are believed to have inhabited most old-growth forests or stands throughout the Pacific Northwest, including northwestern California, prior to beginning of modern settlement in the mid-1800s (USFWS 1989).

The current range of the spotted owl extends from southwest British Columbia through the Cascade Mountains, coastal ranges, and intervening forested lands in Washington, Oregon, and California, as far south as Marin County (USFWS 1990b). The range of the spotted owl is partitioned into 12 physiographic provinces (Figure A-1) based on recognized landscape subdivisions exhibiting different physical and environmental features (Thomas *et al.* 1993). These provinces are distributed across the species' range as follows:

- Four provinces in Washington: Eastern Washington Cascades, Olympic Peninsula, Western Washington Cascades, Western Washington Lowlands
- Five provinces in Oregon: Oregon Coast Range, Willamette Valley, Western Oregon Cascades, Eastern Oregon Cascades, Oregon Klamath
- Three provinces in California: California Coast, California Klamath, California Cascades

The spotted owl has become rare in certain areas, such as British Columbia, southwestern Washington, and the northern coastal ranges of Oregon.

As of July 1, 1994, there were 5,431 known site-centers of spotted owl pairs or resident singles: 851 sites (16 percent) in Washington, 2,893 sites (53 percent) in Oregon, and 1,687 sites (31 percent) in California (USFWS 1995). By June 2004, the number of territorial spotted owl sites recognized by Washington Department of Fish and Wildlife was 1,070 (J. Buchanan pers. comm. 2010). The actual number of currently occupied spotted owl locations across the range is unknown because not all areas have been or can be surveyed on an annual basis (USFWS 1992a, Thomas *et al.* 1993). In addition, many historical sites are no longer occupied because spotted owls have been displaced by barred owls, timber harvest, or severe fires, and it is possible that some new sites have been established due to recruitment of new areas into NRF habitat since 1994. The totals in USFWS (1995) represent the cumulative number of locations recorded in the three States, not population estimates.

Many historical spotted owl sites are no longer occupied because spotted owls have been displaced by barred owls, timber harvest, or fires.

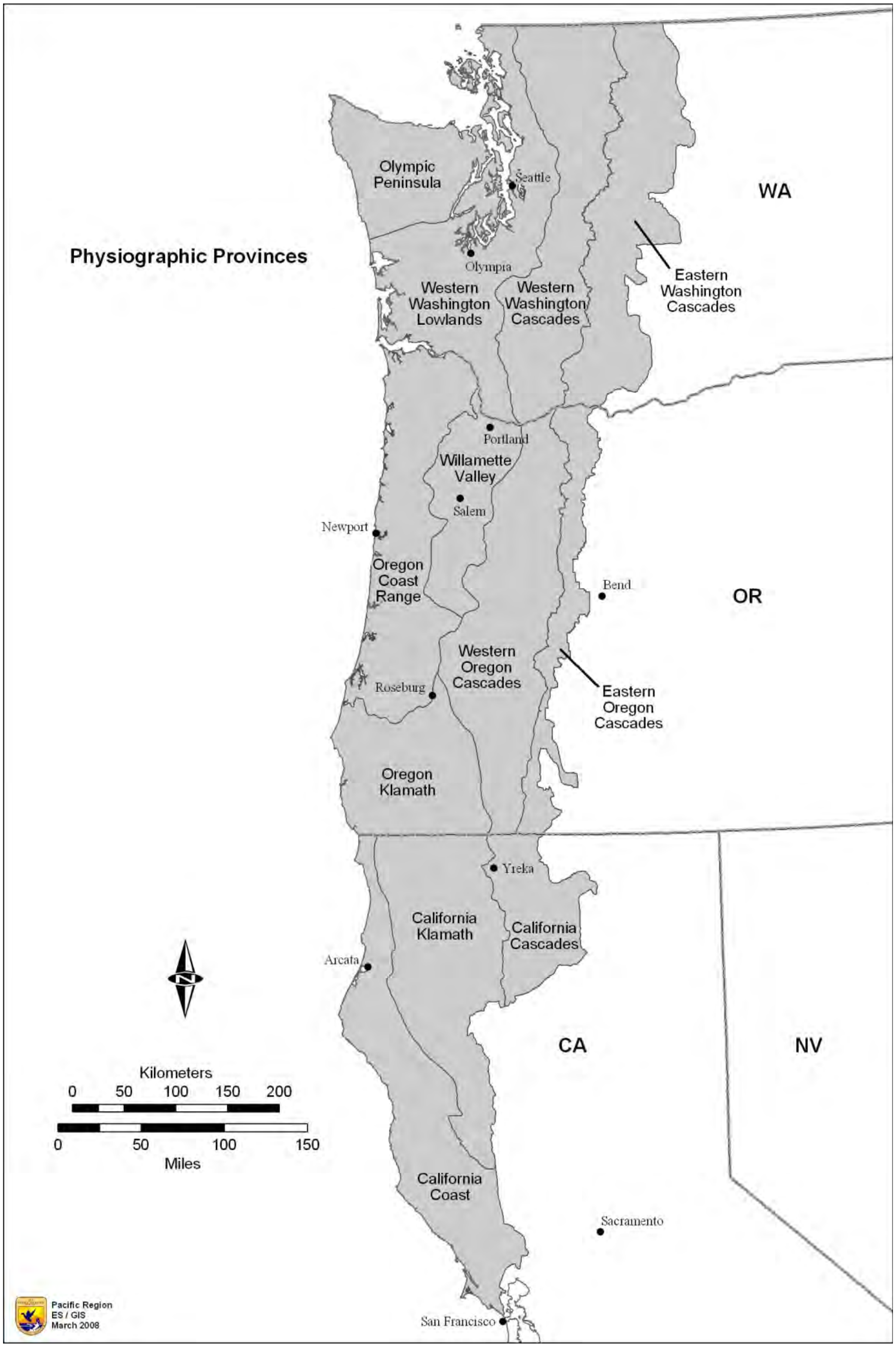


Figure A-1. Physiographic provinces within the range of the spotted owl in the United States.

Because the existing survey coverage and effort are insufficient to produce reliable range-wide estimates of population size, demographic data are used to evaluate trends in spotted owl populations. Analysis of demographic data can provide an estimate of the finite rate of population change (λ) (lambda), which provides information on the direction and magnitude of population change. A λ of 1.0 indicates a stationary population, meaning the population is neither increasing nor decreasing. A λ of less than 1.0 indicates a decreasing population, and a λ of greater than 1.0 indicates a growing population. Demographic data, derived from studies initiated as early as 1985, have been analyzed periodically (Anderson and Burnham 1992, Burnham *et al.* 1994, Forsman *et al.* 1996, Anthony *et al.* 2006, Forsman *et al.* 2011) to estimate trends in the populations of the spotted owl.

In January 2009, two meta-analyses modeled rates of population change for up to 24 years using the re-parameterized Jolly-Seber method (λ_{RJS}). One meta-analysis modeled the 11 long-term study areas (Table A-1), while the other modeled the eight study areas that are part of the effectiveness monitoring program of the NWFP (Forsman *et al.* 2011).

Point estimates of λ_{RJS} were all below 1.0 and ranged from 0.929 to 0.996 for the 11 long-term study areas. There was strong evidence that populations declined on 7 of the 11 areas (Forsman *et al.* 2011), these areas included Rainier, Olympic, Cle Elum, Coast Range, HJ Andrews, Northwest California and Green Diamond. On the other four areas (Tyee, Klamath, Southern Cascades, and Hoopa), populations were either stable, or the precision of the estimates was not sufficient to detect declines.

The weighted mean λ_{RJS} for all of the 11 study areas was 0.971 (standard error [SE] = 0.007, 95 percent confidence interval [CI] = 0.960 to 0.983), which indicated an average population decline of 2.9 percent per year from 1985 to 2006. This is a lower rate of decline than the 3.7 percent reported by Anthony *et al.* (2006), but the rates are not directly comparable because Anthony *et al.* (2006) examined a different series of years and because two of the study areas in their analysis were discontinued and not included in Forsman *et al.* (2011). Forsman *et al.* (2011) explains that the indication populations were declining was based on the fact that the 95 percent confidence intervals around the estimate of mean lambda did not overlap 1.0 (stable) or barely included 1.0. While estimates of mean λ_{RJS} are not directly comparable between Anthony *et al.* (2006) and Forsman *et al.* (2011), results from these studies indicate that rates of population decline for spotted owls have not moderated in recent years. In the most recent meta-analysis, Forsman *et al.* (2011) indicated that the number of populations that showed declines and the rates of decline on study areas in Washington and northern Oregon were noteworthy and should be cause for concern for the long-term sustainability of spotted owl populations throughout the range of the subspecies.

Demographic data suggest that populations over the 11 long-term demographic study areas decreased by about 2.9 percent from 1985 to 2006.

Table A-1. Spotted owl demographic parameters based on data from the spotted owl demographic study areas (adapted from Forsman *et al.* 2011).

Study Area	Fecundity	Apparent Survival[1]	λ_{RJS}	Population change[2]
Cle Elum	Declining	Declining	0.937	Declining
Rainier	Increasing	Declining	0.929	Declining
Olympic	Stable	Declining	0.957	Declining
Coast Ranges	Increasing	Declining since 1998	0.966	Declining
HJ Andrews	Increasing	Declining since 1997	0.977	Declining
Tyee	Stable	Declining since 2000	0.996	Stationary
Klamath	Declining	Stable	0.990	Stationary
Southern Cascades	Declining	Declining since 2000	0.982	Stationary
NW California	Declining	Declining	0.983	Declining
Hoopa	Stable	Declining since 2004	0.989	Stationary
Green Diamond	Declining	Declining	0.972	Declining

[1]Apparent survival calculations are based on model average.
[2]Population trends are based on estimates of realized population change.

The mean λ_{RJS} for the eight demographic monitoring areas (Cle Elum, Olympic, Coast Range, HJ Andrews, Tyee, Klamath, Southern Cascades, and Northwest California) that are part of the effectiveness monitoring program of the NWFP was 0.972 (SE = 0.006, 95 percent CI = 0.958 to 0.985), which indicated an estimated decline of 2.8 percent per year on Federal lands within the range of the spotted owl. The weighted mean estimate λ_{RJS} for the other three study areas (Rainier, Hoopa, and Green Diamond) was 0.969 (SE = 0.016, 95 percent CI = 0.938 to 1.000), yielding an estimated average decline of 3.1 percent per year. These data suggest that demographic rates for spotted owl populations on Federal lands were somewhat better than elsewhere; however, this comparison is confounded by the interspersion of non-federal land in study areas and the likelihood that spotted owls use habitat on multiple ownerships in some demography study areas.

The number of populations that declined and the rate at which they have declined are noteworthy, particularly the precipitous declines in the Olympic, Cle Elum, and Rainier study areas in Washington and the Coast Range study area in Oregon. Estimates of population declines in these areas ranged from 40 to 60 percent during the study period through 2006 (Forsman *et al.* 2011). Spotted owl populations on the HJ Andrews, Northwest California, and Green Diamond study areas declined by 20-30 percent whereas the Tyee, Klamath, Southern Cascades, and Hoopa study areas showed declines of 5 to 15 percent.

Decreases in adult apparent survival rates were an important factor contributing to decreasing population trends.

Decreases in adult apparent survival rates were an important factor contributing to decreasing population trends. Forsman *et al.* (2011) found apparent survival rates were declining on 10 of the study areas with the Klamath study area in Oregon being the exception. Estimated declines in adult survival were most precipitous in Washington where apparent survival rates were less than 80 percent in recent years, a rate that may not allow for sustainable populations (Forsman *et al.* 2011). In addition, declines in adult survival for study areas in Oregon have occurred predominately within the last five years and were not observed in the previous analysis by Anthony *et al.* 2006. Forsman *et al.* (2011) express concerns about the collective declines in adult survival across the subspecies range because spotted owl populations are most sensitive to changes in adult survival.

There are few spotted owls remaining in British Columbia. Chutter *et al.* (2004) suggested immediate action was required to improve the likelihood of recovering the spotted owl population in British Columbia. In 2007, the Spotted Owl Population Enhancement Team recommended to remove spotted owls from the wild in British Columbia. The primary recommendation consisted of two different options – 1) remove all spotted owls immediately and 2) remove most spotted owls in the first year and evaluate subsequently the need to remove additional spotted owls. The second option was selected for implementation (Fenger *et al.* 2007). Personnel in British Columbia captured and brought into captivity the remaining 16 known wild spotted owls. Prior to initiating the captive-breeding program, the population of spotted owls in Canada was declining by as much as 35 percent per year (Chutter *et al.* 2004). The amount of previous interaction between spotted owls in Canada and the United States is unknown (Chutter *et al.* 2004).

Life History and Ecology

Spotted owls are territorial and usually monogamous. Home-range sizes vary geographically, generally increasing from south to north (USFWS 1990b). Estimates of median size of their annual home range vary from 2,955 acres in the Oregon Cascades (Thomas *et al.* 1990) to 14,211 acres on the Olympic Peninsula (Forsman *et al.* 2001). Zabel *et al.* (1995) showed that spotted owl home ranges are larger where flying squirrels are the predominant prey and smaller where wood rats are the predominant prey. Home ranges of adjacent pairs overlap (Forsman *et al.* 1984, Solis and Gutiérrez 1990), suggesting that the defended area is smaller than the area used for foraging. The portion of the home range used during the breeding season is smaller than that used in the remainder of the year (Forsman *et al.* 1984, Sisco 1990).

The spotted owl is relatively long-lived, has a long reproductive life span, invests significantly in parental care, and exhibits high adult survivorship relative to other North American owls (Forsman *et al.* 1984, Gutiérrez *et al.* 1995). Spotted owls are sexually mature at 1 year of age, but rarely breed until they are 2 to 5 years of age (Miller *et al.* 1985, Franklin 1992, Forsman *et al.* 2002). Breeding females lay one to four eggs per clutch, with the average clutch size being two eggs; however, most spotted owl pairs do not nest every year, nor are nesting pairs successful every year (Forsman *et al.* 1984, USFWS 1990b, Anthony *et al.* 2006). The small clutch size, temporal variability in nesting success, and delayed onset of breeding all contribute to the relatively low fecundity of this species (Gutiérrez 1996).

The spotted owl is relatively long-lived, has a long reproductive life span, invests significantly in parental care, and exhibits high adult survivorship relative to other North American owls.

Courtship behavior usually begins in February or March, and females typically lay eggs in late March or April. The timing of nesting and fledging varies with latitude and elevation (Forsman *et al.* 1984). After they leave the nest in late May or June, juvenile spotted owls depend on their parents until they are able to fly and hunt on their own. Parental care continues after fledging into September (Forsman *et al.* 1984, USFWS 1990b). During the first few weeks after the young leave the nest, the adults often roost with them during the day. By late summer, the adults are rarely found roosting with their young and usually only visit the juveniles to feed them at night (Forsman *et al.* 1984).

Natal dispersal of spotted owls typically begins in September and October with a few individuals dispersing in November and December (Miller *et al.* 1997, Forsman *et al.* 2002). Natal dispersal occurs in stages. Juveniles will settle for up to seven months at temporary locations between larger movements (Miller *et al.* 1997, Forsman *et al.* 2002) and may do this multiple times before establishing a territory. The median natal dispersal distance from fledging

Dispersing juvenile spotted owls experience high mortality rates, exceeding 70 percent in some studies. Known or suspected causes of mortality during dispersal include starvation, predation, and accidents.

to "permanent" settlement is about 10 miles for males and 15.5 miles for females (Forsman *et al.* 2002).

During the transience (movement) phase, dispersers used mature and old-growth forest slightly more than its availability. Habitat supporting the transience phase of dispersal contains stands with adequate tree size and canopy closure to provide protection from avian predators and minimal foraging opportunities. This may include younger and less diverse forest stands than foraging habitat, such as even-aged, pole-sized stands, but such stands should contain some roosting structures and foraging habitat to allow for temporary resting and feeding during the movement phase. While the stand-level and landscape-level attributes of forests needed to facilitate successful dispersal have not been thoroughly evaluated (Buchanan 2004), an early attempt to describe dispersal conditions in the Interagency Scientific Committee (ISC) Report (Thomas *et al.* 1990) recommended managing the forested landscape such that 50 percent of each quarter-township has a mean diameter at breast height (dbh) of at least 11 inches and a canopy closure of at least 40 percent (the 50-11-40 rule). The minimum levels of this definition describe habitat supporting the transient phase of dispersal.

Spotted owl dispersal needs are better assessed at the landscape scale than at the stand- or habitat-patch scale (Thomas *et al.* 1990). Existing land allocations and congressional designations (*e.g.*, Wilderness Areas, Wild and Scenic Rivers, etc.) contribute significantly to spotted owl dispersal in some areas, but are not evenly distributed across the landscape. For example, many wilderness areas contain little spotted owl habitat due to elevation or topography. Spotted owls are able to move successfully through highly fragmented landscapes typical of the mountain ranges in western Washington and Oregon (Forsman *et al.* 2002). Still, barriers to spotted owl dispersal do exist and likely include large tracts of unforested lands, such as the Willamette, Rogue and Umpqua valleys and broad expanses of open water, such as Hood Canal and Puget Sound (Forsman *et al.* 2002). Spotted owls have dispersed from the Coastal Mountains to the Cascades Mountains in Oregon though broad forested regions between the Willamette, Umpqua, and Rogue Valleys of Oregon (Forsman *et al.* 2002, p. 22). These "corridors" primarily support relatively rapid movement through such areas, rather than colonization**.**

During the colonization phase, mature and old growth forest was used at nearly twice its availability (Miller *et al.* 1997). Closed pole-sapling-sawtimber habitat was used roughly in proportion to availability in both phases and may represent the minimum condition for movement. Open sapling and clearcuts were used less than expected based on availability during colonization (Miller *et al.* 1997). Habitat supporting the colonization phase of dispersal is generally equivalent to roosting and foraging habitat, although it may be in smaller amounts than needed to support nesting pairs.

Successful juvenile dispersal may depend on locating unoccupied NRF habitat in close proximity to other occupied sites (LaHaye *et al.* 2001). Spotted owls regularly disperse through highly fragmented forested landscapes that are typical of the mountain ranges in western Washington and Oregon (Forsman *et al.* 2002), and have dispersed from the Coastal Mountains to the Cascades Mountains in the broad forested regions between the Willamette, Umpqua, and Rogue Valleys of Oregon (Forsman *et al.* 2002). Corridors of forest through fragmented landscapes serve primarily to support relatively rapid movement through such areas, rather than colonization.

Dispersing juvenile spotted owls experience high mortality rates (more than 70 percent in some studies (Miller 1989, Franklin *et al.* 1999, USFWS 1990b) from starvation, predation, and accidents (Miller 1989, Forsman *et al.* 2002). Parasitic infection may contribute to these causes of mortality, but the relationship between parasite loads and survival is poorly understood (Gutiérrez 1989, Hoberg *et al.* 1989, Forsman *et al.* 2002). Juvenile dispersal is thus a highly vulnerable life stage for spotted owls, and enhancing the survivorship of juveniles during this period could play an important role in maintaining stable populations of spotted owls.

Analysis of the genetic structure of spotted owl populations suggests that gene flow may have been adequate between the Olympic Mountains and the Washington Cascades, and between the Olympic Mountains and the Oregon Coast Range (Haig *et al.* 2001). Although telemetry and genetic studies indicate that close inbreeding between siblings or parents and their offspring is rare (Haig *et al.* 2001, Forsman *et al.* 2002), inbreeding between more distant relatives is fairly common (E. Forsman pers. comm. 2006).

Spotted owls are mostly nocturnal, although they also forage opportunistically during the day (Forsman *et al.* 1984, Sovern *et al.* 1994). The composition of the spotted owl's diet varies geographically and by forest type. Generally, flying squirrels are the most prominent prey for spotted owls in Douglas-fir and western hemlock forests (Forsman *et al.* 1984) in Washington and Oregon, while dusky-footed wood rats are a major part of the diet in the Oregon Klamath, California Klamath, and California Coastal Provinces (Forsman *et al.* 1984, 2001, 2004, Ward *et al.* 1998, Hamer *et al.* 2001). Depending on location, other important prey include deer mice, tree voles, red-backed voles, gophers, snowshoe hare, bushy-tailed wood rats, birds, and insects, although these species comprise a small portion of the spotted owl diet (Forsman *et al.* 1984, 2004, Ward *et al.* 1998, Hamer *et al.* 2001).

Effects to spotted owls from barred owls are described above in Listing Factor E.

Habitat Characteristics

Forsman *et al.* (1984) reported that spotted owls have been observed in the following forest types: Douglas-fir, western hemlock, grand fir, white fir, ponderosa pine, Shasta red fir, mixed evergreen, mixed conifer hardwood (Klamath montane, Marin County), and redwood. In addition, spotted owls in Marin County, California use Bishop pine forests and mixed evergreen-deciduous hardwood forests. The upper elevation limit at which spotted owls occur corresponds to the transition to subalpine forest, which is characterized by relatively simple structure and severe winter weather (Forsman 1975, Forsman *et al.* 1984).

Spotted owls generally rely on older forested habitats (Carroll and Johnson 2008) because such forests contain the structures and characteristics required for nesting, roosting, and foraging. Features that support nesting and roosting typically include a moderate to high canopy closure (60 to 90 percent); a multi-layered, multi-species canopy with large overstory trees (with dbh of greater than 30 inches); a high incidence of large trees with various deformities (large cavities, broken tops, mistletoe infections, and other evidence of decadence); large snags; large accumulations of fallen trees and other woody debris on the ground; and sufficient open space below the canopy for spotted owls to fly (Thomas *et al.* 1990). Forested stands with high canopy closure also provide thermal cover (Weathers *et al.* 2001) and protection from predators.

Foraging habitat generally has attributes similar to those of nesting and roosting habitat, but such habitat may not always support successfully nesting pairs (USFWS 1992b). Dispersal habitat, at a minimum, consists of stands with adequate tree size and canopy closure to provide protection from avian predators and at least minimal foraging opportunities (USFWS 1992b). Forsman *et al.* (2002) found that spotted owls could disperse through highly fragmented forest landscapes, yet the stand-level and landscape-level attributes of forests needed to facilitate successful dispersal have not been thoroughly evaluated (Buchanan 2004). Therefore, a more complete description of dispersal habitat may be determined in the future. There is little evidence that small openings in forest habitat influence the dispersal of spotted owls, but large, non-forested valleys such as the Willamette Valley apparently are barriers to both natal and breeding dispersal (Forsman *et al.* 2002). The degree to which water bodies, such as the Columbia River and Puget Sound, function as barriers to dispersal is unclear, although radio telemetry data indicate that spotted owls move around large water bodies rather than cross them (Forsman *et al.* 2002).

Recent landscape-level analyses in portions of southwest Oregon and California Klamath Province suggest that a mosaic of late-successional habitat interspersed with other seral conditions may benefit spotted owls more than large, homogeneous expanses of older forests in areas where woodrats are a major component of spotted owl diets (Meyer *et al.* 1998, Franklin *et al.* 2000, Zabel *et al.* 2003). In Oregon Klamath and Western Oregon Cascade Provinces, Dugger *et al.* (2005) found that apparent survival and reproduction was positively associated with the proportion of older forest near the territory center (within 730 meters) (2,395 feet). Survival decreased dramatically when the amount of non-habitat (non-forest areas, sapling stands, etc.) exceeded approximately 50 percent of the home range (Dugger *et al.* 2005). The authors concluded there was no support for either a positive or negative direct effect of intermediate-aged forest—that is, all forest stages between sapling and mature,

One study indicated that while mid-seral and late-seral forests are important to spotted owls, a mixture of these forest types with younger forest and non-forest may be best for spotted owl survival and reproduction in certain parts of the range.

with total canopy cover greater than 40 percent—on either the survival or reproduction of spotted owls. It is unknown how these results were affected by the low habitat fitness potential in their study area, which Dugger *et al.* (2005) stated was generally much lower than those in Franklin *et al.* (2000) and Olson *et al.* (2004), and the low reproductive rate and survival in their study area, which they reported were generally lower than those studied by Anthony *et al.* (2006). Olson *et al.* (2004) found that reproductive rates fluctuated biennially and were positively related to the amount of edge between late-seral and mid-seral forests and other habitat classes in the central Oregon Coast Range. Olson *et al.* (2004) concluded that their results indicate that while mid-seral and late-seral forests are important to spotted owls, a mixture of these forest types with younger forest and non-forest may be best for spotted owl survival and reproduction in their study area.

While the effects of wildfire on spotted owls and their habitat vary, in the fire-adapted portions of the spotted owl's range, low- to moderate-severity fires may contribute to this mixture of habitats. Bond *et al.* (2002) examined the demography of the three spotted owl subspecies after wildfires, in which wildfire burned through spotted owl nest and roost sites in varying degrees of severity[1]. Post-fire demography parameters for the three subspecies were similar or better than long-term demographic parameters for each of the three subspecies in those same areas (Bond *et al.* 2002). In a preliminary study conducted by Anthony and Andrews (2004) in the Oregon Klamath Province, their sample of spotted owls appeared to be using a variety of habitats within the area of the Timbered Rock fire, including areas where burning had been moderate. In 1994, the Hatchery Complex fire burned 17,603 hectares in the Wenatchee National Forest in Washington's eastern Cascades, affecting six spotted owl activity centers (Gaines *et al.* 1997). Spotted owl habitat within a 2.9 km (1.8 mile) radius of the activity centers was reduced by 8 to 45 percent (mean = 31 percent) as a result of the direct effects of the fire and by 10 to 85 percent (mean = 55 percent) as a result of delayed mortality of fire-damaged trees and insects. Direct mortality of spotted owls was assumed to have occurred at one site, and spotted owls were present at two of the six sites 1 year after the fire, with reproduction occurring at only one. In 1994, two wildfires burned in the Yakama Indian Reservation in Washington's eastern Cascades, affecting the home ranges of two radio-tagged spotted owls (King *et al.* 1997). Although the amount of home ranges burned was not quantified, spotted owls were observed using areas that burned at low and medium intensities. No direct mortality of spotted owls was observed, even though thick smoke covered several spotted owl site-centers for a week. Spotted owls have been observed foraging in areas

[1] Fire severity is defined in several ways. See the individual studies cited for further information on the definitions of fire severity.

burned by fires of all severity categories (Clark 2007, Bond *et al.* 2009). While Clark (2007) found that spotted owls did not use large patches of high-severity burns, Bond *et al.* (2009) found spotted owls selecting burned areas, even high-severity burns, when they were within 1.5 km of a nest or roost site. Results of several of these studies are confounded because of post-fire salvaging that occurred (*e.g.*, King *et al.* 1997, Clark 2007). More research is needed to further understand the relationship between fire and spotted owl habitat use.

Spotted owls may be found in younger forest stands that have the structural characteristics of older forests or retained structural elements from the previous forest. In redwood forests and mixed conifer-hardwood forests along the coast of northwestern California, considerable numbers of spotted owls also occur in younger forest stands, particularly in areas where hardwoods provide a multi-layered structure at an early age (Thomas *et al.* 1990, Diller and Thome 1999). The results of numerous studies of spotted owl habitat relationships in the Redwood zone suggest stump-sprouting and rapid growth rates of redwoods, combined with high availability of large-bodied prey (woodrats) in patchy, intensively-managed forests, enables spotted owls to maintain high densities in a wide range of forest structural conditions.

In mixed conifer forests in the eastern Cascades in Washington, 27 percent of nest sites were in old-growth forests, 57 percent were in the understory reinitiation phase of stand development, and 17 percent were in the stem exclusion phase (Buchanan *et al.* 1995). In the western Cascades of Oregon, 50 percent of spotted owl nests were in late-seral/old-growth stands (greater than 80 years old), and none were found in stands of less than 40 years old (Irwin *et al.* 2000).

In the western Washington Cascades, spotted owls roosted in mature forests dominated by trees greater than 50 centimeters (19.7 inches) dbh with greater than 60 percent canopy closure more often than expected for roosting during the non-breeding season. Spotted owls also used young forest (trees of 20 to 50 centimeters (7.9 inches to 19.7 inches) dbh with greater than 60 percent canopy closure) less often than expected based on this habitat's availability (Herter *et al.* 2002). In the Coast Ranges, western Oregon Cascades and the Olympic Peninsula, radio-marked spotted owls selected for old-growth and mature forests for foraging and roosting and used young forests less than predicted based on availability (Forsman *et al.* 1984, Carey *et al.* 1990, 1992, Thomas *et al.* 1990). Glenn *et al.* (2004) studied spotted owls in young forests in western Oregon and found little preference among age classes of young forest.

Habitat use also is influenced by prey availability. Ward (1990) found that spotted owls foraged in areas with lower variance in prey densities (*i.e.*, where the occurrence of prey was more predictable) within older forests and near ecotones of old forest and brush seral stages. Zabel *et al.* (1995) showed that spotted owl home ranges are larger and smaller where flying squirrels and wood rats, respectively, are the predominant prey.

Critical Habitat

On January 15, 1992, the Service designated critical habitat for the spotted owl within 190 Critical Habitat Units encompassing nearly 6.9 million acres (2.2 million acres in Washington, 3.3 million acres in Oregon, and 1.4 million acres in California (USFWS 1992a). Primary constituent elements (the physical and biological features of critical habitat essential to a species' conservation) identified in the spotted owl critical habitat final rule include those features that support nesting, roosting, foraging, and dispersal (USFWS 1992b). In 2008 the Service completed a revision of spotted owl critical habitat, designating 5.3 million acres (1.8 million acres in Washington, 2.3 million acres in Oregon, and 1.2 million acres in California). The primary constituent elements included suitable forest types and the areas within these containing nesting, roosting, foraging, or dispersal habitat.

Revised spotted owl critical habitat was designated based on large blocks of habitat identified for spotted owl conservation in the 2008 Recovery Plan (MOCAs) on the west side of the range (USFWS 2008a). The Service designated the Federal lands within these MOCAs as critical habitat, excluding congressionally-reserved areas such as Wilderness Areas and National Parks. Because the 2008 Recovery Plan did not include mapped areas in the eastern Cascades of Oregon and Washington, focusing instead on a landscape approach, we relied on the information used to map the areas in these provinces for the 2007 draft Recovery Plan(USFWS 2007).

As part of this recovery plan, the Service has completed a habitat modeling effort which provides a more in-depth evaluation of various habitat features that affect spotted owl habitat use, when compared to the process used to develop the MOCAs. This information will be used to evaluate potential habitat conservation network scenarios. The Service will use this information and other results of the modeling as it evaluates revisions to spotted owl critical habitat.

Conservation Efforts

Federal Lands

Since it was signed on April 13, 1994, the NWFP has guided the management of Federal forest lands within the range of the spotted owl (USDA and USDI 1994a, b). The NWFP was designed to protect large blocks of late-successional forest and provide habitat for species that depend on those forests including the spotted owl, as well as to "produce a predictable and sustainable level of timber sales and non-timber resources that will not degrade or destroy the environment" (USDA and USDI 1994a). The NWFP includes land-use allocations that would provide for population clusters of spotted owls (*i.e.,* demographic support) and maintain connectivity between population clusters. Certain land-use allocations in the NWFP contribute to supporting population clusters: LSRs, Managed Late-Successional Areas, and Congressionally Reserved

Areas. Riparian Reserves, Adaptive Management Areas and Administratively Withdrawn Areas can provide both demographic support and connectivity/dispersal between the larger blocks, but are not necessarily designed for that purpose. Matrix areas were to support timber production while also retaining biological legacy components important to old-growth obligate species that would persist into future managed timber stands.

The NWFP was directly incorporated into 4 National Forest LRMPs and amended the LRMPs that guide the management of each of the 15 National Forests and six BLM Districts across the range of the spotted owl to adopt a series of reserves and management guidelines that were intended to protect spotted owls and their habitat. The LRMPs adopted a set of reserves and standards and guidelines described in the Record of Decision for the NWFP.

The NWFP with its rangewide network of LSRs was adapted from work completed by three previous studies (Thomas *et al.* 2006): the 1990 ISC Report (Thomas *et al.* 1990), the 1991 report for the Conservation of Late-successional Forests and Aquatic Ecosystems (Johnson *et al.* 1991), and the 1993 report of the Scientific Assessment Team (Thomas *et al.* 1993). In addition, the 1992 Draft Recovery Plan for the Northern Spotted Owl (USFWS 1992b) was based on the ISC report.

The FEMAT predicted, based on expert opinion, the spotted owl population would decline in non-reserve lands over time, while the population would stabilize and eventually increase within LSRs as habitat conditions improved over the next 50 to 100 years (USDA *et al.* 1993, USDA and USDI 1994a, b). Based on the results of the first decade of monitoring, Lint (2005) could not determine whether implementation of the NWFP would reverse the spotted owl's declining population trend because not enough time had passed to provide the necessary measure of certainty. However, the results from the first decade of monitoring do not provide any reason to depart from the objective of habitat maintenance and restoration as described in the NWFP and incorporated into LRMPs (Lint 2005, Noon and Blakesley 2006). Bigley and Franklin (2004) suggested that more fuels treatments are needed in east-side forests to preclude large-scale losses of habitat to stand-replacing wildfires. Other stressors that occur in NRF habitat, such as the range expansion of the barred owl (already in action) and infection with WNV (which may or may not occur) may complicate the conservation of the spotted owl. Recent reports about the status of the spotted owl offer few management recommendations to deal with these emerging threats.

Results from the first decade of monitoring do not provide any reason to depart from the objective of habitat maintenance and restoration as described in the Northwest Forest Plan.

Non-federal Lands

In the report from the ISC (Thomas *et al.* 1990), the draft Recovery Plan (USFWS 1992b), and the report from the FEMAT (USDA *et al.* 1993), it was noted that limited Federal ownership in some areas constrained the ability to form a network of old-forest reserves to meet the conservation needs of the spotted owl. In these areas in particular, non-federal lands would be important to the range-wide goal of achieving conservation and recovery of the spotted owl.

There are 17 current and ongoing conservation plans (CP) including HCPs and SHAs that have incidental take permits issued for spotted owls—eight in Washington, three in Oregon, and six in California. The CPs range in size from 76 acres to more than 1.8 million acres, although not all acres are included in the mitigation for spotted owls. In total, the CPs cover approximately 3 million acres (9.4 percent) of the 32 million acres of non-federal forest lands in the range of the spotted owl. The period of time that the HCPs will be in place ranges from 20 to 100 years. While each CP is unique, there are several general approaches to mitigation of incidental take:

- Reserves of various sizes, some associated with adjacent Federal reserves
- Forest management that maintains or develops nesting habitat
- Forest management that maintains or develops foraging habitat
- Forest management that maintains or develops dispersal habitat
- Deferral of harvest near specific sites

Washington. In Washington State, there are over 2.1 million acres of land in conservation plans (6 HCPs and 2 SHAs). Some of these CPs focus on providing nesting, roosting habitat throughout the area or in strategic locations; while others focus on providing connectivity through foraging habitat and/or dispersal habitat. Most of the Washington HCPs have foraging as a minimal target for habitat quality. In addition, there is a long-term habitat management agreement covering 13,000 acres in which authorization of take was provided through an incidental take statement (section 7) associated with a Federal land exchange.

Two Washington HCPs are based upon municipal watershed management and will provide older forest conditions over time. One HCP occurs within checkerboard ownership in the central Cascades and focuses on connectivity through a combination of nesting habitat in strategic locations as well as a distribution of nesting habitat and foraging habitat across the ownership and the planning area. Several HCPs, a Habitat Management Agreement (via section 7), and one safe harbor agreement focus on connectivity from a dispersal standpoint, including providing foraging habitat and landscape conditions conducive to spotted owl movement and potential residence. The largest HCP in Washington State (WDNR State lands) was designed by a scientific advisory team which analyzed the manner in which State lands could contribute to support the NWFP reserves. That HCP has a system of designated areas designed to provide demographic support in some areas, and foraging and dispersal in other areas.

Oregon. The three spotted owl-related HCPs currently in effect cover more than 300,000 acres of non-federal lands. These HCPs are intended to provide some nesting habitat and connectivity over the next few decades. On July 27, 2010, the Service completed a Programmatic Safe Harbor Agreement with the Oregon Department of Forestry that will enroll up to 50,000 acres of non-federal lands within the State over a total of 50 years. It is primarily intended to increase the time between harvests (defer harvest), and to lightly to moderately thin younger forest stands that are currently not habitat to increase tree diameter size and stand diversity (species, canopy layers, presence of snags).

California. Four HCPs and 2 SHAs authorizing take of spotted owls have been approved; these CPs cover more than 622,000 acres of non-federal lands. Implementation of these plans is intended to provide for spotted owl demography and connectivity support to NWFP lands.

Appendix B. Threats

Habitat Changes

Historical Levels of Spotted Owl Habitat and Rates of Loss

In 1990, the Service estimated spotted owl habitat had declined 60 to 88 percent since the early 1800s (USFWS 1990b). This loss, which was concentrated mostly at lower elevations and in the Coast Ranges, was attributed primarily to timber harvest and land-conversion activities, and to a lesser degree to natural perturbations (USFWS 1990a). Davis and Lint (2005) compared the current condition of forests throughout the range of the species to maps from the 1930s and 1940s and found that, in Oregon and Washington, fragmentation of forests had increased substantially; in some physiographic provinces, the increase was more than five-fold. However, fragmentation in California decreased, which the authors speculate may be due to fire suppression in fire-dependent provinces (Davis and Lint 2005).

Recent Rates of Loss of Spotted Owl Habitat as a Result of Timber Harvest

Until 1990, the annual rate of removal of spotted owl habitat on national forests as a result of logging was approximately 1 percent per year in California and 1.5 percent per year in Oregon and Washington. Anticipated future rates of habitat removal on BLM lands in Oregon at that time were projected to eliminate all NRF habitat on non-protected BLM lands (except the Medford District) within 26 years (USFWS 1990b).

Since 1990, there have been only a few efforts that have produced indices or more direct estimates of trends or change in the amount of NRF habitat for spotted owls. Cohen *et al.* (2002) reported landscape-level changes in forest cover across the Pacific Northwest using remote sensing technology. Their study indicated, "a steep decline in harvest rates between the late 1980s and the early 1990s on State and Federal and private industrial forest lands" (as described in Bigley and Franklin 2004:6-11).

Recent data has become available through the NWFP monitoring efforts (Davis and Dugger in press). This information tracked changes in spotted owl nesting and roosting habitat across all ownerships from timber harvest and natural disturbances (wildfire, insects, and disease); it did not track all foraging habitat. Based on vegetation data, they produced maps of forest stands that compared the stand's level of similarity to stand conditions known to be used for nesting and roosting by spotted owls. These stands were placed into one of four categories: highly suitable, suitable, marginal, and unsuitable. Highly suitable and suitable categories are likely nesting or roosting habitat, marginal stands may occasionally contain the habitat characteristics associated with nesting or roosting (see Davis and Dugger in press for more details). Data from California covered 14 years from 1994 to 2007, data from Oregon and Washington covered 10 years from 1996 to 2006 (Table B-1). Changes in habitat were evaluated comparing mapped differences in habitat condition between the initial and final vegetation maps. Habitat was considered "lost" if its condition moved from suitable or highly suitable to marginal or unsuitable.

Harvest rates for spotted owl nesting and roosting habitat on Federal lands were highest in the California Cascades (3.0 percent, 6,500 acres) and lowest in the Olympic Peninsula (0.06 percent, 500 acres). Overall, timber harvest on Federal lands removed 0.6 percent (53,800 acres) of nesting and roosting habitat during the reporting period.

Table B-1. Spotted owl habitat loss on Federal lands resulting from harvest and natural disturbances from 1994/96[1] to 2006-7[1] (acres) (adapted from Davis and Dugger in press).

Physiographic Provinces	1994/96 acres	Harvest *(%)*[2]	Natural Disturbance			Total Habitat Loss	Total Percent loss[2,3]
			Wildfire	Insects and disease	Total *(%)*[2]		
Olympic Peninsula	763,100	**500** ***(0.06%)***	200	0	**200** ***(0.03%)***	700	**0.1%**
Eastern WA Cascades	673,600	**8,100** ***(1.2%)***	20,000	2,000	**22,000** ***(3.3%)***	30,100	**4.5%**
Western WA Cascades	1,283,000	**3,700** **(0.3%)**	700	400	**1,100** **(0.09%)**	4,800	**0.4%**
Western WA Lowlands	24,700	**400** ***(1.6%)***	0	0	**0**	400	**1.6%**
OR Coast Range	611,200	**3,300** ***(0.5%)***	0	0	**0**	3,300	**0.5%**
OR Klamath	985,000	**6,800** ***(0.7%)***	93,600	300	**93,900** ***(9.5%)***	100,700	**10.2%**
Eastern OR Cascades	402,900	**5,800** ***(1.4%)***	17,800	2,300	**20,100** ***(5.0%)***	25,900	**6.4%**
Western OR Cascades	2,258,700	**13,900** ***(0.6%)***	28,900	1,100	**30,000** ***(1.3%)***	43,900	**1.9%**
Willamette Valley	3,400	**100** ***(2.9%)***	0	0	**0**	100	**2.9%**
CA Coast	145,400	**300** ***(0.2%)***	2,100	100	**2,200** ***(1.5%)***	2,500	**1.7%**
CA Cascades	213,200	**6,500** ***(3.0%)***	1,800	300	**2,100** ***(1.0%)***	8,600	**4.0%**
CA Klamath	1,489,800	**4,400** ***(0.3%)***	71,600	1,600	**73,200** ***(4.9%)***	77,600	**5.2%**
Range-wide total	8,853,000	**53,800** ***(0.6%)***	236,700	8,100	**244,800** ***(2.8%)***	298,600	**3.4%**

[1] 1996 and 2006 for Oregon and Washington, 1994 and 2007 for California.
[2] Percent of 1994/96 habitat.
[3] Loss is the term used in Davis and Dugger (in press) to describe their data, which is summarized here.

Raphael (2006) estimated that approximately 7.5 million acres of spotted owl habitat existed on non-federal lands within California, Oregon, and Washington in 1994. Cohen *et al.* (2002) reported that, from the early 1970s through the mid-1990s, the harvest rates on private industrial lands were consistently about twice the average rate of harvest on public land. Bigley and Franklin (2004:6-11) noted that:

> "In the late 1980s and early 1990s the harvest rate was estimated at 2.4 percent per year for private industrial land. An increase in non-industrial private landowner's harvest rates started in the 1970s when the rate was 0.2 percent per year and continued to increase to the early 1990s when the rate was similar to that of the private industrial lands."

Recently, data on actual information on harvest of nesting and roosting habitat for non-federal lands became available through the NWFP monitoring program. On non-federal lands, 14.92 percent (625,600 acres) of the nesting and roosting habitat was harvested in the 10-14 years of the analysis. This compares to 0.6 percent (53,800 acres) on Federal lands in the same period.

Table B-2. Estimated amount of spotted owl nesting and roosting habitat1 at the start of the Northwest Forest Plan (baseline 1994/96[2]) and losses owing to harvest through 2006/7[2], by State and ownership (adapted from Davis and Dugger in press).

Land class	Baseline (1994/96[2])	Harvest	Total Percent loss[3]
Federal reserved			
Washington	2,274,200	7,900	0.3%
Oregon	2,699,600	6,100	0.2%
California	1,214,000	2,500	0.2%
Range-wide total	**6,187,800**	**16,500**	**0.3%**
Federal non-reserved			
Washington	470,200	4,800	1.0%
Oregon	1,561,400	23,800	1.5%
California	634,400	8,700	1.4%
Range-wide total	**2,666,000**	**37,300**	**1.4%**
Non-federal			
Washington	1,258,900	234,200	18.6%
Oregon	1,382,400	301,200	21.8%
California	1,556,700	90,200	5.8%
Range-wide total	**4,198,000**	**625,600**	14.9%
Range-wide total	**13,052,000**	**679,400**	**5.2%**

[1] See Davis and Dugger (in press) for description of habitat.
[2] 1996 and 2006 for Oregon and Washington, 1994 and 2007 for California.
[3] Loss is the term used in Davis and Dugger (in press) to describe their data, which is summarized here.

Recent Rates of Loss of NRF Habitat as a Result of Natural Events

The effects of wildfire and other natural disturbances on spotted owls and their habitat vary by location, severity, and habitat function, though most of the data is related specifically to fire. Spotted owl use of post fire habitat varies, depending on fire severity and the function of the site for spotted owls (*i.e.*, nesting, roosting, or foraging). Few studies are available to clarify this relationship, and many of these are complicated by small sample sizes, post-fire logging, lack of long-term data, and inadequate pre-fire spotted owl data. Spotted owl reproduction and nesting have been observed in the short-term in some burned landscapes and even in core areas in which some portion was burned by high-severity fire. No nest trees were found in high-severity burns, though have been observed in moderate and low severity burned areas. Spotted owls have been observed roosting in forests experiencing the full range of fire severity, though most were associated with low or moderate severity burns. Spotted owls were observed to forage in burned areas within their home range in areas where dusky-footed woodrats are a primary food source, but there is no similar data in more northern conditions. Based on this information we conclude that, while spotted owls can make use of some post-fire landscapes, fire also reduces the function of some habitat and likely removes some from immediate usability, particularly in areas of high-severity fire.

Recent data from the NWFP Effectiveness Monitoring program provides an insight into the change in spotted owl nesting and roosting habitat from natural disturbances on Federal (Table B-1) and non-federal lands (Table B-3). Changes in habitat were evaluated comparing mapped differences in habitat condition over time. Habitat was considered “lost” if its condition moved from suitable or highly suitable to marginal or unsuitable. We use the term “loss” in this case because this is how the authors describe their data, though as described above, not all burned areas are necessarily lost as habitat. The level of losses varies widely by province, from extremely low (0.03percent of the nesting and roosting habitat) in the Olympic Peninsula Province to 9.5 percent in the Oregon Klamath Province. Wildfire caused most of the loss (236,700 acres) while insects and disease resulted in 8,100 acres of habitat. On non-federal lands, the level was very low, less than 1percent in each state (Table B-3).

Table B-3. Spotted owl nesting and roosting habitat loss from natural disturbances on non-federal lands from 1994/96[1] to 2006-7[1] (acres) (adapted from Davis and Dugger in press).

State	1994/96 habitat	Fire	Insects and disease	Total	Percent habitat loss[2]
Washington	1,258,900	2,400	6,000	8,400	0.7%
Oregon	1,382,400	5,100	2,700	7,800	0.6%
California	1,556,700	5,600	1,900	7,500	0.4%
Total	4,198,000	13,100	10,600	23,700	0.6%

[1] 1996 and 2006 for Oregon and Washington, 1994 and 2007 for California.

[2] Loss is the term used in Davis and Dugger (in press) to describe their data, which is summarized here.

Summary of Recent Rates of Loss of Spotted Owl Habitat as a Result of Timber Harvest and Natural Disturbances

Range-wide, 0.6 percent (53,800 acres) of the spotted owl nesting and roosting habitat on Federal lands were lost to timber harvest and 2.8 percent (244,800 acres) to natural disturbances, primarily wildfire, resulting in a total range-wide loss of 3.4 percent (298,600 acres). The greatest percentage of Federal land habitat loss was in Oregon, specifically in the Oregon Klamath Province (10.9 percent of the habitat) due primarily to wildfire. Two provinces, the Oregon and California Klamath accounted for 60 percent of the total habitat loss on Federal lands. In contrast, less than 1 percent of the nesting and roosting habitat in the Olympic Peninsula, Western Washington Cascades, and Oregon Coast Ranges were loss during the time period.

Habitat Recruitment

Several groups have attempted to estimate the rate or amount of spotted owl habitat recruitment. Most of these estimates were not specific to spotted owl habitat. In reality, projecting the transition of a forest's age and size classes to different levels of habitat function requires extensive field verification. The SEI report (SEI 2004:6-29) provided a clear caution relative to habitat development.

> "Habitat development certainly is not a mechanistic process and there is considerable variability with predictions of habitat development. The habitat complexity that most definitions project as suitable habitat develops

> over multiple decades and is not a threshold that is achieved with an average size class. Stand age or size does not account for the history, growing conditions, species composition, and other factors that determine the rate of habitat development. There is considerable uncertainty in the transition between mid-seral stage stands and suitable habitat. These uncertainties still exist with remote sensing information or inventory methods that are not specifically designed to sample the key components of suitable habitat."

In addition, determining when a forest progresses from non-habitat to habitat on an ecologically-short time frame (10-15 years) is fraught with assumptions and potential inaccuracy. Given the uncertainty about the rate of complex forest structure, it is likely that habitat development was overestimated, although the extent of overestimation cannot be determined (Bigley and Franklin 2004).

Given the degree of uncertainty, potential inaccuracy, and disagreements between results, we cannot at this time reach any conclusions on the issue of habitat recruitment. We will continue to follow this issue as new information becomes available.

Disease

WNV has killed millions of wild birds in North America since it arrived in 1999 (McLean *et al.* 2001, Caffrey 2003, Fitzgerald *et al.* 2003, Marra *et al.* 2004). Mosquitoes are the primary carriers of this virus that causes encephalitis in humans, horses, and birds. Although birds are the primary hosts of WNV, additional non-human hosts include horses and other ungulates, felines, canines, rodents, rabbits, bats, alligators, and frogs (Hubálek and Halouzka 1999, Gubler 2007). Mammalian prey may play a role in spreading WNV, if predators like spotted owls contract the disease by eating infected prey (Garmendia *et al.* 2000, Komar *et al.* 2001). One captive spotted owl in Ontario, Canada, is known to have contracted WNV and died (Gancz *et al.* 2004), but there are no documented cases of the virus in wild spotted owls.

Health officials expect that WNV eventually will spread throughout the range of the spotted owl (Blakesley *et al.* 2004), but it is unknown how the virus will ultimately affect spotted owl populations. Susceptibility to infection and the mortality rates of infected individuals vary among bird species (Blakesley *et al.* 2004), but most owls appear to be quite susceptible. For example, eastern screech-owls breeding in Ohio that were exposed to WNV experienced 100 percent mortality (T. Grubb pers. comm. in Blakesley *et al.* 2004). Barred owls, in contrast, showed lower susceptibility (B. Hunter pers. comm. in Blakesley *et al.* 2004). Wild birds may develop resistance to WNV through immune responses (Deubel *et al.* 2001).

Blakesley *et al.* (2004) offer competing scenarios for the likely outcome of spotted owl populations being infected by WNV. One scenario is that spotted owls can tolerate severe, short-term population reductions caused by the virus because spotted owl populations are widely distributed and number in the several thousands. An alternative scenario is that the virus will cause unsustainable mortality because of the frequency and/or magnitude of infection, thereby resulting in long-term population declines and extirpation from parts of the spotted owl's current range.

Ishak *et al.* (2008) document Plasmodium spp. in a spotted owl. They also found 10 spotted owls with multiple infections (Ishak *et al.* 2008). It is unclear, however, if this rate of infection is significant and if it might affect the recovery of the species.

Inadequacy of Regulatory Mechanisms

The original listing document (USFWS 1990b), Franklin and Courtney (2004), and the 5-year review (USFWS 2004b) noted some inadequacies in existing regulatory mechanisms. The 1990 listing rule concluded that current State regulations and policies did not provide adequate protection for spotted owls; less than 1 percent of the non-federal lands provided long-term protection for spotted owls (USFWS 1990b). The listing rule stated that the rate of harvest on Federal lands, the limited amount of permanently reserved habitat, and the management of spotted owls based on a network of individually protected sites did not provide adequate protection for the spotted owl. If continued, these management practices would result in an estimated 60 percent decline in the remaining spotted owl habitat, and the resulting amount of habitat might not be sufficient to ensure long-term viability of the spotted owl.

When it was adopted in 1994, the NWFP significantly altered management of Federal lands (USDA and USDI 1994a, b, Noon and Blakesley 2006, Thomas *et al.* 2006). The substantial increase in reserved areas and associated reduced harvest (ranging from approximately 1 percent per year to 0.24 percent per year) has substantially lowered the timber-harvest threat to spotted owls. However, the NWFP allows some loss of habitat and assumed some unspecified level of continued decline in spotted owls. Franklin and Courtney (2004) noted that many, but not all, of the scientific building blocks of the NWFP have been confirmed or validated in the decade since the plan was adopted. One major limitation appears to be the inability of the conservation network presented in the plan to deal with invasive species. However, this deficiency does not diminish the important contribution of the relevant LRMPs to spotted owl conservation (Franklin and Courtney 2004).

As the Federal agencies develop new LRMPs, they will consider the conservation needs of the spotted owl and the goals and objectives of this Revised Recovery Plan. If needed, actions to implement Federal land use plans will be accompanied with either plan or project level consultations to assure management actions align with recovery goals.

Barred Owls

Barred owls expanded their range from eastern to western North America during the past century. They were first documented in British Columbia in 1943 (Rand 1944, Munro and McTaggart-Cowan 1947), Washington in 1965 (Rogers 1966), Oregon in 1972 (E. Forsman in Livezey 2009a), California in 1976 (B. Marcot in Livezey 2009a). This range expansion may have been facilitated by increases in distribution of trees in the Great Plains due to exclusion of fires historically set by Native Americans, fire suppression, tree planting , extirpation of bison and beaver, and other factors (Dark *et al.* 1998, R. Gutiérrez in Levy 1999, 2004, Mazur and James 2000, USFWS 2003, Livezey 2009b). The range of the barred owl now completely overlaps that of its slightly smaller congener, the spotted owl (Gutiérrez *et al.* 1995).

Barred owls have been observed physically attacking spotted owls (pers. comms. in Pearson and Livezey 2003) and circumstantial evidence suggests that a barred owl killed a spotted owl (Leskiw and Gutiérrez 1998). Based on early studies conducted on the west slope of the Washington Cascades (Hamer 1988, Iverson 1993), barred owls were thought by some to be more closely associated with early successional forests than spotted owls are, though even then they were known to use old-growth. Recent studies in the Pacific Northwest (Herter and Hicks 2000, Pearson and Livezey 2003, Gremel 2005, Schmidt 2006, Hamer *et al.* 2007, Singleton *et al.* 2010) show that barred owls also use, and in some cases, appear to prefer old-growth forest and older forest. Diets of spotted and barred owls in the western Washington Cascades overlap by approximately 76 percent (Hamer *et al.* 2001). Barred owl diets are more diverse than those of spotted owls (Forsman *et al.* 2004) and include more species associated with riparian and other moist habitats, along with more terrestrial and diurnal species (Hamer *et al.* 2001). The more-diverse food habits of barred owls appears to be the reason that barred owls have much smaller home-ranges than spotted owls do (Hamer *et al.* 2007).

Barred owls reportedly have reduced probability of detection (response behavior), site occupancy, reproduction, and survival of spotted owls. The probability of detecting spotted owls during surveys in Washington, Oregon, and California was significantly reduced by the presence of barred owls (Olson *et al.* 2005, Crozier *et al.* 2006). In the eastern Cascades of Washington, probabilities of detecting any spotted owl or a pair of spotted owls were significantly lower when barred owls were detected during surveys than when no barred owls were detected (Kroll *et al.* 2010). In addition, studies in Oregon showed that detection of both species was negatively influenced by presence of the other (Bailey *et al.* 2009) and barred owls frequently were not detected during surveys for spotted owls (Bailey *et al.* 2009).

Forsman *et al.* (2011) and Anthony *et al.* (2006) have documented increasing barred owl numbers across Washington, Oregon, and California from 1990-2008. While barred owls have expanded into California more recently (Kelly *et al.* 2003), Forsman *et al.* (2011) provides strong evidence of increasing barred owl populations in this region. Occupancy of territories by spotted owls in study areas in Washington and Oregon was significantly lower after barred owls were detected within 0.5 miles of the territory center but was "only marginally lower" if barred owls were located more than 0.5 miles from the spotted owl territory center (Kelly *et al.* 2003:51). In the Gifford Pinchot National Forest, there were significantly more barred owl site-centers in unoccupied spotted owl circles than in occupied spotted owl circles with radii of 0.5 miles, 1 mile, and 1.8 miles centered on spotted owl sites (Pearson and Livezey 2003). In the eastern Washington Cascades, barred owls had a significant negative effect on site occupancy by any spotted owl (both single and pair spotted owl detections combined); however, barred owls did not have a negative effect on site occupancy by spotted owl pairs (Kroll *et al.* 2010). Spotted owl simple extinction probabilities (probability that a site center changed from occupied to unoccupied) were significantly higher in the eastern Washington Cascades when barred owls were detected in a site center during the year (Kroll *et al.* 2010). In Olympic National Park, spotted owl pair occupancy declined significantly at sites where barred owls had been detected, whereas pair occupancy remained stable at spotted owl sites without barred owls (Gremel 2005). Annual probability that a spotted owl territory would be occupied by a pair of spotted owls after barred owls were detected at the site declined by five percent in the HJ Andrews study area, 12 percent in the Coast Range study area, and 15 percent in the Tyee study area (Olson *et al.* 2005).

Barred owls evidently are appropriating spotted owl sites in flatter, lower-elevation forests in some areas (Pearson and Livezey 2003, Gremel 2005, Hamer *et al.* 2007). Apparently in response to barred owls, some marked spotted owl site centers have moved higher up slopes (Gremel 2005). According to one study, "the trade-off for living in high elevation forests could be reduced survival or fecundity in years with severe winters (Hamer *et al.* 2007:764)." It is unknown whether this slope/elevation tendency found in Washington is prevalent throughout the range of the spotted owl, how long spotted owls can persist where they are relegated to only steep, higher-elevation areas, and whether barred owls will continue to move upslope and eventually supplant the remaining spotted owls in these areas.

Reproduction of spotted owls in the Roseburg study area, Oregon, was negatively affected by the presence of barred owls (Olson *et al.* 2004). Apparent survival of spotted owls was negatively affected by barred owls in two (Olympic and Wenatchee) of 14 study areas throughout the range of the spotted owl (Anthony *et al.* 2006). The researchers attributed the equivocal results for most of their study areas to the coarse nature of their barred owl covariate. It is likely that this study underestimated the effects of barred owls on the reproduction of spotted owls because spotted owls often cannot be relocated after they are displaced by barred owls (E. Forsman pers. comm. 2006).

Only 47 spotted owl/barred owl hybrids were detected in an analysis of more than 9,000 banded spotted owls throughout their range (Kelly and Forsman 2004). Consequently, hybridization with the barred owl is considered to be "an interesting biological phenomenon that is probably inconsequential, compared with the real threat—direct competition between the two species for food and space" (Kelly and Forsman 2004:808).

Data indicating negative effects of barred owls on spotted owls are largely correlational and are almost exclusively gathered incidentally to data collected on spotted owls (Gutiérrez *et al.* 2004, Livezey and Fleming 2007). Competition theory predicts that barred owls will compete with spotted owls because they are similar in size and have overlapping diet and habitat requirements (Hamer *et al.* 2001, 2007, Gutiérrez *et al.* 2007). Limited experimental evidence (Crozier *et al.* 2006), preliminary response by spotted owls to a scientific collection of barred owls (L. Diller pers. comm. 2010), correlational studies (Kelly *et al.* 2003, Pearson and Livezey 2003, Gremel 2005, Olson *et al.* 2005, Hamer *et al.* 2007, Dugger *et al.* in press), and anecdotal information (Leskiw and Gutiérrez 1998, Gutiérrez *et al.* 2004) suggest that barred owls are negatively affecting spotted owls through exploitive and interference competition. The preponderance of evidence suggests barred owls are contributing to the population decline of spotted owls, especially in Washington, portions of Oregon, and the northern coast of California (Gutiérrez *et al.* 2004, Olson *et al.* 2005) which may explain the sharper decline in the spotted owl population trend in the northern portion of the spotted owl's range compared to those in the southern portion of the range.

Loss of Genetic Variation

One possible threat to spotted owls is a loss of genetic variation from population bottlenecks which could lead to increased inbreeding depression and decreased adaptive potential. Funk *et al.* (2010) found evidence of recent genetic bottlenecks in the spotted owl population, estimating these have occurred within the last few decades. They found the strongest evidence for recent bottlenecks in the Washington Cascades, which they correlate with data on significant population declines in the same area. However, they did not find strong evidence of bottlenecks in other areas that showed population declines. While they could not determine "whether inbreeding is contributing to vital rate reductions" (pg. 7), they do caution that "future efforts to conserve northern spotted owl populations will require greater consideration of genetic threats to persistence" (pg. 7).

SEI (2008) reviewed a presentation and two unpublished manuscripts, provided by Dr. Susan Haig, on the evidence for genetic bottlenecks in spotted owl populations. Using microsatellite markers and a computer program called "Bottleneck," Haig provided evidence of recent genetic bottlenecks at several spatial scales (individual "populations" [demographic study areas], regions, and subspecies). Haig explicitly stated she could not conclude these bottlenecks were the cause for, nor were they necessarily related to, the recently documented declines in spotted owl populations. However, she did present a "cross-walk" of her results with a table depicting the status of spotted owl populations from Anthony *et al.* (2006).

SEI (2008) concluded Haig's observed bottlenecks are likely the result of population declines and not the cause of it; they are signatures of something that occurred in the past. SEI (2008) advises the population dynamics of the spotted owl likely will be more important to its short-term survival than will be its genetic makeup, regardless of the evidence for bottlenecks having occurred in the past (Barrowclough and Coats 1985).

Appendix C. Development of a Modeling Framework to Support Recovery Implementation and Habitat Conservation Planning

Introduction by U.S. Fish and Wildlife Service

The Service believes a spatially explicit demographic model would greatly improve recovery planning and implementation for the spotted owl. Peer reviewers were critical of the 2008 Recovery Plan's habitat conservation network strategy and the general lack of updated habitat modeling capacity. The Service considered this criticism and concluded that a spatially explicit demographic model would greatly improve recovery implementation for the spotted owl, as well as other land use management decisions.

For this Revised Recovery Plan, the Service appointed a team of experts to develop and test a modeling framework that can be used in numerous spotted owl management decisions. This spatially-explicit approach is designed to allow for a more in-depth evaluation of various factors that affect spotted owl distribution and populations**.** This approach also allows for a unique opportunity to integrate new data sets, such as information from the NWFP 15-year Monitoring Report (Davis and Dugger in press) and the recent spotted owl population meta-analysis (Forsman *et al.* 2011).

The Service expects this modeling framework will be applied by Federal, State, and private scientists to make better informed decisions concerning what areas should be conserved or managed to achieve spotted owl recovery. Specifically, the modeling framework can be applied to various spotted owl management challenges, such as to:

1) Inform evaluations of meeting population goals and Recovery Criteria.
2) Develop reliable analysis and modeling tools to enable evaluation of the influence of habitat suitability and barred owls on spotted owl demographics.
3) Support future implementation and evaluation of the efficacy of spotted owl conservation measures described in various recovery actions.
4) Provide a framework for landscape-scale planning by both Federal and non-federal land managers that enables evaluation of potential demographic responses to various habitat conservation scenarios, including information that could be used in developing a proposed critical habitat rule.

These and other potential applications of the modeling framework described herein represent a significant advancement in spotted owl recovery planning. Although the completed model framework will be included in the Revised Recovery Plan, the Service hopes that future application of this modeling approach will lead to refinement and improvements, such as incorporation of population connectivity and source-sink dynamics, over time as experience and new scientific insights are realized.

To meet these objectives, the Service established the Spotted Owl Modeling Team (hereafter the "modeling team") to develop and apply modeling tools for the Service's use in designing and evaluating various conservation options for achieving spotted owl recovery. The modeling team was informally organized along lines of function and level of participation. Jeffrey Dunk (Humboldt State University), Brian Woodbridge (USFWS), Bruce Marcot (USFS, Pacific Northwest Research Station), Nathan Schumaker (USEPA), and Dave LaPlante (a contractor with Natural Resource Geospatial) composed the primary group which was responsible for conducting the data analyses and modeling. They were assisted by spotted owl researchers, agency staff and modeling specialists who individually provided data sets and advice on particular issues within their areas of expertise, and reviewed modeling processes and outputs. These experts were: Robert Anthony (Oregon State University), Katie Dugger (Oregon State University), Marty Raphael (USFS, Pacific Northwest Research Station), Jim Thrailkill (USFWS), Ray Davis (USFS, Northwest Forest Plan Monitoring Group), Eric Greenquist (BLM), and Brendan White (USFWS). Additionally, technical specialists—Craig Ducey (BLM), Karen West (USFWS) and Dan Hansen and M.J. Mazurek (contractors with Humboldt State University Foundation) conducted literature reviews and assisted with data collection and analyses.

To ensure that the modeling effort was based on the most current information, scientific knowledge and opinion, the modeling team also sought the assistance of numerous individual scientists and habitat managers from government, industry and a non-profit conservation organization (listed in acknowledgements) in development of habitat descriptions, modeling regions and many other aspects of spotted owl and forest ecology. To facilitate this effort, the Service held a series of meetings with spotted owl experts (habitat expert panels) to obtain additional information, data sets, and expertise regarding spotted owl habitats.

Representatives of the modeling team have prepared this Appendix to provide a thorough description of the modeling framework developed by the team, the results of model development and testing, and examples of how the modeling process can be used to evaluate habitat conservation scenarios and their relative contribution to recovery.

While this framework represents state-of-the-art science, it is not intended to represent absolute spotted owl population numbers or be a perfect reflection of reality. Instead, it provides a comparison of the relative spotted owl responses to a variety of potential conservation measures and habitat conservation networks. The implementation of spotted owl recovery actions should consider the results of the modeling framework as one of numerous sources of information to be incorporated into the decision-making process.

General Approach

The spotted owl modeling team (hereafter "modeling team" or "we") employed state-of–the-art modeling tools in a multi-step analysis similar to that proposed by Heinrichs *et al.* (2010) and Reed *et al.* (2006) for designing habitat conservation networks and evaluating their contributions to spotted owl recovery. In addition to this objective, the modeling tools in this framework, individually or in combination, are designed to enable evaluation of the efficacy of spotted owl conservation measures such as Recovery Action 10 and management of barred owls**.**

Our conservation planning framework integrates a spotted owl habitat model, a habitat conservation planning model, and a population simulation model. Collectively, these modeling tools allow comparison of estimated spotted owl population performance among alternative habitat conservation network scenarios under a variety of potential conditions. This will enable the Service and other interested managers to use relative population viability (timing and probability of population recovery) as a criterion for evaluating habitat conservation network scenarios and other conservation measures for the spotted owl.

The evaluation approach the modeling team developed consists of three main steps (Figure C1):

> **Step 1** – Create a map of spotted owl habitat suitability throughout the species' U.S. range, based on a statistical model of spotted owl habitat associations.
>
> **Step 2** – Develop a spotted owl conservation planning model, based on the habitat suitability model developed in Step 1, and use it to design an array of habitat conservation network scenarios.
>
> **Step 3** – Develop a spatially explicit spotted owl population model that reliably predicts relative responses of spotted owls to environmental conditions, and use it to test the effectiveness of habitat conservation network scenarios designed in step 2 in recovering the spotted owl. The simulations from this spotted owl population model are not meant to be estimates of what will occur in the future, but provide information on trends predicted to occur under differing habitat conservation scenarios.

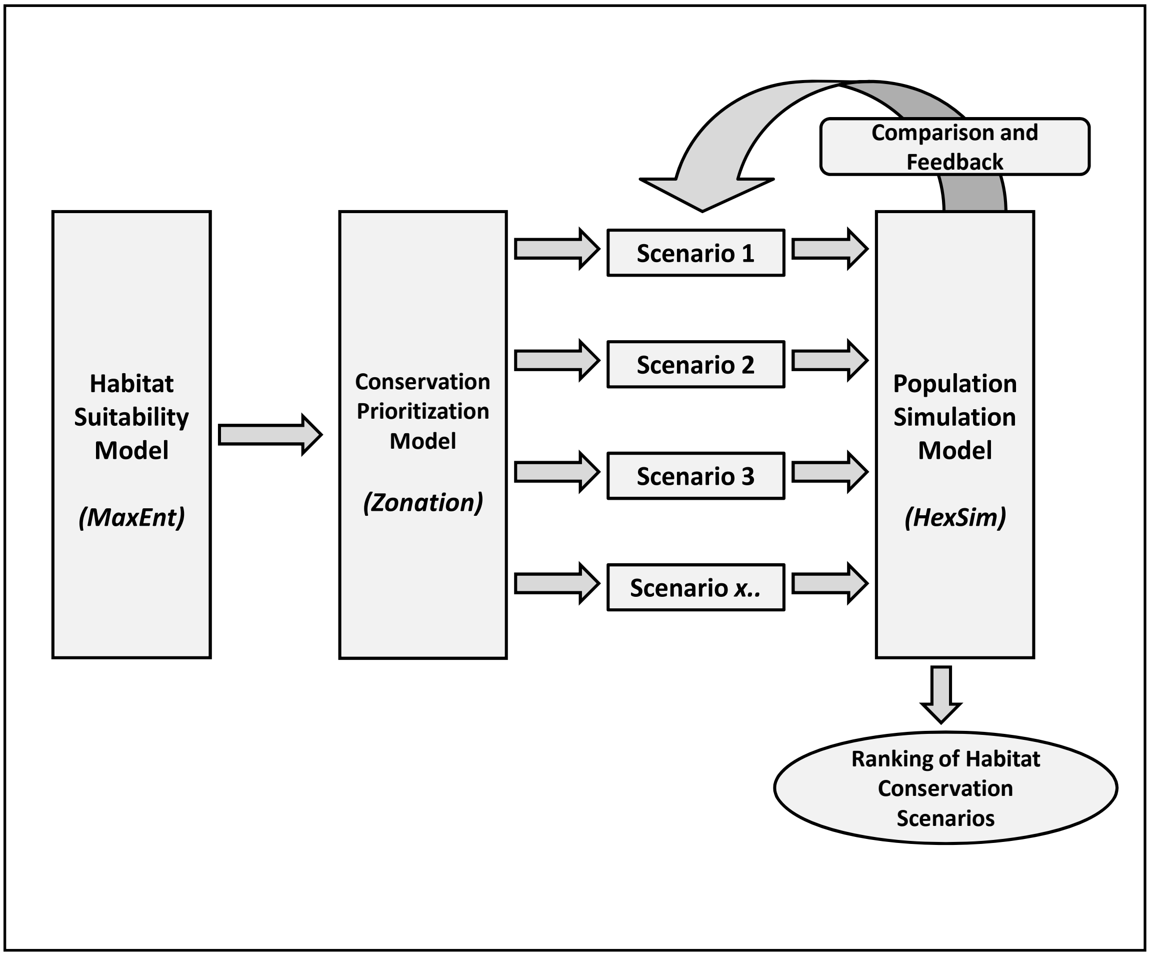
The Service or other practitioners can use the population simulation model developed in Step 3 to test the degree to which various recovery actions and habitat conservation network scenarios contribute to recovery of the spotted owl. For example, it can be used to evaluate relative population size and trend, as well as distribution and connectivity of modeled spotted owl populations through time.

Each of the steps noted above involved statistical and/or mathematical modeling and is not meant to be exact predictions of what currently exists or what will occur in the future, but represent our best estimates of current conditions and relationships. These models allow the use of powerful, up-to-date scientific tools in a repeatable and scientifically accepted manner to develop and evaluate habitat conservation networks and other conservation measures to recover the spotted owl. We view the benefit and utility of such models in the same way that Johnson (2001) articulated, "*A model has value if it provides better insight, predictions, or control than would be available without the model*." The modeling tools described herein meet this standard.

The overall framework and evaluations outlined in Figure C1 are somewhat similar to Raphael *et al.* (1998). Our modeling process differs fundamentally from the conservation planning approach used by the ISC (Thomas *et al*. 1990), 1992 Draft Recovery Plan (USFWS 1992b), FEMAT (1993), and the 2008 Recovery plan (USFWS 2008b), which were based on *a priori* rule sets derived from best expert judgment regarding the size of reserves or habitat conservation blocks, target number of spotted owl pairs per reserve or block, and targeted spacing between reserves or blocks. The new modeling framework we developed instead uses a series of spatially explicit modeling processes to develop habitat conservation networks (or "reserves") based on the distribution of habitat value. Issues of habitat connectivity and population isolation are identified within the population simulation model outputs.

The spotted owl modeling team has completed the development and evaluation of the overall modeling framework described in Steps 1 through 3 above. The *use* of the modeling framework, for example, to inform design and evaluation of various habitat conservation network scenarios (including potential effects of barred owl management), other conservation measures described in recovery actions, and evaluate potential effects of climate change will be completed as a part of recovery plan implementation or other analytical and regulatory processes.

Figure C-1. Diagram of stepwise modeling process for developing and evaluating habitat conservation scenarios for the spotted owl.



Modeling Process Step 1 – Create a spotted owl habitat suitability map covering the U.S. range of the subspecies based on a statistical model of spotted owl habitat associations.

Habitat modeling objective and overall approach:

A variety of methods are available for modeling species-habitat relationships (Morrison *et al*. 1992, Elith *et al.* 2006), with divergent assumptions and underlying statistical bases (Breiman 2001). The selection of a modeling tool is influenced foremost by the objectives of the modeling exercise, and by the characteristics of data available for modeling. The primary objective of our recovery plan modeling was to develop a map that reliably predicts relative habitat suitability for the spotted owl. Our primary goals were to develop predictive models that: 1) had good discriminatory ability, 2) were well calibrated, 3) were robust, and 4) had good generality. Our modeling was not an attempt to quantify or refine our understanding of the spotted owl's niche; but instead focused on predictions. Because we were primarily focused on obtaining reliable predictions, we were less concerned about covariates and their associated parameter estimates, or the relative importance of each habitat variable. This objective enabled us to consider newer algorithmic modeling approaches that emphasize prediction (Breiman 2001).

The nature of the spotted owl data available to us also influenced our choice of a modeling approach. We gathered several datasets which resulted in a large number of spotted owl locations, but only a relatively small subset of those data sets also had survey effort information (that could be used for occupancy modeling) and absence data (locations that were adequately sampled and where spotted owls were not detected). Because the majority of spotted owl data available was best characterized as 'presence-only' data, we elected not to employ occupancy modeling approaches.

Our objectives and the nature of the data available to us lead us to choose the species distribution model MaxEnt (Phillips *et al*. 2006, Phillips and Dudik 2008) to model spotted owl relative habitat suitability. MaxEnt is specifically designed for presence-only data. Moreover, MaxEnt has been thoroughly evaluated on a number of taxa, geographic regions, and sample sizes and has been found to perform extremely well (Elith *et al.* 2006, Wisz *et al*. 2008).

Distributional Models and the Spotted Owl:

Species distributional models are used to evaluate species-habitat relationships, evaluate an area's suitability for the species, and to predict a species' presence (Elith and Leathwick 2009). These models, also called environmental (or ecological) niche models, correlate environmental conditions with species distribution and thereby predict the relative suitability of habitat within some geographic area (Warren and Seifert 2011). When translated into maps depicting the spatial distribution of predicted habitat suitability, these models have great utility for evaluating conservation reserve design and function (Zabel *et al.* 2002, Zabel *et al*. 2003, Carroll and Johnson 2008, Carroll *et al.* 2010). Because the spotted owl is one of the most studied raptors in the world; we had available hundreds of peer-reviewed papers on various aspects of the species' ecology, including habitat use and selection (see reviews by Gutiérrez *et al.* 1995, Blakesley 2004). Only a few range-wide (in the U.S.) evaluations of habitat association (Carroll and Johnson 2008) or habitat distribution (Davis and Lint 2005, Davis and Dugger in press) have been conducted. While we capitalized on this large body of literature and other information to build models for conservation planning purposes, we were primarily interested in using such models to map relative habitat suitability rather than to provide new ecological understanding of spotted owl habitat associations.

Meetings with spotted owl habitat experts and review of literature and data sets:

Because the spotted owl is among the most-studied birds in the world, there is a wealth of information on its ecology and habitat associations. To ensure that the modeling effort was based on this scientific foundation, our first step was to conduct an extensive review of published and unpublished information on the species. Concurrent with this effort, team members travelled throughout the spotted owl's range and met with researchers and biologists with extensive experience studying spotted owls. Some of these meetings were one-on-one, and at other times we held meetings with several experts at one time to seek their individual advice. We have sometimes referred to these meetings as "expert panels." At these meetings, biologists were each asked to identify (1) the environmental factors to which spotted owls respond within particular physiographic provinces (*e.g.* Klamath Mountains of southern Oregon and northern California, Olympic Peninsula, Redwood Coast), and (2) regions believed to be distinct where spotted owls may be responding to conditions uniquely. In order to identify distinct modeling areas and definitions of spotted owl habitat (see below), we used both empirical findings (*i.e.*, published information) and the professional judgment of spotted owl experts.

Modeling regions - Partitioning the species' range:

Several authors have noted that spotted owls exhibit different habitat associations in different portions of their range, which is often attributed to regional differences in forest environments and factors such as important prey species (Carey *et al.* 1992, Franklin *et al.* 2000, Noon and Franklin 2002, Zabel *et al.* 2003), or presence of Douglas-fir dwarf mistletoe (expert panels). The distribution of these features is likely influenced by relatively large east-west and north-south gradients in ecological conditions (*e.g.*, temperature, precipitation, net primary productivity) and subsequent variation in forest environments. Hence, we developed and evaluated region-specific habitat suitability models under the assumption that spotted owls *within* a modeling region respond to habitat conditions more similarly than do spotted owls *between* modeling regions where conditions differ.

For monitoring, management and regulatory purposes, the spotted owl's range has historically been divided into 12 physiographic provinces (USDI 1992, Davis and Lint 2005) based largely on the regional distribution of major forest types and state boundaries. Based on differences and similarities in spotted owl habitat, we combined some provinces (California and Oregon Klamath provinces), retained others, and divided some provinces into smaller modeling regions (see Figure C2). We did not establish modeling regions or develop models for the Puget Lowlands, Southwestern Washington, and Willamette Valley, where spotted owls are almost completely absent and sample sizes were too small to support for model development. Instead, we projected the models developed for the closest adjacent area to those areas. This decision had the influence of allowing those regions to have at least some potential value to simulated spotted owls as opposed to assuming zero value.

The predictive ability and accuracy of habitat suitability models are influenced by the range of environmental conditions that are incorporated into the training data used in model development. Models developed from data sets encompassing broad environmental gradients tend to be overly general; conversely, models developed with data representing a small subset of conditions have limited applicability across the species' larger distribution. The practice of partitioning a species' range into "modeling regions" that encompass relatively dissimilar subsets of species-habitat relationships and developing models specific to each region was used to reduce this source of variability. The challenge is balancing the high degree of variability within large regions against the tendency to create many small modeling regions (with potentially small sample sizes) based on locally unique environmental conditions.

We queried experts to suggest potential modeling region boundaries, and they provided input on broad-scale patterns in climate, topography, forest communities, spotted owl habitat relationships, and prey-base that supported delineation of the draft spotted owl modeling regions (Figure C2). Franklin and Dyrness (1973), Kuchler (1977) and other published sources of information on the distribution of major ecological boundaries were also consulted. Using information provided through our discussions with the expert panels and existing ecological section and subsection boundaries (McNab and Avers 1994), we delineated 11 spotted owl modeling regions (Figure C2).

In general, the spotted owl modeling regions varied in terms of these ecological features:

1) Degree of similarity between structural characteristics of habitats used by spotted owls primarily for nesting/roosting and habitats used for foraging and other nocturnal activities. This similarity is largely influenced by habitat characteristics of the spotted owl's dominant prey (proportion of flying squirrels versus woodrats).

2) Latitudinal patterns of topography and climate. For example, in the WA Cascades, spotted owls are rarely found at elevations above 1,219-1,372 m, whereas in southern Oregon and the Klamath province spotted owls commonly reside up to 1,830 m.

3) Regional patterns of topography, climate, and forest communities.

4) Geographic distributions of habitat elements that influence the range of conditions occupied by spotted owls. For example, several panelists pointed out that the distribution of dwarf mistletoe influences the range of stand structural values associated with spotted owl use. Other examples include the geographic distribution of elements such as evergreen hardwoods, Oregon white oak woodlands, and ponderosa pine-dominated forests.

Modeling Region Descriptions:

North Coast Ranges and Olympic Peninsula (NCO): This region consists of the Oregon and Washington Coast Ranges Section M242A (McNab and Avers 1994). This region is characterized by high rainfall, cool to moderate temperatures, and generally low topography (448 to 750 m). High elevations and cold temperatures occur in the interior portions of the Olympic Peninsula, but spotted owls in this area are limited to the lower elevations (<900 m.). Forests in the NCO are dominated by western hemlock, Sitka spruce, Douglas-fir, and western red cedar. Hardwoods are limited in species diversity (consist mostly of bigleaf maple and red alder) and distribution within this region, and typically occur in riparian zones. Root pathogens like laminated root rot (*Phellinus weirii*) are important gap formers, and vine maple, among others, fills these gaps. Because Douglas-fir dwarf mistletoe is unusual in this region, spotted owl nesting habitat consists of stands providing very large trees with cavities or deformities. A few nests are associated with western hemlock dwarf mistletoe. Spotted owl diets are dominated by species associated with mature to late-successional forests (flying squirrels, red tree voles), resulting in similar definitions of habitats used for nesting/roosting and foraging by spotted owls. This region contains the Olympic Demographic Study Area (DSA).

Oregon Coast Ranges (OCR): This region consists of the southern 1/3 of the Oregon and Washington Coast Ranges Section M242A (McNab and Avers 1994). We split the section in the vicinity of Otter Rock, OR, based on gradients of increased temperature and decreased moisture that result in different patterns of vegetation to the south. Generally this region is characterized by high rainfall, cool to moderate temperatures, and generally low topography (300 to 750 m.). Forests in this region are dominated by western hemlock, Sitka spruce, and Douglas-fir; hardwoods are limited in species diversity (largely bigleaf maple and red alder) and distribution, and are typically limited to riparian zones. Douglas-fir and hardwood species associated with the California Floristic Province (tanoak, Pacific madrone, black oak, giant chinquapin) increase toward the southern end of the OCR. On the eastern side of the Coast Ranges crest, habitats tend to be drier and dominated by Douglas-fir. Root pathogens like laminated root rot (*P. weirii*) are important gap formers, and vine maple among others fills these gaps. Because Douglas-fir dwarf mistletoe is unusual in this region, spotted owl nesting habitat tends to be limited to stands providing very large trees with cavities or deformities. A few nests are associated with western hemlock dwarf mistletoe. Spotted owl diets are dominated by species associated with mature to late-successional forests (flying squirrels, red tree voles), resulting in similar definitions of habitats used for nesting/roosting and foraging by spotted owls. One significant difference between OCR and NCO is that woodrats comprise an increasing proportion of the diet in the southern portion of the modeling region. This region contains the Tyee and Oregon Coast Range DSAs.

Redwood Coast (RDC): This region consists of the Northern California Coast Ecological Section 263 (McNab and Avers 1994). This region is characterized by low-lying terrain (0 to 900 m.) with a maritime climate; generally mesic conditions and moderate temperatures. Climatic conditions are rarely limiting to spotted owls at all elevations. Forest communities are dominated by redwood, Douglas-fir-tanoak forest, coast liveoak, and tanoak series. The vast majority of the region is in private ownership, dominated by a few large industrial timberland holdings. The results of numerous studies of spotted owl habitat relationships suggest stump-sprouting and rapid growth rates of redwoods, combined with high availability of woodrats in patchy, intensively-managed forests, enables spotted owls to maintain high densities in a wide range of habitat conditions within the Redwood zone. This modeling region contains the Green Diamond and Marin DSAs.

Western Cascades North (WCN): This region generally coincides with the northern Western Cascades Section M242B (McNab and Avers 1994), combined with western portion of M242D (Northern Cascades Section), extending from the U.S. - Canadian border south to Snoqualmie Pass in central Washington. It is similar to the Northern Cascades Province of Franklin and Dyrness (1974). This region is characterized by high mountainous terrain with extensive areas of glaciers and snowfields at higher elevation. The marine climate brings high precipitation (both annual and summer) but is modified by high elevations and low temperatures over much of this modeling region. The resulting distribution of forest vegetation is dominated by subalpine species, mountain hemlock and silver fir; the western hemlock and Douglas-fir forests typically used by spotted owls are more limited to lower elevations and river valleys (spotted owls are rarely found at elevations greater than 1,280 m. in this region) grading into the mesic Puget lowland to the west. Root pathogens like laminated root rot (*P. weirii*) are important gap formers, and vine maple, among others, fills these gaps. Because Douglas-fir dwarf mistletoe occurs rarely in this region, spotted owl nests sites are limited to defects in large trees, and occasionally nests of other raptors. Diets of spotted owls in this northern region contain higher proportions of red-backed voles and deer mice than in the region to the south, where flying squirrels are dominant (expert panels). There are no Demographic Study Areas in this modeling region.

Western Cascades Central (WCC): This region consists of the midsection of the Western Cascades Section M242B (McNab and Avers 1994), extending from Snoqualmie Pass in central Washington south to the Columbia River. It is similar to the Southern Washington Cascades Province of Franklin and Dyrness (1974). We separated this region from the northern section based on differences is spotted owl habitat due to relatively milder temperatures, lower elevations, and greater proportion of western hemlock/Douglas-fir forest and occurrence of noble fir to the south of Snoqualmie Pass. Because Douglas-fir dwarf mistletoe occurs rarely in this region, spotted owl nest sites are largely limited to defects in large trees, and occasionally nests of other raptors. This region contains the Rainier DSA and small portions of the Wenatchee and Cle Elum DSAs.

Western Cascades South (WCS): This region consists of the southern portion of the Western Cascades Section M242B (McNab and Avers 1994) and extends from the Columbia River south to the North Umpqua River. We separated this region from the northern section due to its relatively milder temperatures, reduced summer precipitation due to the influence of the Willamette Valley to the west, lower elevations, and greater proportion of western hemlock/Douglas-fir forest. The southern portion of this region exhibits a gradient between Douglas-fir/western hemlock and increasing Klamath-like vegetation (mixed conifer/evergreen hardwoods) which continues across the Umpqua divide area. The southern boundary of this region is novel and reflects a transition to mixed conifer sensu Franklin and Dyrness (1974). The importance of Douglas-fir dwarf mistletoe increases to the south in this region, but most spotted owl nest sites in defective large trees, and occasionally nests of other raptors. The HJ Andrews DSA occurs within this modeling region.

Eastern Cascades North (ECN): This region consists of the eastern slopes of the Cascade range, extending from the Canadian border south to the Deschutes National Forest near Bend, OR. Terrain in portions of this region is glaciated and steeply dissected. This region is characterized by a continental climate (cold, snowy winters and dry summers) and a high-frequency/low-mixed severity fire regime. Increased precipitation from marine air passing east through Snoqualmie Pass and the Columbia River results in extensions of moist forest conditions into this region (Hessburg *et al.* 2000b). Forest composition, particularly the presence of grand fir and western larch, distinguishes this modeling region from the southern section of the eastern Cascades. While ponderosa pine forest dominates lower and middle elevations in both this and the southern section, the northern section supports grand fir and Douglas fir habitat at middle elevations. Dwarf mistletoe provides an important component of nesting habitat, enabling spotted owls to nest within stands of relatively younger, small trees. This modeling region contains the Wenatchee and Cle Elum DSAs.

Eastern Cascades South (ECS): This region incorporates the Southern Cascades Ecological Section M261D (McNab and Avers 1994) and the eastern slopes of the Cascades from the Crescent Ranger District of the Deschutes National Forest south to the Shasta area. Topography is gentler and less dissected than the glaciated northern section of the eastern Cascades. A large expanse of recent volcanic soils (pumice region: Franklin and Dyrness 1974), large areas of lodgepole pine, and increasing presence of red fir and white fir (and decreasing grand fir) along a south-trending gradient further supported separation of this region from the northern portion of the eastern Cascades. This region is characterized by a continental climate (cold, snowy winters and dry summers) and a high-frequency/low-mixed severity fire regime. Ponderosa pine is a dominant forest type at mid-to lower elevations, with a narrow band of Douglas-fir and white fir at middle elevations providing the majority of spotted owl habitat. Dwarf mistletoe provides an important component of nesting habitat, enabling spotted owls to nest within stands of relatively younger, smaller trees.

The Warm Springs DSA and eastern half of the South Cascades DSA occur in this modeling region.

Western Klamath Region (KLW): This region consists of the western portion of the Klamath Mountains Ecological Section M261A (McNab and Avers 1994). A long north-south trending system of mountains (particularly South Fork Mountain) creates a rainshadow effect that separates this region from more mesic conditions to the west. This region is characterized by very high climatic and vegetative diversity resulting from steep gradients of elevation, dissected topography, and the influence of marine air (relatively high potential precipitation). These conditions support a highly diverse mix of mesic forest communities such as Pacific Douglas-fir, Douglas-fir tanoak, and mixed evergreen forest interspersed with more xeric forest types. Overall, the distribution of tanoak is a dominant factor distinguishing the Western Klamath Region. Douglas-fir dwarf mistletoe is uncommon and seldom used for nesting platforms by spotted owls. The prey base of spotted owls within the Western Klamath is diverse, but dominated by woodrats and flying squirrels. This region contains the Willow Creek, Hoopa, and the western half of the Oregon Klamath DSAs.

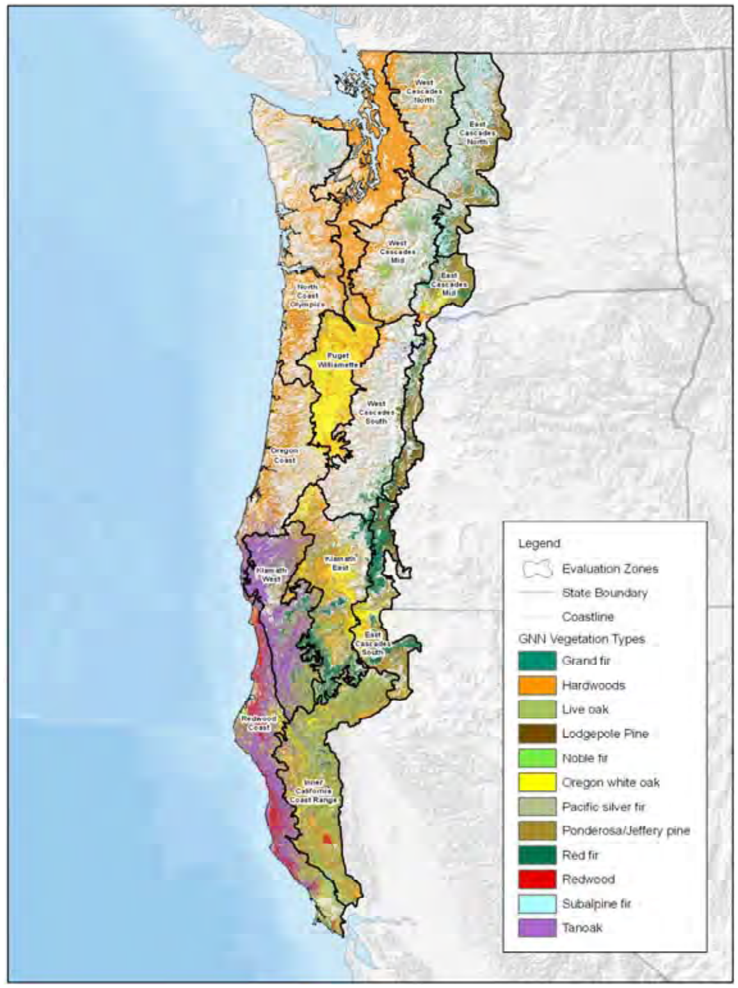
Eastern Klamath Region (KLE): This composite region consists of the eastern portion of the Klamath Mountains Ecological Section M261A (McNab and Avers 1994) and portions of the Southern Cascades Ecological Section M261D in Oregon. This region is characterized by a Mediterranean climate, greatly reduced influence of marine air, and steep, dissected terrain. Franklin and Dyrness (1974) differentiate the mixed conifer forest occurring on the "Cascade side of the Klamath from the more mesic mixed evergreen forests on the western portion (Siskiyou Mountains), and Kuchler (1977) separates out the eastern Klamath based on increased occurrence of ponderosa pine. The mixed conifer/evergreen hardwood forest types typical of the Klamath region extend into the southern Cascades in the vicinity of Roseburg and the North Umpqua River, where they grade into the western hemlock forest typical of the Cascades. High summer temperatures and a mosaic of open forest conditions and Oregon white oak woodlands act to influence spotted owl distribution in this region. Spotted owls occur at elevations up to 1,768 m. Dwarf mistletoe provides an important component of nesting habitat, enabling spotted owls to nest within stands of relatively younger, small trees. The western half of the South Cascades DSA and the eastern half of the Klamath DSA are located within this modeling region.

Northern California Interior Coast Ranges Region (ICC): This region consists of the Northern California Coast Ranges ecological Section M261B (McNab and Avers 1994), and differs markedly from the adjacent redwood coast region. Marine air moderates winter climate, but precipitation is limited by rainshadow effects from steep elevational gradients (100 to 2,400 m.) along a series of north-south trending mountain ridges. Due to the influence of the adjacent Central Valley, summer temperatures in the interior portions of this region are among the highest within the spotted owl's range. Forest communities tend to be relatively dry mixed conifer, blue and Oregon white oak, and the Douglas-fir-tanoak series. Spotted owl habitat within this region is poorly known; there are no DSAs and few studies have been conducted here. Spotted owl habitat data obtained during this project suggests that some spotted owls occupy steep canyons dominated by liveoak and Douglas-fir; the distribution of dense conifer habitats is limited to higher-elevations on the Mendocino National Forest.

Figure C-2. Modeling regions used in development of relative habitat suitability models for the spotted owl.

Modeling Regions

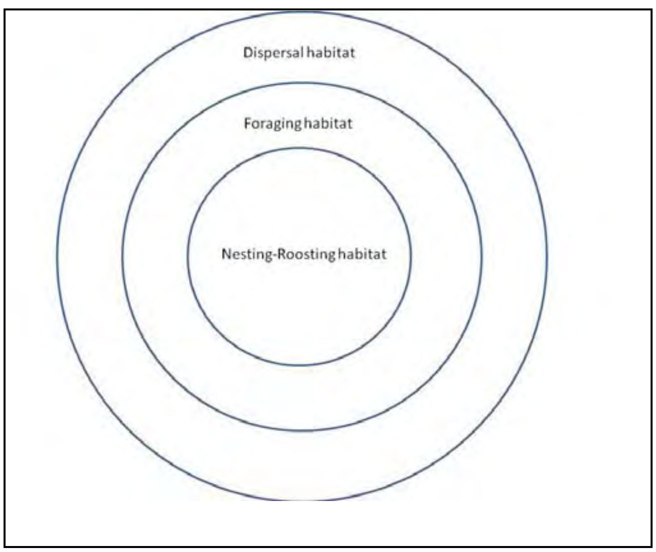
CODE	Description
NCO	North Coast and Olympic
OCR	Oregon Coast
RDC	Redwood Coast
WCN	Western Cascades - North
WCC	Western Cascades - Central
WCS	Western Cascades - South
ECN	Eastern Cascades - North
ECS	Eastern Cascades - South
KLW	Klamath-Siskiyou - West
KLE	Klamath-Siskiyou - East
ICC	Interior California Coast



Habitat Modeling Process

Because spotted owl habitat use is influenced by factors occurring at different spatial scales, we developed habitat suitability models in two stages. In the first stage we used information from our literature review and experts to develop a series of alternative models of forest conditions corresponding to nesting-roosting habitat and foraging habitat within each modeling region. We used statistical modeling to test the effectiveness of these models and identify the forest structural models that best predicted the relative likelihood of a spotted owl territory being present. Spotted owl habitat is often subdivided into distinct components including: nesting habitat, roosting habitat, foraging habitat, and dispersal habitat. Habitats used for nesting and roosting are very similar, and so we combined them into nesting-roosting. Such areas are used for nesting, roosting, foraging, and dispersal by spotted owls, and are usually forests with more late-seral forest characteristics than "foraging" or "dispersal" habitat. Foraging habitat is thought to be largely used for foraging and other nocturnal activities, but also for dispersal (USFWS 1992; see Figure C3). Dispersal habitat is thought to largely have value for dispersal, to lack nest/roost sites and to provide few foraging opportunities. These categories are not absolutes, but instead represent generalizations (*e.g.*, one should not infer that spotted owls never roost in "foraging" habitat). That said, it is important to understand that

Figure C-3. Venn diagram of relationships among spotted owl nesting-roosting, foraging, and dispersal habitats.



nesting-roosting habitat is generally considered to provide all or most habitat requirements, whereas foraging and dispersal habitats are considered to provide only a subset of the spotted owl's habitat requirements. For this effort, we attempted to accurately model the suitability of breeding habitat for spotted owls. Thus, we evaluated and modeled nesting-roosting and foraging habitat, but not dispersal habitat. While we recognized that dispersal plays an important role in population performance, we elected not to formally model dispersal habitat. This is because relatively little is known about habitat selection during dispersal and, more importantly, the likely influences of habitat conditions on dispersal success. The influence of habitat on dispersal and population performance is treated within the HexSim portion of the modeling framework (see Overview of HexSim Spotted Owl Scenario, page C-56).

Spatial scale for developing and evaluating models:

To determine the spatial scale at which to develop habitat models, the modeling team sought a uniform analysis area size that generally corresponded to large differences between use and availability. Spotted owls have been found to respond to habitats at a variety of spatial scales (Solis and Gutiérrez 1990, Meyer *et al.* 1998, Franklin *et al*. 2000, Swindle *et al.* 1999, Thome *et al*. 1999, Zabel *et al.* 2003). Spotted owls do not build their own nests, but primarily utilize broken-top snags, tree cavities, dwarf mistletoe witch's brooms, or nests made by other species (Gutiérrez *et al.* 1995). Spotted owl habitat selection in the immediate vicinity of the nest (tens of meters around the nest tree) has been found to be strongly non-random, and largely associated with late-seral forest characteristics (Solis and Gutiérrez 1990, Meyer *et al.* 1998, Swindle *et al.* 1999). Areas at this small spatial scale are necessary, but often not sufficient to be selected by spotted owls because areas at larger spatial scales around the nest-site must contain attributes that also contribute to their survival and reproductive success (*e.g.*, Franklin *et al*. 2000, Olson *et al.* 2004, Dugger *et al.* 2005).

Ripple *et al.* (1991), Carey *et al.* (1992), Hunter *et al.* (1995), Thome *et al.* (1999), Meyer *et al*. (1998), and Zabel *et al.* (2003) all evaluated spotted owl habitat selection at a variety of spatial scales beyond the nest site itself. Spatial scales evaluated in these studies were based on the distribution of radio telemetry locations, presumed territorial behavior (nearest-neighbor distances), or various 'nested rings'. All studies found differences between spotted owl-centered (nest or activity center) locations and random or unoccupied locations across the range of spatial scales examined. However, the largest differences were often found in areas approximately the size of what Bingham and Noon (1997) defined as "core areas" (areas of the home range that received disproportionately more use than would be expected). An area of 158 to 200-ha has been used to describe/define spotted owl 'territory core areas', in western Oregon and the Klamath region (Hunter *et al.* 1995, Meyer *et al.* 1998, Franklin *et al*. 2000, Zabel *et al*. 2003, Olson *et al.* 2004, and Dugger *et al.* 2005). In northwestern Oregon, Glenn *et al.* (2005) found mean cumulative core areas to be 94 ha (SE = 14.9; n = 24). For the northern portion of the range we found little information directly comparable to the abovementioned studies, but estimated home range and core areas sizes and nearest-neighbor distances are larger in the extreme northern portion of the spotted owl's range (Forsman *et al*. 2005, Hamer *et al.* 2007, Davis and Dugger in press). Based on this review, we felt a 200-ha analysis area represented an area that is disproportionately used (more than expected) surrounding nest sites. We deal explicitly with geographic variation in home range size in HexSim (see below).

Data Used for Model Development and Testing

Vegetation data – the GNN-LT Database:

To develop rangewide models of relative habitat suitability for spotted owls, we required maps of forest composition and structure of sufficient accuracy to allow discrimination of attributes used for nesting, roosting and foraging by spotted owls. Past efforts to model, map and quantify habitat selection by spotted owls at regional scales have often suffered from lack of important vegetation variables, inadequate spatial coverage, and/or coarse resolution of available vegetation databases (Davis and Lint 2005). However, recent development of vegetation mapping products for the NWFP's Effectiveness Monitoring program (Hemstrom *et al*. 1998, Lint *et al.* 1999) provided detailed maps of forest composition and structural attributes for all lands within the NWFP area (coextensive with the range of the spotted owl). These maps were developed using Gradient Nearest Neighbor (GNN) imputation (Ohmann and Gregory 2002) and LandTrendr algorithms (Kennedy *et al.* 2007, 2010) and were available for two "bookend" dates (1996 and 2006 in Oregon and Washington, 1994 and 2007 in California).

The GNN approach is a method for predictive vegetation mapping that uses direct gradient analysis and nearest-neighbor imputation to ascribe detailed attributes of vegetation to each pixel in a digital landscape map (Ohmann and Gregory 2002). Forest attributes from inventory plots (Forest Inventory and Analysis, Current Vegetation Surveys, etc.) are imputed to map pixels based on modeled relationships between plots and predictor variables from Landsat thematic mapper imagery, climatic variables, topographic variables, and soil parent materials. The assumption behind GNN methods is that two locations with similar combined spatial "signatures" should also have similar forest structure and composition. The GNN models were developed for habitat modeling regions used for the NWFP northern spotted owl effectiveness monitoring modeling (Davis and Dugger in press). For the NWFP Effectiveness Monitoring program, GNN maps were created for the two bookend time periods mentioned above to 'frame' their analysis period for habitat status and trends. This novel bookend mapping approach presents challenges associated with spectral differences due to different satellite image dates, which might produce false vegetation changes. To minimize the potential for this, the bookend models were based on Landsat imagery that was geometrically rectified and radiometrically normalized using the LandTrendr process (Kennedy *et al.* 2007, 2010).

The large list of forest species composition and structure variables provided by GNN vegetation maps constitute an improvement in vegetation data for modeling and evaluating spotted owl habitat. For our modeling, we selected from a set of 163 variables, including basal area and tree density by size class and species, canopy cover of conifers and/or hardwoods, stand height, age, mean diameter and quadratic mean diameter by dominance class, stand density index, and measures of snags and coarse woody debris. Additional variables pertaining to stand structural diversity and variability proved particularly useful for modeling spotted owl habitat.

The reliability or accuracy of vegetation databases poses a primary concern for wildlife habitat evaluation and modeling. The GNN maps come with a large suite of diagnostics detailing map quality and accuracy; these are contained in model region-specific accuracy assessment reports available at the LEMMA website (http://www.fsl.orst.edu/lemma/). For developing *a priori* models of spotted owl nesting/roosting habitat and foraging habitat, we generally selected GNN structural variables with plot correlation coefficients > 0.5 for an individual modeling region (42% were >0.7). On a few occasions when expert opinion or research results suggested a particular variable might be important, we used variables with plot correlations from 0.31 to 0.5 (Table C-1). For species composition variables, we attempted to use only variables with Kappas > 0.3. However, because we combined species variables into groups that expert opinion and research results suggested may represent influential community types, we occasionally accepted variables with Kappas > 0.2 and < 0.3 for individual variables within a group (Table C-2).

The GNN vegetation database was specifically developed for mid- to large-scale spatial analysis (Ohmann and Gregory 2002), suggesting that accuracies at the 30-m pixel scale may be less influential to results obtained at larger scales. Because we were interested in the utility of GNN at our analysis area (200 ha) spatial scale, we conducted less formal assessments where we compared the distribution of GNN variable values at a large sample of actual locations (known spotted owl nest sites and foraging sites) to published estimates of those variables at the same scale. In addition, we received comparisons of GNN maps to a number of local plot-based vegetation maps prepared by various field personnel. Based on these informal evaluations, we determined that GNN represents a dramatic improvement over past vegetation databases used for modeling and evaluating spotted owl habitat, and used the GNN-LandTrendr maps as the vegetation data for our habitat modeling.

Table C-1. Pearson correlation coefficients for GNN structural variables used in modeling relative habitat suitability models for spotted owls.

Variable	Modeling region												
	ECN	ECS	ICC	KLE	KLW	NCO	ORC	RDC	WCC	WCN	WCS	AVG	STD
BAA_75_100			0.42									0.49	0.09
BAA_GE_100			0.37									0.46	0.12
BAA_GE_3	0.75					0.71			0.71	0.71		0.70	0.06
BAC_50_75								0.46				0.45	0.06
BAC_75_100								0.31				0.50	0.09
BAC_GE_100								0.57				0.47	0.12
BAC_GE_3					0.65							0.73	0.06
BAH_3_25			0.50									0.50	0.07
BAH_PROP					0.67							0.66	0.03
CANCOV	0.76	0.80	0.71	0.71	0.71			0.70	0.74	0.74	0.80	0.74	0.04
CANCOV_CON				0.67			0.73					0.74	0.07
DDI	0.65	0.73	0.65	0.65	0.65	0.77	0.74		0.77	0.77	0.73	0.69	0.08
QMDC_DOM	0.44	0.64	0.52	0.52	0.52						0.64	0.59	0.11
TPH_50_75				0.35			0.52		0.44	0.44		0.42	0.06
TPH_75_100		0.52		0.41		0.56	0.58		0.56	0.56	0.52	0.48	0.09
TPH_GE_100		0.48		0.45		0.57	0.63		0.57	0.57	0.48	0.49	0.10
TPHC_GE_100									0.57	0.57		0.50	0.10

Table C-2. Local scale accuracy assessments (kappa coefficients) for individual species variables within stand species composition variable groupings used in applicable modeling regions. N/A = variable not in best models for modeling region.

	GNN DOM SPP	Common Name	East Cascades North	East Cascades South	Inner California Coast Ranges	Klamath East	Klamath West	North Coast Olympics	Oregon Coast	Redwood Coast	West Cascades Central	West Cascades North	West Cascades South	Average Kappa
Evergreen hardwoods	ARME	Pacific madrone	n/a	n/a	0.43	n/a	0.43	n/a	0.49	n/a	n/a	n/a	n/a	0.45
	LIDE3	tanoak	n/a	n/a	0.58	n/a	0.58	n/a	0.72	n/a	n/a	n/a	n/a	0.63
	QUCH2	canyon live oak	n/a	n/a	0.35	n/a	0.35	n/a	0.46	n/a	n/a	n/a	n/a	0.39
	UMCA	California laurel	n/a	n/a	0.29	n/a	0.29	n/a	0.43	n/a	n/a	n/a	n/a	0.34
Northern Hardwoods	ACMA3	bigleaf maple	n/a	n/a	n/a	n/a	n/a	0.41	0.30	n/a	0.41	0.41	n/a	0.38
	ALRU2	red alder	n/a	n/a	n/a	n/a	n/a	0.44	0.33	n/a	0.44	0.44	n/a	0.41
Oak woodlands	QUDO	blue oak	n/a	n/a	0.68	0.68	0.68	n/a	n/a	0.41	n/a	n/a	n/a	0.62
	QUGA4	Oregon white oak	n/a	n/a	0.35	0.35	0.35	n/a	n/a	0.34	n/a	n/a	0.52	0.38
Pines	PICO	lodgepole pine	0.26	0.57	0.28	0.28	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.35
	PIJE	Jeffrey pine	n/a	0.27	0.28	0.28	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.28
	PIMU	Bishop pine	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	
	PIPO	ponderosa pine	0.62	0.58	0.34	0.34	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.47
Douglas-fir	PSME	Douglas-fir	0.47	0.65	n/a	0.31	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.48
Subalpine	ABAM	Pacific silver fir	0.66	0.59	n/a	n/a	n/a	0.53	n/a	n/a	0.53	0.53	0.59	0.57
	ABLA	subalpine fir	0.58	0.39	n/a	n/a	n/a	0.48	n/a	n/a	0.48	0.48	0.39	0.47
	ABMA	California red fir	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	
	ABPR	noble fir	0.29	n/a	n/a	n/a	n/a	0.32	n/a	n/a	0.32	0.32	n/a	0.31
	ABSH	Shasta red fir	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	
	CHNO	Alaska cedar	0.29	0.19	n/a	n/a	n/a	0.28	n/a	n/a	0.28	0.28	0.19	0.25
Redwood	SESE3	redwood	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.59	n/a	n/a	n/a	0.59

Spotted owl location data:

Spotted owl data used in model development consisted of site center locations documented within three years (plus or minus) of the date of the GNN vegetation data. Site centers are the location of spotted owl nests or daytime roosts containing paired spotted owls. Site center data for the habitat suitability modeling was made available through the cooperation of a variety of sources throughout the spotted owl's range. Data come from long-term demographic studies as well as locations from other research projects, public, private, and tribal sources.

Substantial effort was expended on verification of both the spatial accuracy and territory status of each site center in the data set. We specifically requested and received very high-quality data from spotted owl demography study areas (DSAs). For areas outside of DSAs, we obtained a large set of additional locations from NWFP Effectiveness Monitoring program (Davis and Dugger in press); the majority of these site centers had been evaluated for spatial accuracy. We also obtained and verified data sets from private timber companies, USFS Region 5 NRIS database and a number of research and monitoring projects across the species' range.

Because of the spatial extent of our analysis area (>23 million ha), we do not have the luxury of having equal survey effort throughout the region. Instead we have data from research studies, monitoring of demographic rates, management efforts, and other sources. While spotted owl demographic study areas have been intensively and extensively studied for long periods of time (see Anthony *et al.* 2006 and Forsman *et al.* 2011) and provide the highest- quality data sets, they comprise ~12% of the spotted owl's geographic range (based on our masked modeling regions). As importantly, for some modeling regions the proportion of total area and/or spotted owl locations within DSAs is very low. Given the DSAs represent nearly the only areas within the spotted owl's range that have consistently been surveyed over long periods of time and that they represent a smaller portion of the species' geographic range, the data from them (at the scale of a modeling region) is generally spatially aggregated. Spotted owl site location data from the DSAs represent a much smaller portion of the spotted owl's range than the full data set we used (Table C-3), and the larger data set represents more fully the spectrum or gradient of biotic and abiotic features that spotted owls select for nesting and roosting. For example, the total number of spotted owl site locations inside DSAs was 1,199, and when thinned by 3 km was 755. In contrast, the total number of site locations outside of DSAs was 2,591, and when thinned was 2,110. With our 200-ha analysis area, if we would have sampled from only the DSAs we would have sampled ~151,000 ha around thinned DSA sites versus the 573,000 ha sampled around all thinned sites.

Table C-3. Comparison of area and spotted owl location data within modeling regions and demographic study areas (DSAs).

Modeling Region	Acronym	Percentage of Region in DSA	Number of NSO Sites in DSA	Number of NSO Sites Outside DSA
ALL MODELING REGIONS	ALL	12.34%	1199	2591
North Coast Olympics	NCO	7.29%	166	79
Oregon Coast	ORC	30.88%	352	102
East Cascades South	ECS	20.49%	78	45
East Cascades North	ECN	23.45%	132	84
West Cascades North	WCN	0.92%	3	77
West Cascades Central	WCC	19.21%	57	157
West Cascades South	WCS	6.58%	57	435
Klamath East	KLE	10.31%	98	374
Klamath West	KLW	15.24%	127	335
Inner California Coast Ranges	ICC	0.75%	8	300
Redwood Coast	RDC	10.23%	121	603

Outside of DSAs, the quantity and density of site center data varies widely. While we have attempted to compile a large sample of site centers that is broadly representative of the entire distribution of spotted owls, the overall distribution of sample sites is somewhat clumped. Areas with few nest locations are a result of: 1) few surveys being conducted, 2) the absence of spotted owls, or 3) data being unavailable. We did not want the modeling results to be a function of the intensity of spotted owl sampling throughout the region, but to be as close of an approximation as possible of spotted owl-habitat relationships. Phillips *et al*. (2009) noted that spatially biased survey data present major challenges to distributional modeling by over-weighting areas where intensive sampling has occurred. Therefore, within each modeling region we “thinned” the spotted owl nest locations such that the minimum distance between nest locations would be 3.0 km (thinning with a 3 km distance resulted in removing ~25% of the locations available to us). Carroll *et al.* (2010) used a similar approach in their modeling of other species whereby clusters of records were identified and one record from the cluster was randomly selected from the set. Using a 3 km thinning distance retained 75% of the total data, and did not have a large effect on those modeling regions with small initial sample sizes (<100) of site center locations (Table C4).

Table C-4. Sample size of spotted owl site center locations (1993-1999) by modeling region and the impact of various thinning distances (minimum allowable distance between site centers) on sample size.

		Thinning Distance					
Modeling Region	**Total Sites**	**1 km**	**1.5 km**	**2 km**	**2.5 km**	**3 km**	**4 KM**
NCO	241	236	229	221	209	196	162
OCR	454	430	414	371	325	281	202
RDC	724	716	670	547	461	392	284
WCN	80	80	79	78	77	77	74
WCC	214	211	205	195	182	173	144
WCS	489	489	487	482	477	470	342
ECN	216	215	209	203	195	184	155
ECS	123	122	119	112	104	93	67
KLW	462	460	454	440	414	358	275
KLE	472	468	463	455	434	381	285
ICC	308	308	307	300	286	253	199
Total	**3783**	**3735**	**3636**	**3404**	**3164**	**2858**	**2189**
Percentage of total	**100**	**98.7**	**96.1**	**90.0**	**83.6**	**75.5**	**57.9**

Due to the increased influence of the barred owl on spotted owls, we followed, in part, the modeling approach used by Davis and Dugger (in press) to reduce the influence of barred owls on apparent habitat associations of spotted owls. For our effort, we wanted our models to identify areas with more or less nesting suitability for spotted owls. Because barred owls have apparently displaced many spotted owls from previously-occupied nesting areas, sometimes into habitat types/conditions that spotted owls only rarely used prior to the barred owl's invasion (Gremel 2005, Gutiérrez *et al.* 2007), we did not want to evaluate their "displaced habitat use", but instead their use of habitat without the larger, current impact of barred owls. Although barred owls were known to be widely distributed in the northern portion of the spotted owl's range in 1996, Gremel (pers. comm. 2010) suggested barred owl densities were substantially lower in 1996 than in 2006. Pearson and Livezey (2003) reported that barred owls had increased by an average of 8.6% per year between 1982 and 2000 on parts of the Gifford Pinchot National Forest (GPNF), Washington. Subsequently, Livezey *et al.* (2007) reported that the 98 known barred owl sites on the GPNF in 2001 had increased to 143 sites in 2006. Thus, in an attempt to reduce the influence of barred owls on spotted owl habitat use, we developed and tested models using GNN vegetation data from 1996 (assumed to be the period with lower barred owl influence) along with spotted owl location information plus or minus three years from 1996. Those models were then projected to the most current (2006) GNN layer to predict contemporary relative habitat suitability (RHS). Each region's model was then tested by comparing with RHS values at independent sites from the 2006 spotted owl locations (only those that did not overlap with the 1996 locations).

Developing Habitat Definitions:

Nesting and roosting habitat

Prior to developing models, we attempted to synthesize both the literature and information from experts. From the literature, we emphasized studies evaluating habitat selection over those that described habitat features (associations) around spotted owl locations, but did not evaluate selection. This synthesis resulted in the development of a series of definitions of spotted owl nesting-roosting and foraging habitat. For example, several published studies concluded that nesting spotted owls strongly select for areas with canopy cover >70% and many large trees nearby and strongly select against areas with lower amounts of canopy cover and few or no large trees nearby. We therefore created definition "NR_1" (nesting-roosting definition number 1) based on canopy cover and density of large trees (*e.g.*, trees >75 cm dbh). Because experts and/or other published studies typically supported several (i) alternative NR definitions, we created roughly ten alternative NR habitat definitions (NR_2, NR_3, NR_i, etc.) per modeling region. We used an identical process to develop a series of foraging (F) habitat definitions for each modeling region (Tables C5 and C6 provide an example of this process). It is important to recognize that these habitat definitions are binary for each pixel; either the pixel contained each of the features in the definition (and was therefore considered habitat), or it did not (it was considered non-habitat).

Table C-5. Spotted owl nesting-roosting habitat variables for the northern Coast Ranges and Olympic Peninsula.

Habitat characteristics from expert panel, literature	GNN Variable expression
Canopy cover of conifers is ≥ than 80%	CANCOV_CON_GE_80
Mean stand diameter is ≥ than 50cm	MNDBHBA_CON_GE_50
Structure should include ≥ 70 medium trees/ha	TPH_GE_50_GE_70
Structure should include ≥ 20 larger trees/ha	TPH_GE_75_GE_20
Very large remnant trees are important (≥5/ha)	TPH_GE_100_GE_5
Canopy layering/diversity is important	DDI_GE_6 *

*DDI = Diameter Diversity Index (ranges from 1-10)

Table C-6. Sample definitions of spotted owl nesting-roosting habitat based on variables and values from Table 5.

	Candidate nesting/roosting habitat definitions
NR_1	CANCOV_CON_GE_80 + MNDBHBA_CON_GE_50 + DDI_GE6
NR_2	CANCOV_CON_GE_80 + MNDBHBA_CON_GE_50 + TPH_GE_75_GE_20 + TPH_GE_100_GE_5 + DDI_GE_6
NR_3	CANCOV_CON_GE_80 + TPH_GE_50_GE_70 + TPH_GE_75_GE_20 + TPH_GE_100_GE_5 + DDI_GE_6
NR_4	CANCOV_CON_GE_70 + MNDBHBA_CON_GE_50 + TPH_GE_75_GE_20 + DDI_GE_5

Foraging habitat

Foraging habitat definitions were informed by published and unpublished literature and input from experts. In this process, foraging habitat was, by definition, different than nesting-roosting habitat. This is not to suggest that spotted owls do not forage in nesting-roosting habitat, but for the sake of being explicit in this process, foraging habitat was distinct from nesting-roosting habitat. In general, foraging habitat definitions had lower thresholds of canopy cover, tree size, and canopy layering than nesting-roosting definitions (Tables C7 and C8 provide an example of this process).

Table C-7. Spotted owl foraging habitat variables for the northern Coast Ranges and Olympic Peninsula.

Habitat characteristics from expert panel, literature	GNN Variable expression
Canopy cover of conifers is ≥ than 70%	CANCOV_CON_GE_70
Mean stand diameter is ≥ than 40 cm	MNDBHBA_CON_GE_40
Structure should include ≥ 50 medium trees/ha	TPH_GE_50_GE_50
Structure should include ≥ 8 larger trees/ha	TPH_GE_75_GE_8
Canopy layering/diversity is important	DDI_GE_4 *

*DDI = Diameter Diversity Index (ranges from 1-10)

Table C-8. Sample definitions of spotted owl foraging habitat based on variables and values from Table C7.

	Candidate nesting/roosting habitat definitions
F_1	CANCOV_CON_GE_70 + MNDBHBA_CON_GE_40 + DDI_GE_4
F_2	CANCOV_CON_GE_70 + MNDBHBA_CON_GE_40 + TPH_GE_75_GE_8 + DDI_GE_6
F_3	CANCOV_CON_GE_70 + TPH_GE_50_GE_50 + TPH_GE_75_GE_8 + DDI_GE_4
F_4	CANCOV_CON_GE_60 + MNDBHBA_CON_GE_40 + TPH_GE_75_GE_8 + DDI_GE_4

Because attributes of habitat such as amount of edge and core area have been shown to influence both habitat selection and fitness (Franklin *et al.* 2000) of spotted owls, we also included NR "core" and "edge" metrics.

Abiotic variables

Because published literature and information from experts suggested that abiotic features might be important in determining spotted owl habitat use and selection, we evaluated a series of abiotic features known or suspected to influence spotted owl habitat selection and use (Table C9). Numerous studies have shown that local geographic features such as slope position, aspect, distance to water, and elevation have been found to influence spotted owl site selection (Stalberg *et al.* 2009, Clark 2007). Several authors (Blakesley *et al.* 1992, Hershey *et al.* 1998, LaHaye and Gutiérrez 1999) have noted the absence of spotted owls above particular elevational limits (whether this limit is due to forest structure, prey, competitors, parasites, diseases, and/or extremes of temperature or precipitation is not known). At broader scales, temporal variation in climate has been shown to be related to fitness (Franklin *et al.* 2000, Olson *et al.* 2004, Dugger *et al.* 2005, Glenn *et al.* 2010), suggesting that spatial variation in climate may also influence habitat suitability for spotted owls. Ganey *et al.* (1993) found that Mexican spotted owls (*S. o. lucida*) have a narrow thermal neutral zone and others (*e.g.*, Franklin *et al*. 2000) have assumed the northern spotted owl to be similar in this regard. Furthermore, the spotted owl's selection for areas with older-forest characteristics has been hypothesized to, in part, be related to its needing cooler areas in summer to avoid heat stress (Barrows and Barrows 1978). Temperature extremes (winter low and summer high) as well as potential breeding-season specific stressors (spring low temperature and high spring precipitation) are also considered potentially useful predictor variables for our purposes (Carroll 2010, Glenn *et al.* 2010). By including climate variables as candidate variables in our habitat suitability modeling, we evaluated whether climate effects on spotted owl fitness are translated into patterns of the species' distribution.

Developing models:

MaxEnt compares the characteristics (variables included in the models) of the training data sites to a random selection of ~10,000 random "background" (available) locations. We only used the linear, quadratic, and threshold features within MaxEnt (*i.e.,* hinge and product features were not used).

We used the following model-building and evaluation process within each modeling region

1) Each nesting-roosting habitat definition is a single-variable model. Thus, if we developed 10 nesting-roosting habitat definitions for a region, we compared 10 nesting-roosting habitat models for that region. We used MaxEnt to determine the best nesting-roosting habitat definition within each region (see model evaluation, below).
2) Within each modeling region that has foraging habitat definitions, we combined the best nesting-roosting habitat definition(s) with each foraging habitat definition to evaluate whether the addition of foraging habitat improved model performance. Models were considered to have been improved if the addition of foraging habitat increases the ranking of the model. If the addition of foraging habitat improved the model's performance, we used the nesting-roosting + foraging habitat model for step 3 (below). If not, we used the best nesting-roosting model(s) for step 3.
3) For abiotic variables, we developed univariate or multivariate models using the variables in Table C9. Carroll (2010) found that mean January precipitation, mean July precipitation, mean January temperature, and mean July temperature were the variables in the best, of 30, climate models he evaluated. He found the two precipitation metrics were the most influential of the four. Franklin *et al.* (2000) also found climate variables to influence spotted owl survival and reproduction. We included three climate models: 1) the four variables Carroll (2010) reported, 2) mean January precipitation and mean July precipitation, 3) mean January precipitation and mean January temperature. We "challenged" the best model(s) after step 2 by adding each abiotic model to it (*sensu* Dunk *et al.* 2004), in an attempt to improve its predictive ability. The abiotic models were not compared to each other, but were compared in order to see if their addition to the best biotic (nesting-roosting or nesting-roosting + foraging) model resulted in an improved model (see step 2). If the biotic plus abiotic model was an improvement over the biotic-only model, we used the combination model, otherwise we used the biotic-only model. The reason abiotic-only models were not evaluated is that it is illogical to suggest that spotted owls (a species that nests in trees) might only respond to abiotic factors when selecting nesting areas. In contrast, we could develop a logical biological argument that spotted owls might respond only to biotic features when selecting nesting areas. We could also develop logical biological arguments

articulating how a combination of biotic and abiotic factors might influence the selection of nesting areas.

Model-building hierarchy

The spatial distribution of spotted owl territories is influenced by a wide variety of environmental gradients operating at different spatial scales. At the smallest scale we evaluated, features such as the amount of nesting-roosting and/or foraging habitat within a core area, the amount of edge between spotted owl habitat and non-habitat, or amount of "core habitat" (*sensu* Franklin *et al*. 2000) have all be shown to influence spotted owl distribution, abundance, or fitness. Each of those variables, however, is a structural variable. That is, they are based on habitats comprised of various structural elements (*e.g.*, large trees, high canopy cover). However important and influential these variables are to spotted owls, other variables such as plant species composition (broadly speaking), topographic position, climate, and/or elevation are also likely to influence their distribution, abundance, and perhaps fitness (Franklin *et al.* 2000, Olson *et al*. 2004, Dugger *et al.* 2005, Glenn 2009).

In part, the partitioning of the spotted owl's geographic range into 11 modeling regions should act to reduce the influence of broad patterns in plant species composition, climate and/or elevation on the species. Nonetheless, we were interested in evaluating whether habitat suitability is influenced by local variation in these non-structural variables.

Stand structure and the spatial arrangement of forest patches have been found to influence spotted owl fitness (Franklin *et al*. 2000, Olson *et al*. 2004, Dugger *et al*. 2005). Edge between nesting-roosting habitat and other habitat types is thought to afford foraging spotted owl opportunities when habitats, but which are rarely used, are juxtaposed closely with habitats spotted owls use. "Core" habitat includes those areas of spotted owl nesting habitat not subjected to edge-effects. Franklin *et al*. (2000) estimated core habitat by buffering all spotted owl habitat (largely mature forest areas) by 100 m and estimating the size of the habitat excluding the 100 m buffer.

Spotted owl experts noted that mid-scale or landscape level patterns such as tree species composition and topography may also influence the local distribution and density of spotted owls. For example, within many of the modeling regions, there exists variation in tree species composition, but forests with different species compositions may still have similar structural attributes (*e.g.*, high canopy cover, multi-storied, large trees). Some forest types (regardless of their structural attributes) are rarely, if ever, used by spotted owls, so we attempted to account for this variation by evaluating models that include some compositional variables.

Many of our 11 modeling regions contain high-elevation areas above the elevational extremes normally used by spotted owls. In some higher elevation areas there exist structurally complex, multi-storied forests with large trees – areas with similar structural characteristics to those used by spotted owls.

However, spotted owls rarely if ever use such areas. Our intention was to attempt to account for this in our modeling.

We recognize the hierarchical nature of these environmental factors and their possible influence on spotted owl distribution. Our model building approach took this into consideration, by starting at the smallest scale and sequentially "challenging" models with variables from larger spatial scales. In order to focus on environmental features most directly linked to territory location, habitat selection, and individual fitness of spotted owls, we employed a bottom-up approach to building models (Table C9).

Table C-9. Categories of candidate variables, variable names, and order of the entry of variables into modeling process.

Category	Variable	Order
Best climate/elevation model	Mean July Precipitation	↑
	Mean July Temperature	
	Mean July Precipitation	
	Mean July Temperature	
	Mean Elevation	
Topographic position	Curvature	
	Insolation	
	Slope Position	
Compositional variables (percent of basal area)	Redwood	
	Oak Woodland	
	Pine-dominated	
	Northern Deciduous Hardwoods	
	Evergreen Hardwoods	
	Douglas-fir	
	Subalpine forest	
Habitat pattern	Core of NR habitat	
	Edge of NR habitat	
Habitat structure	Foraging Habitat Amount	
	Nesting/Roosting Habitat	

Goals of MaxEnt Modeling:

Our goals for the relative habitat suitability models were to find models that: 1) had good discriminatory ability, 2) were well calibrated, 3) were robust, and 4) had good generality. We sought models that were not over-fit, the consequences of which would be to have models that fit the developmental data very closely, but which would not have worked well on data that were not used in their development. That is we sought models with good generality (*i.e.*, models that worked well in the modeling regions in general, not simply at classifying the developmental/training data). MaxEnt attempts to balance model fit and complexity through the use of regularization (see Elith *et al.* 2011). Elith *et al.* (2011) noted that MaxEnt fits a penalized maximum likelihood model, closely related to other penalties for complexity such as Akaike's Information Criterion (AIC, Akaike 1974). In order to evaluate whether any model region's model was over-fit we conducted rigorous cross-validation on each model (see below), and, when available we evaluated how well models classified independent data (see below).

Model discrimination

Once the best model was found for each region, we conducted a cross-validation of each model to evaluate how robust the model was. Each of 10 times we removed a random subset of 25% of the spotted owl locations, developed the model with the remaining 75% and classified using the withheld 25%. The area under the receiver operating characteristic curve (AUC) was evaluated for both training and test data within each region. AUC is a measure of a model's discrimination ability; in our case discrimination between spotted owl-presence locations and available locations (not discrimination of presence versus absence locations). AUC values, theoretically, range between 0 and 1.0, with values less than 0.5 having worse discriminatory ability than expected by chance, values closer to 0.5 suggesting no to poor discriminatory ability, and values closer to 1.0 suggesting excellent discriminatory ability.

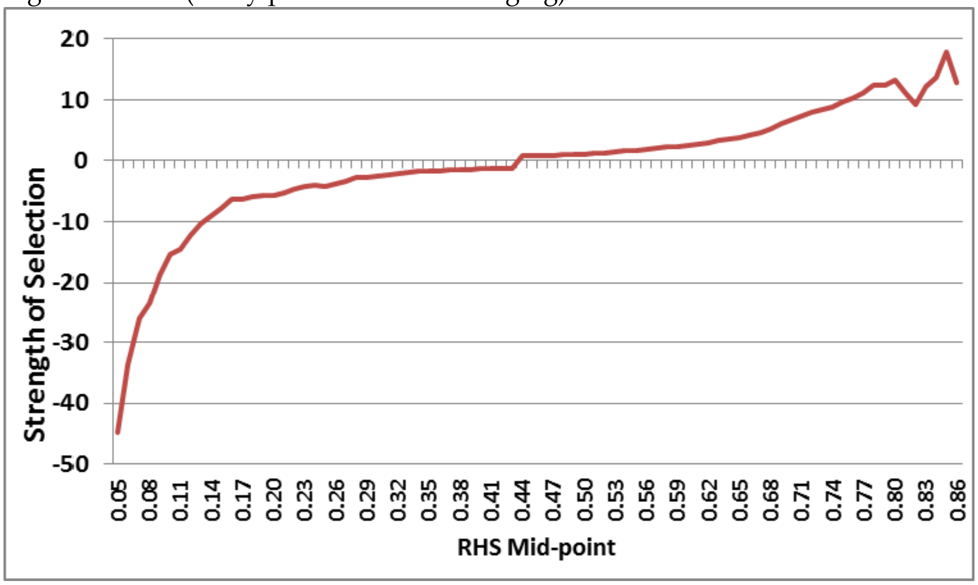
For these analyses, AUC values essentially describe the proportion of times one could expect a random selection of an actual spotted owl nest site location to have a larger relative habitat suitability value than a random selection from available locations. It is therefore a threshold-independent measure of model discriminatory ability. Because our evaluation represents use versus availability and not use versus non-use, AUC values have an upper limit somewhat less than 1.0 (because some of the available locations are actually used by spotted owls). Even for good (well-discriminating) models, AUC values should be lower in areas where the background areas contain larger amounts of suitable habitat. Two contrasting examples are provided to make this point: 1) a model estimating a riparian-dependent bird species' distribution in the Great Basin may have a very high AUC value because there is large contrast between riparian vegetation where the bird nests and the vast majority of background locations in sage-steppe, vs. 2) a model estimating the distribution of a generalist omnivore (like a black-bear) in a national forest may have a lower AUC because so much of the background habitat is suitable for the species. The point is that AUC is a measure of discrimination, but that a use-versus-availability model's ability to discriminate is a function of both the animal's habitat specificity and the abundance of the animal's habitat in the region of interest. To evaluate the degree to which AUC values from each modeling region's MaxEnt model were related to the abundance of suitable habitat we regressed AUC values against the proportion of each modeling region comprised of RHS values >30, >40, and >50 (the SOS values for all modeling regions showed selection for areas within this range – see Figure C-5 below). If the abundance of suitable habitat is high in areas with lower AUC values, and lower in areas with higher AUC values, the interpretation would be that the abundance of suitable habitat, not model discrimination ability, best explains this relationship.

In order to evaluate the degree to which AUC values were a function of the amount of suitable habitat in modeling regions, and thus help us interpret whether somewhat lower AUC values represented poor models versus a larger amount of suitable habitat in the modeling region, we evaluated the correlation between AUC values and the percentage of each modeling region with RHS scores above various thresholds corresponding to RHS values showing higher use than expected (see Model Calibration section below).

Model Calibration

To assess model calibration we evaluated the agreement between RHS and observed proportions of sites occupied. Phillips and Elith (2010) noted that model discrimination and model calibration are independent measures. Model calibration refers to the agreement between predicted probabilities of occurrence (habitat suitability for our study) and observed proportions of sites occupied (Pearce and Ferrier 2000, Phillips and Elith 2010). Phillips and Elith (2010) note that model discrimination and model calibration are independent measures. Hirzel *et al.* (2006) (whose work Phillips and Elith [2010] expand upon), developed "strength of selection" metrics for species distribution models using a moving-window approach. Strength of selection (SOS) evaluations allow for an understanding of the use that areas with various habitat suitability values receive (by nesting spotted owls in our case) relative to the abundance of such areas in the study area (see Figure C4 below). Essentially, a well-calibrated model will show the species to use higher suitability areas disproportionately more and lower suitability areas disproportionately less. The shape of the relationship provides insights into the degree to which the species avoids or is attracted to areas with particular habitat suitability values.

Figure C-4. This *example* of the strength of selection (SOS) evaluation shows a well-calibrated model. Areas with a mid-point RHS (*i.e.*, relative habitat suitability value) of 0.05 (the moving window size here was 0.1) were used ~45-times *less* than would be expected based on its extent in the study area. Similarly, areas with a mid-point RHS of 0.8 (window of 0.75-0.85) were used ~12-times *more* than expected based on its extent in the study area. This figure was developed from a model trained on >3,000 spotted owl night locations (many presumed to be foraging).



Habitat Modeling Results:

The following section provides summary descriptions of the final "best" models for each modeling region; including information on the relative contribution of each covariate to the model, model evaluation metrics, and the results of validation against independent data sets conducted to date. Because the primary objective of this habitat modeling step was to provide accurate prediction of relative habitat suitability and subsequent likelihood of spotted owl occupancy, we focus on presenting evaluation of model performance, rather than description of spotted owl habitat associations. Tables and table series C10 to C17 provide descriptions of the best nesting-roosting habitat model, foraging habitat model, and full model for each modeling region, as well as model evaluation metrics (AUC and Gain) and the relative contribution of each variable to the full model (a heuristic estimate provided in the standard output from MaxEnt). AUC values were highly correlated with the percentage of each modeling region comprised of RHS values >30, >40, and >50 (r^2 = 0.9685, 0.9649, 0.9574, respectively). Hence, variation in AUC values among modeling regions (which ranged from 0.76 – 0.93) has less to do with model discrimination ability (*i.e.*, the quality of the model) and more to do with the quantity of suitably habitat in each modeling region.

See Table C18 for codes and descriptions of variables used in the models.

Table Series C-10. Highest-ranking (best) Nesting/Roosting habitat (NR), foraging habitat (F), and full models for coastal Washington, Oregon and California modeling regions.

North Coast and Olympics Modeling Region (N= 196 training sites):

Model		**AUC**	**GAIN**
NR06	DDI (≥6) + TPH ≥ (>25/ha) + BAA GE3 (≥ 55 m²/ha)	0.8365	0.7667
F04	MNDBHBA_CON (≥40); TPH_GE75 (≥10)	0.8619	0.8817
Full Model	NR06 + NR06EDGE + F04 + SLOPE POSITION+ ELEVATION + CURVATURE + SUBALPINE FOREST+JULY MAX TEMP+JANUARY PRECIP + JULY PRECP + INSOLATION + JANUARY MIN TEMP + NORTHERN HARDWOODS	0.8989	1.057

Oregon Coast Ranges Modeling Region (N = 281training sites)

Model		**AUC**	**GAIN**
NR08	CANCOV_CON (≥55) + DDI (≥6) + TPH_GE75 (≥20)	0.7683	0.4498
F04	DDI (≥4) + TPH_GE50 (≥30)	0.7787	0.467
Full Model	NR08 + NR08 EDGE + SLOPE POSITION + JULY MAX TEMP + JANUARY MIN TEMP + F04 + CURVATURE + INSOLATION + JULY PRECIP + JANUARY PRECIP + ELEVATION + NR08 CORE + NORTHERN HARDWOODS + EVERGREEN HARDWOODS	0.864	0.811

Redwood Coast Modeling Region (N = 389 training sites)

Model		**AUC**	**GAIN**
NR03	CANCOV (≥70) + MNDBHBA_CON (≥44)	0.5928	0.0509
F05	CANCOV (≥65) + BAC_GE50 (≥3)	0.6256	0.0785
Full Model	SLOPE POSITION + CURVATURE + NR03 EDGE + F05 + NR03 + REDWOOD + ELEVATION + JANUARY PRECIP + OAK WOODLAND + JULY MAX TEMP + INSOLATION + JANUARY MIN TEMP + NR03 CORE + JULY PRECIP	0.760	0.335

Table C-11. Individual covariates and their contribution to full model.

North Coast / Olympics		Oregon Coast Ranges		Redwood Coast	
Full Model	**%**	**Full Model**	**%**	**Full Model**	**%**
NR 06	42.4	NR 08	29.4	Slope Position	48.2
NR06Edge	21.5	NR08 Edge	24.2	Curvature	11.2
NR06+F04	20.1	Slope position	11.9	NR03 Edge	10.3
Slope position	6.0	July Max Temp	10.1	NR03 + F05	6.1
Elevation	3.6	Jan Min Temp	8	NR 03	5.7
Curvature	1.8	NR08 + F04	5.5	Redwood (%BA)	4.8
Subalpine	1.1	Curvature	4.1	Elevation	4.1
July Max Temp.	0.9	Insolation	3.1	January Precip	3.2
Jan Precip.	0.9	July Precip	1.5	Oak Woodland	2.6
July Precip.	0.8	Jan Precip	1.3	July Max Temp	1.3
Insolation	0.6	Elevation	0.4	Insolation	0.9
Jan Min Temp	0.3	NR08 Core	0.2	Jan Min Temp	0.7
Northern Hdwd	0.1	Northern Hdwd	0.2	NR03 Core	0.7
		Evergreen Hdwd	0.1	July precip	0.4

Table Series C-12. Nesting/Roosting habitat, foraging habitat, and full models for Western Cascades modeling regions.

Western Cascades Modeling Region (Northern Section) (N = 76 training sites)

Model		AUC	GAIN
NR05	CANCOV (≥80) + MNDBHBA_CON (≥60) + TPHC_GE100 (≥7)	0.8377	0.7555
F01	CANCOV (≥70); DDI (≥5); TPH_GE50 (≥42); BAA_GE3 (≥40)	0.8417	0.7698
Full Model	NR05 EDGE + NR05 + SLOPE POSITION + CURVATURE + ELEVATION + JANUARY PRECIP + NORTHERN HARDWOODS + JULY MAX TEMP + SUBALPINE FOREST + INSOLATION + JULY PRECIP + F01 + JANUARY MIN TEMP + NR05 CORE	0.931	1.393

Western Cascades Modeling Region (Central Section) (N = 171 training sites)

Model		AUC	GAIN
NR09	TPH_GE50 (≥ 64) + TPH_GE75 (≥ 16) + TPHC_GE100 (≥ 4)	0.7965	0.5825
F01	CANCOV (≥70) + DDI (≥4) + TPH_GE50 (≥37) + BAA_GE3 (≥ 37)	0.816	0.6575
Full Model	NR09 EDGE + F01 + CURVATURE + ELEVATION + NORTHERN HARDWOODS + SUBALPINE + SLOPE POSITION + JANUARY MIN TEMP + NR09 + JULY PRECIP + JULY MAX TEMP + INSOLATION + NR09 CORE + JANUARY PRECIP	0.892	1.024

Western Cascades Modeling Region (Southern Section) (N = 470 training sites)

Model		AUC	GAIN
NR02	CANCOV (≥ 70) + MNDBHBA_CON (≥ 50) + TPH_GE75 (≥ 22)	**0.6877**	**0.2343**
F01	CANCOV (≥ 60) + DDI (≥ 4) + QMDC_DOM (≥ 37)	**0.6931**	**0.2385**
Full Model	NR02 + SLOPE POSITION + CURVATURE + F01 + JANUARY MIN TEMP + NORTHERN HARDWOODS + INSOLATION + JULY PRECIP + JANUARY PRECIP + JULY MAX TEMP + ELEVATION	**0.762**	**0.355**

Table C-13. Individual covariates and their contribution to full model.

Western Cascades North		**Western Cascades Mid**		**Western Cascades South**	
Full Model	%	**Full Model**	%	**Full Model**	%
NR05 Edge	34.4	NR09 Edge	44.8	NR 02	62.9
NR 05	17.2	NR09 + F01	13.9	Slope Position	17.8
Slope Position	13.0	Curvature	8.5	Curvature	4.7
Curvature	12.6	Elevation	7.6	NR02 + F01	3.9
Elevation	8.0	Northern Hdwd	7.4	Jan Min Temp	3.9
Jan Precip	4.3	Subalpine	4.2	Northern Hdwd	1.9
Northern Hdwd	3.7	Slope Position	4.1	Insolation	1.5
July Max Temp	2.2	Jan Min Temp	2.4	July Precip	1.5
Subalpine	1.4	NR 09	1.8	January Precip	0.9
Insolation	0.9	July Precip	1.5	July Max Temp	0.5
July Precip	0.9	July Max Temp	1.4	Elevation	0.5
NR05 + F01	0.8	Insolation	1.0		
Jan Min Temp	0.5	NR09 Core	0.7		
NR05 Core	0.2	Jan Precip	0.7		
NR05 Edge	34.4				

Table Series C-14: Nesting/Roosting habitat, foraging habitat, and full models for Eastern Cascades modeling regions.

Eastern Cascades Modeling Region (Northern Section) (n = 182 training sites)

Model		AUC	GAIN
NR06	CANCOV (≥ 70) + DDI (≥ 5) + MNDBHBA_CON (≥ 42)	0.685	0.2263
F03	CANCOV (≥52) + QMDC_DOM (≥30) + BAA_GE3 (≥23)	0.7347	0.3114
Full Model	NR06 + SLOPE POSITION + DOUGLAS-FIR + JANUARY MIN TEMP + ELEVATION + F03 + NR06 EDGE + JULY MAX TEMP + SUBALPINE FOREST + JANUARY PRECIP + CURVATURE + INSOLATION + JULY PRECIP + PINE	0.879	0.843

Eastern Cascades Modeling Region (Southern Section) (N = training sites)

Model		AUC	GAIN
NR07	CANCOV (≥ 70) + MNDBHBA_CON (≥ 45) + TPH_GE75 (≥ 9)	0.7263	0.2912
F03	MNDBHBA_CON(≥ 38) + DDI(≥ 4) + QMDC_DOM(≥ 32)	0.7868	0.4797
Full Model	(F03 + NR07) + NR07 + NR07 EDGE + PINE + DOUGLAS-FIR + JANUARY MIN TEMP + ELEVATION + SLOPE POSITION + NR07 CORE + JULY MAX TEMP + INSOLATION + JANUARY PRECIP + CURVATURE + SUBALPINE FOREST + JULY PRECIP	0.889	0.957

Table C-15. Individual covariates and their contribution to full model.

Eastern Cascades South		**Eastern Cascades North**	
Full Model	**%**	**Full Model**	**%**
NR07 + F03	18.4	NR06	20
NR 07	13.9	Slope Position	14.6
NR07 Edge	11.7	Douglas-fir	13.6
Pine	10.7	Jan Min Temp	10.6
Douglas-fir	10.7	Elevation	8.3
Jan Min Temp	9.5	NR06 + F03	6.8
Elevation	5.4	NR06 Edge	5.7
Slope Position	4.6	July Max Temp	4.1
NR07 Core	4.5	Subalpine	4.0
July Max Temp	3.3	January Precip	3.3
Insolation	3.2	Curvature	2.9
January Precip	1.6	Insolation	2.7
Curvature	1.5	July Precip	2.1
Subalpine	0.6	Pine	1.5
July Precip	0.4		

Table Series C-16. Nesting/Roosting habitat, foraging habitat, and full models for Klamath-Siskiyou Mountains and Interior California modeling regions.

Western Klamath Mountains (N = 357 training sites)

Model		AUC	GAIN
NR01	CANCOV (≥75) + DDI (≥6) + QMDC_DOM (≥50)	0.6608	0.1677
F03	DDI (≥4) + BAH_PROP (0.25 - 0.70) + BAC_GE3 (≥18)	0.6751	0.1886
Full Model	SLOPE POSITION + NR01 EDGE + NR01 + CURVATURE + JANUARY PRECIP + JULY PRECIP + NR01 CORE + JANUARY MIN TEMP + ELEVATION + INSOLATION + JULY MAX TEMP + F03 + OAK WOODLAND + EVERGREEN HARDWOODS	0.769	0.396

Eastern Klamath Mountains Modeling Region (N = 378 training sites)

Model		AUC	GAIN
NR01	CANCOV (≥65) + DDI (≥5.5) + QMDC_DOM (≥42)	0.7052	0.2601
F05	CANCOV_CON (≥45) + TPH_GE50 (≥23) + QMDC_DOM (≥30)	0.7075	0.2613
Full Model	NR01 + SLOPE POSITION+ DOUGLAS-FIR+ ELEVATION + NR01 EDGE + INSOLATION + JAN PRECIP+ F05 + CURVATURE + JULY MAX TEMP+ JAN MIN TEMP+ NR01 CORE + OAK WOODLAND+ PINE + SUBALPINE	0.830	0.605

Interior California Coast Ranges (N = 251 training sites)

Model		AUC	GAIN
NR02	CANCOV (≥65) + MNDBHBA_CON (≥46) + BAA_GE ≥75)	0.7136	0.2975
F04	DDI (≥3.5) + QMDC_DOM (≥30) + BAH_3_25 (≥5)	0.7296	0.3286
Full Model	NR02 + NR02 EDGE + SLOPE POSITION + JULY MAX TEMP + CURVATURE + F04 + NR02 CORE + JULY PRECIP + JAN PRECIP + INSOLATION + JAN MIN TEMP + EVERGRN HDWD + PINE +OAK WOODLAND + ELEVATION	0.820	0.540

Table C-17. Individual covariates and their contribution to full model.

Western Klamath		**Eastern Klamath**		**Interior CA Coast Ranges**	
Full Model	%	**Full Model**	%	**Full Model**	%
Slope Position	33.0	NR01	28.3	NR02	29.9
NR01 Edge	32.2	Slope Position	24.6	NR02 Edge	19.8
NR01	10.9	Douglas-fir	12.1	Slope Position	12.4
Curvature	6.6	Elevation	9.2	July Max Temp	11.1
January Precip	6.1	NR01 Edge	6.8	Curvature	5.6
July Precip	4.4	Insolation	5.4	NR02 + F04	4.9
NR01 Core	1.6	Jan Precip	4.9	NR02 Core	3.3
Jan Min Temp	1.3	NR01 + F05	3.3	July Precip	2.6
Elevation	1.1	Curvature	2.2	Jan. Precip	2.4
Insolation	1.0	July Max Temp	1.2	Insolation	2.0
July Max Temp	0.8	Jan Min Temp	0.8	Jan. Min Temp	1.8
NR01 + F03	0.5	NR01 Core	0.5	Evergrn Hdwd	1.7
Oak Woodland	0.2	Oak Woodland	0.2	Pine	1.3
Evergrn Hrdwd	0.2	Pine	0.2	Oak Woodland	0.7
		Subalpine	0.1	Elevation	0.5

Table C-18. Codes and descriptions of stand structural variables from GNN and compositional variables used in relative habitat suitability models.

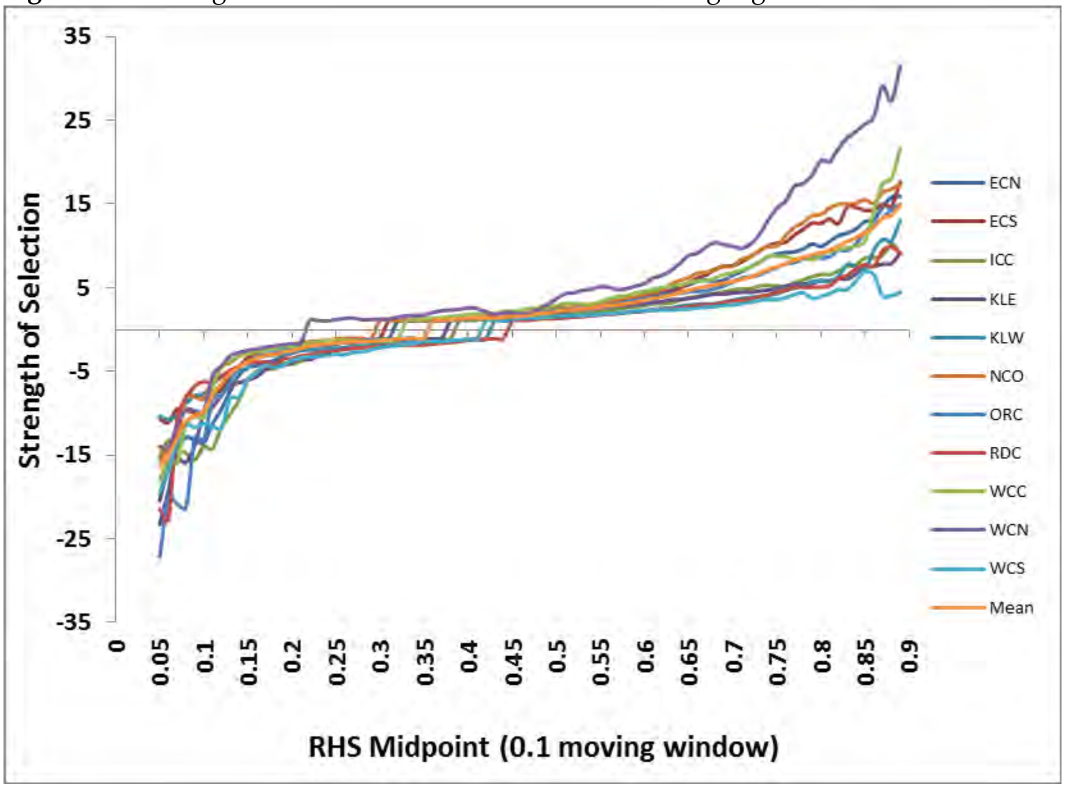
Variable	Definition
CANCOV	Canopy cover of all live trees
CANCOV_CON	Canopy cover of all conifers
DDI	Diameter diversity index (structural diversity within a stand, based on tree densities within different DBH classes)
SDDBH	Standard deviation of DBH of all live trees
MNDBHBA_CON	Basal area weighted mean diameter of all live conifers
TPH_GE_50	Live trees per hectare greater than or equal to 50 cm DBH
TPHC_GE_50	Conifers per hectare greater than or equal to 50 cm DBH
TPH_GE_75	Live trees per hectare greater than or equal to 75 cm DBH
TPHC_GE_75	Conifers per hectare greater than or equal to 75 cm DBH
TPHC_GE_100	Conifers per hectare greater than or equal to 100 cm DBH
QMDC_DOM	Quadratic mean diameter of all dominant and co-dominant conifers
BAA_GE_3	Basal area of all live trees greater than or equal to 2.5 cm DBH
BAA_3_25	Basal area of all live trees 2.5 to 25 cm DBH
BAA_GE_75	Basal area of all live trees greater than or equal to 75 cm DBH
BAC_GE_3	Basal area of conifers greater than or equal to 2.5 cm DBH
BAC_GE_50	Basal area of conifers greater than or equal to 50 cm DBH
BAH_PROP	Proportion of BAA_GE_3 that is hardwood
BAH_3_25	Basal area of all live hardwoods 2.5 to 25 cm DBH
Compositional Variables	
Evergreen Hardwoods	Basal area of tanoak, canyon, coast and interior live oaks, giant chinquapin, California bay and Pacific madrone
Subalpine	Basal area of silver fir, mountain hemlock, subalpine fir, red fir, Englemann spruce,
Pine	Basal area of ponderosa pine, Jeffrey pine, lodgepole pine, and Bishop pine
Northern Hardwoods	Basal area of red alder and bigleaf maple
Oak Woodland	Oregon white oak and blue oak

Results of Model Evaluation and Testing:

<u>Strength of selection results</u>

We plotted the observed use that areas with various RHS values receive (by nesting spotted owls in our case) relative to the abundance of such areas in each modeling region. Figure C5 shows the SOS curves for all 11 modeling regions. Although the degree of calibration varies among modeling regions, the RHS models are generally well-calibrated, with strong selection for areas of RHS > 0.6 to 0.7, and avoidance of RHS <0.15 to 0.25.

Figure C-5. Strength of Selection evaluation for all modeling regions.



Results of Model Cross-Validation

Overall, each modeling region's model proved to be fairly robust, and thus gave us confidence in the model's generality. When we evaluated the differences in the percentages of spotted owl sites classified among 10 equally-sized RHS bins between the full model (using all of the spotted owl locations – thinned by 3 km) and the cross-validated (CV) models (*i.e.*, the 25% of observations that were withheld from the developmental model, each of 10-times for each modeling region) there were generally very small differences (Table C19). The maximum percentage point difference (percentage of observations from the full model minus percentage of observations CV model) was 11.1 (see Table C19). The mean difference of the absolute values among modeling regions ranged from 1.6 (for the Klamath West) to 4.5 (for the West Cascades North). Absolute values were used for calculating means because without doing so, the positive and negative values within a modeling region will always have a mean of 0, and thus don't accurately represent overall differences between full and cross-validated models. There was an inverse (negative logarithmic) relationship between sample size of spotted owl sites and mean difference in absolute value ($r^2 = 0.537$, $P = 0.01$). Nonetheless, the magnitude of differences was generally quite low. For example, 39% of the differences were <2.0, 81% of the differences were <5.0, and only 7% of the differences were >7.0 (absolute value in each case). These findings suggest that none of the modeling region's full models were over-fit, and that all full models have good generality.

Table C-19. Results from cross-validation tests, showing absolute values of differences (% classified by full model - % classified in cross-validated model) among modeling regions.

	Absolute value of differences										
Po Bin	**ECN**	**ECS**	**ICC**	**KLE**	**KLW**	**NCO**	**ORC**	**RDC**	**WCC**	**WCN**	**WCS**
0-0.099	5.2	4.8	3.9	3.0	0.9	5.2	3.3	1.9	7.9	11.1	1.7
0.1-0.199	4.4	4.6	6.1	1.1	5.0	0.2	3.3	3.1	1.9	4.2	1.7
0.2-0.299	3.3	1.0	3.1	4.6	1.4	1.1	0.2	1.4	4.0	3.4	2.6
0.3-0.399	2.8	4.5	0.9	3.7	2.8	0.5	3.0	3.5	0.9	1.3	2.6
0.4-0.499	2.8	7.9	2.5	2.4	0.0	4.5	0.7	5.2	3.7	1.3	0.8
0.5-0.599	3.1	1.0	3.6	4.4	0.8	0.1	6.2	6.1	4.4	4.5	5.5
0.6-0.699	5.2	3.1	7.0	7.3	0.3	1.4	1.9	3.3	9.9	5.3	8.1
0.7-0.799	3.5	9.7	3.4	0.6	4.0	10.2	3.4	6.8	1.7	5.8	2.9
0.8-0.899	1.5	2.5	2.1	1.0	1.1	0.2	2.0	2.2	4.0	6.8	1.2
0.9-1.0	0.3	2.4	0.4	0.3	0.1	0.8	0.4	0.5	1.0	1.1	0.1
Mean	**3.2**	**4.1**	**3.3**	**2.8**	**1.6**	**2.4**	**2.4**	**3.4**	**3.9**	**4.5**	**2.7**

<u>Results of comparisons with independent data sets</u>

To further evaluate the reliability of the models' predictions, we obtained independent (*i.e.* not used in model development) samples of spotted owl territory locations that represented the period 1993 to 1999 (Test96) and 2003 to 2009 (Test06) and compared their associated RHS values to corresponding values for spotted owl sites used in model development. All test sites were greater than 0.8 km from a training site. Because the RHS models were developed using spotted owl territories from the 1996 time period, comparison with Test96 most directly addresses model accuracy. Comparison with independent spotted owl locations from 2006, however, enabled us to evaluate accuracy of the models when projected to a new time period (model transferability), and to investigate systematic shifts in RHS at spotted owl sites. These shifts may occur, for example, in areas where densities of barred owls have increased during the 1996 to 2006 period, and are displacing spotted owls from favorable habitat. If this is the case (as has been hypothesized), we might expect to see reduced use of RHS area at 2006 spotted owl sites, relative to 1996 values (see Methods: Spotted owl location data).

We obtained adequate (N ≥ 100) test samples for 2006 in four modeling regions. As data for additional modeling regions and Test96 become available, further evaluation of model accuracy should be conducted. Table C20 shows the proportions of spotted owl sites in each of five RHS "bins" for the training data (Train), and Test06. Because they allow comparison of RHS values across a gradient of relative habitat suitability, these comparisons are more informative than binary "correct classification" analyses.

Table C-20. Comparison of percentage of 1996 training sites versus test samples of 2006 spotted owl locations in 5 categories of Relative Habitat Suitability.

	Oregon Coast		**Western Klamath**		**Eastern Klamath**		**Redwood Coast**		**Rangewide**	
	Train	**Test**	**Train**	**Test**	**Train**	**Test**	**Train**	**Test**	**Train**	**Test**
N	247	169	358	136	375	108	392	284	2742	916
RHS bin										
0 – 0.2	7.3	7.1	8.7	2.2	6.1	4.6	4.8	3.2	6.1	4.6
0.2 – 0.4	19.0	23.1	18.2	19.8	14.1	20.4	13.8	12.7	16.5	17.8
0.4 – 0.6	35.6	35.5	38.5	46.3	38.4	39.8	42.1	44.7	36.7	41.8
0.6 – 0.8	32.8	30.2	33.5	30.8	38.7	35.2	37.2	37.7	36.7	33.8
0.8 – 1.0	5.3	4.1	1.1	0.74	2.7	0	2.0	1.8	4.0	1.2

Model evaluation summary:

All modeling regions' models were well calibrated and showed a quite similar pattern in terms of strength of selection (see Figure C5). Cross-validation results by modeling region showed that all models were relatively robust to the 25% iterative reduction in sample size (see Table C19). Lastly, comparison of model results with independent test data showed the models had good ability to predict spotted owl locations (Table C20), and performed well when projected to 2006 vegetation conditions. Overall, these evaluations suggest that our RHS models were robust and have good generality. Subsequently, we used the full dataset models.

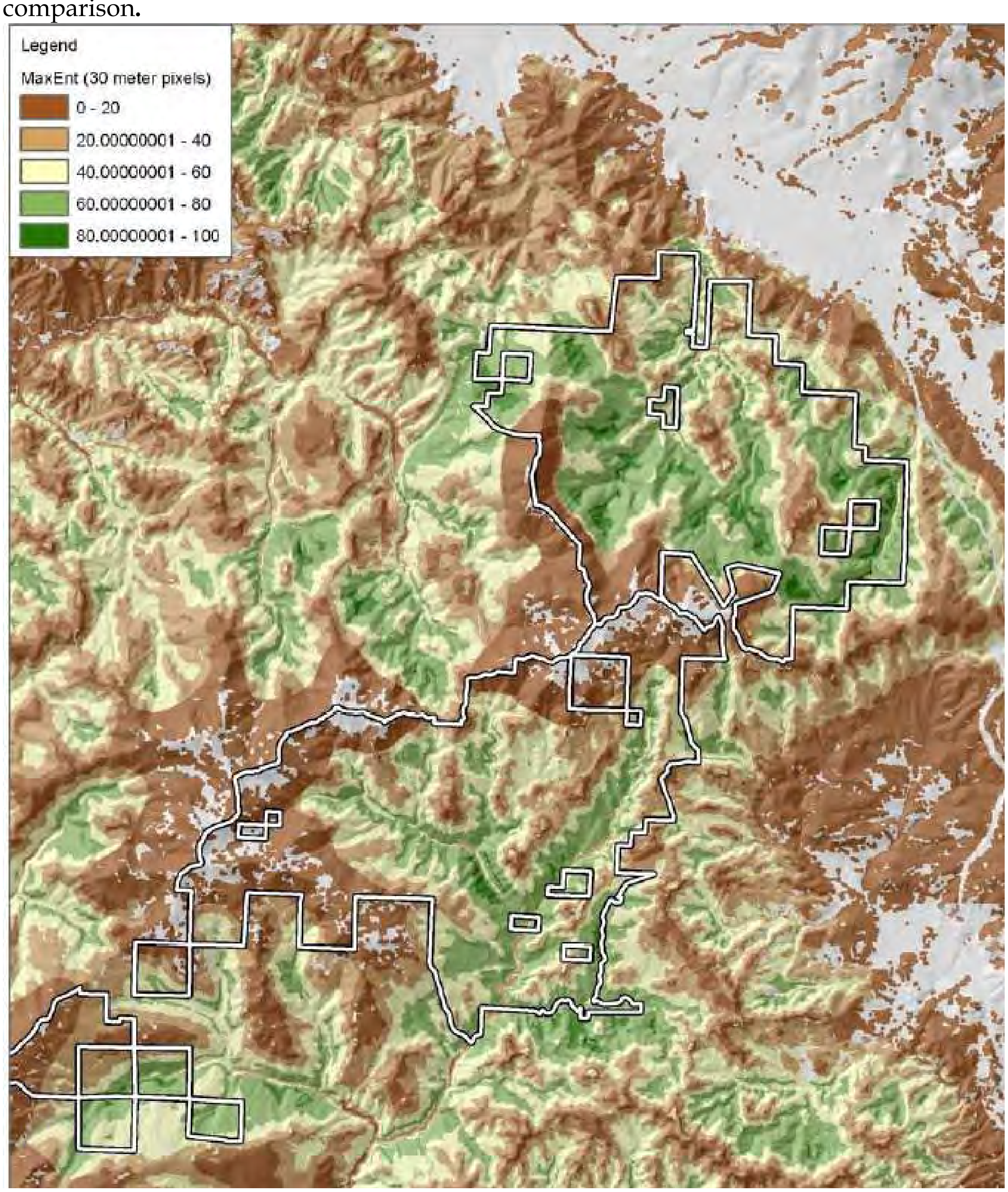
Interpretation of model output:

Elith *et al.* (2011) state that the MaxEnt logistic output is an attempt to estimate the probability that a species is present, given the environment (*i.e.*, the environmental conditions). For our purposes, we have taken a more conservative interpretation of the MaxEnt logistic output and interpret it to represent the relative habitat suitability (RHS) for nesting spotted owls within each modeling region. The map below (Figure C6) is the result of running each modeling region's best RHS model on each 30-m pixel within the region. That is, MaxEnt estimates a RHS value for each pixel based on the biotic and abiotic features within the 200-ha (~800 m radius) area around it (*i.e.*, based only on the variables in the best MaxEnt model for that modeling region). It is important to understand that a high RHS value is possible for a pixel that has little inherent value (*e.g.*, there are no trees in the 30x30 m focal pixel). It may, however, be that the surrounding 200-ha has many of the attributes associated with high RHS. Similarly, a focal pixel could have many of the positive characteristics that spotted owls generally select for, but it receives a low RHS value owing to the surrounding 200-ha having few or none of the attributes associated with high RHS values.

As noted above the RHS map is designed to facilitate and enable a wide variety of processes, discussions and analyses, including section 7 consultation, implementation and evaluation of the efficacy of spotted owl conservation measures such as Recovery Action 10 and management of barred owls. This model likely has utility for a wider variety of uses and processes than we currently envision, and it can be refined by future advances in the understanding of spotted owl habitat associations.

Maps depicting the RHS model outputs for the range of the spotted owl are available at:
http://www.fws.gov/oregonfwo/Species/Data/NorthernSpottedOwl/Recovery/Library/Default.aspx#Files
Once there, click on "maps" and "AppendixCMaps.pdf" The layers can be turned on and off using the "layers" button in the upper left-hand corner. The RHS values are the base layer on this map.

Figure C-6. Map depicting Relative Habitat Suitability from MaxEnt model. Higher suitability habitat conditions are indicated by darker green areas; brown colors denote lower suitability. Outline of the Mount Ashland Late-successional Reserve is shown for comparison**.**



Modeling Process Step 2 – Develop a spotted owl conservation planning model, based on the habitat suitability model developed in Step 1, and use it to design an array of habitat conservation network scenarios.

Because the RHS maps from Step 1 consisted of finely-distributed patterns of habitat suitability across the spotted owl's geographic range, we also wanted to provide a rigorous, repeatable method for aggregating habitat value into habitat conservation networks. We used the conservation planning model "Zonation" (Moilanen and Kujala 2008) to develop a spotted owl conservation planning model which can be used to design an array of habitat conservation network scenarios. To test this model we mapped a series of alternative spotted owl conservation network scenarios based on a series of rule-sets (*e.g.*, varying land ownership categories, the inclusion of existing reserves, identifying a specific amount of "habitat value" to include). The primary output of a Zonation analysis of the landscape is a "hierarchical ranking" of conservation priority of all cells or pixels in the landscape. Zonation allows analysts to incorporate species-specific factors such as dispersal capabilities and response to habitat fragmentation into the ranking of cells, and also allows the inclusion of factors such as land ownership and status into various evaluations. It is important to recognize that the maps produced by Zonation represent user-defined scenarios that were evaluated and compared in subsequent population modeling to test this modeling process; they do not represent decisions about the size or distribution of habitat conservation areas. While Zonation uses the term "reserve" to describe the conservation areas it identifies, this term does not dictate the types of management actions that could occur in those areas.

Zonation produces a hierarchical prioritization of the landscape based on the conservation value or "habitat value" of cells. A cell's habitat value is a function of its "base" value (*i.e.*, its RHS value) as well as the value of cells surrounding it. Thus, two cells of identical RHS may have different habitat value depending on how many other high, medium, and low value cells are nearby. The term habitat value therefore incorporates a larger spatial context than does RHS. Hierarchical, in this case, means that the most valuable five percent is also within the most valuable 10 percent; the top two percent is within the top five percent, and so on. Zonation uses minimization of marginal loss as the criterion to decide which cell is removed, and iteratively removes the least valuable cells from the landscape until no cells remain. The order of cell removal and its proportion of the total habitat value are recorded and can later be used to select any top fraction of cells or habitat value, the best 10 percent of cells or the top 10 percent of habitat value, for example, of the landscape.

To ensure that spotted owls and their habitat would be well-distributed throughout their range (one of the goals for recovery), Zonation analyses were conducted separately for each modeling region. This modeling region decision also had the impact of ensuring that conservation areas would be better distributed across the range of the species.

Zonation allows analysts to identify specific areas of the landscape that represent a particular percentage of the total estimated habitat value to the species. An important attribute of the Zonation algorithm is that it attempts to produce "efficient" solutions. That is, it prioritizes cells into units that maximize the habitat value per unit area within the solution (Figure C7). For example, in one Zonation scenario, 70% of the habitat value existed on ~40% of the landscape.

Figure C-7. *Hypothetical* relationship between total size of habitat conservation system (x-axis) and percentage of habitat value "captured" (y-axis). Theoretically, the only way to capture 100% of the habitat value is to have the entire area to be considered reserve (or all areas with value >0). For this example, the entire area is ~ 19 million ha. In this example, a reserve system that is ~4 million ha "captures" ~50% of the habitat value, one that is ~9 million ha captures ~75% of the habitat value, etc.

Because Zonation is spatially explicit, in a GIS environment the user can control several aspects of how the program evaluates the distribution of habitat value. This enables the program to emulate important aspects of the species' life history, landscape pattern of habitat, and desired attributes of a habitat conservation network.

Zonation's **Distribution Smoothing** function is a species-specific aggregation method that retains high-value areas (pixels) that are better-connected to others, resulting in a more compact solution. The user specifies the area or "smoothing kernel" within which Zonation averages or smooths habitat values, based on a two-dimensional habitat density calculation, in accordance with attributes of an organism's movement patterns or abilities, such as home range area. We compared kernel sizes corresponding to the core use area (800 m radius), median home range (2100 m), and median dispersal distance (27.7 km; Forsman *et al.* 2002). The main difference in the resulting solutions from these three different settings is that the results from the kernel estimated from dispersal distance or home range were less fine-grained than the results from the kernel value estimated from a core area. Given that we are estimating habitat conservation network scenarios at relatively large scales, the coarser-grained (home range-derived kernel values) maps provided more discrete areas as estimated networks, and thus we used the home range scale kernel size.

Zonation's **Cell Removal Method** function allows users to control the spatial pattern or "grain" of priority areas by specifying whether cell removal begins around the edges of the analysis area or at cells scattered across the analysis area. The idea behind the "Edge Removal" setting is that it is more likely to result in connectivity of higher-value areas within the more central areas of the landscape. However, because cell removal is limited to the perimeters of large landscapes, the Edge Removal option can result in large blocks containing extensive areas of unsuitable habitat such as interior valleys and high mountain peaks. The "Edge Removal with Add Edge Points" option allows the user to randomly distribute a specified number of edge points where cell removal occurs within large landscapes. This setting allows more flexibility than edge removal and provides a greater chance that interior areas of poor-suitability habitat will be removed from the solution, and results in more finely-grained pattern of priority areas. The "No Edge Removal" option does not predispose Zonation to start cell removal from any particular area or region, but removes the lowest value cells in the landscape first, then the next lowest, and so on. This results in very finely-grained prioritized areas (and very long computer run times). We conducted side-by-side comparisons and found that Add Edge Points and No Edge Removal end up with nearly identical solutions (~95% overlap in identifying the top 25% habitat value areas in the landscape). To develop a series of alternative habitat conservation networks, we selected Add Edge Points, distributing 2,000 edge points into each modeling region.

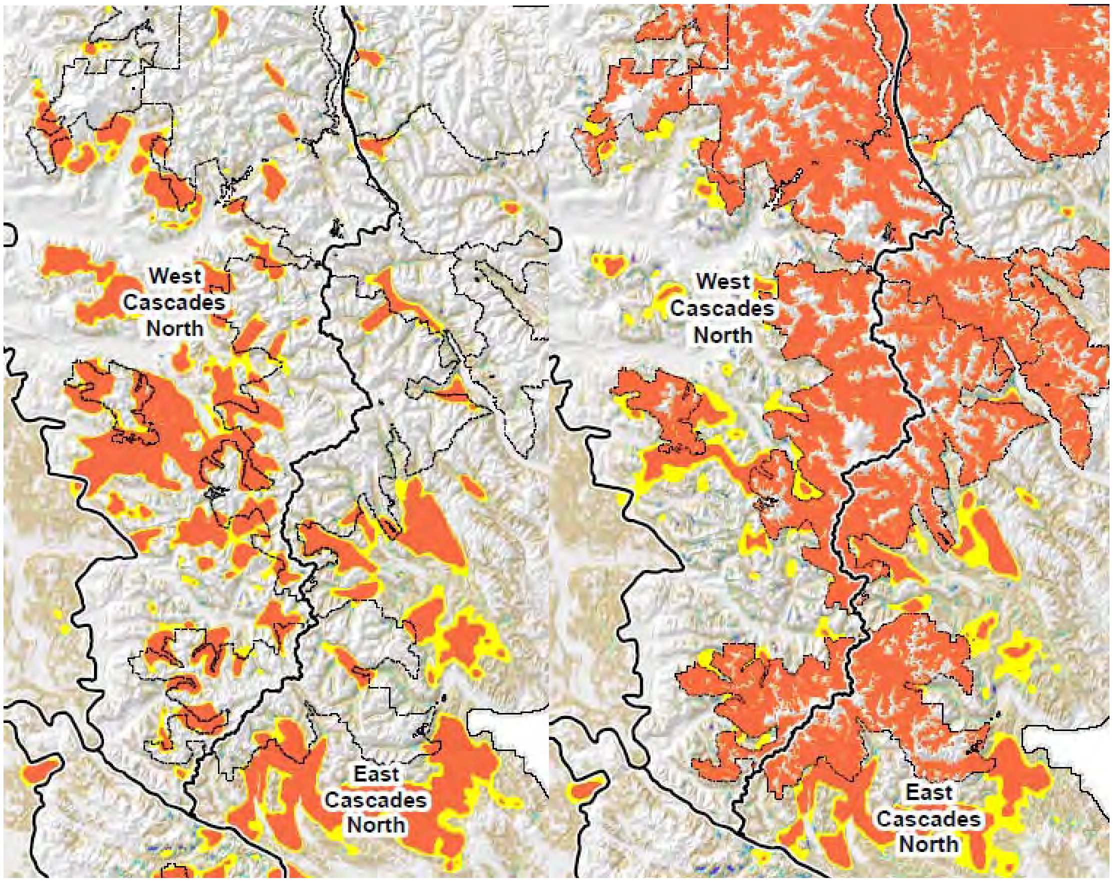
Exclusion Areas are areas that were excluded from the habitat suitability base maps prior to running Zonation. Examples are areas such as high elevation alpine areas as well as generally low elevation valley areas (*e.g.*, the Willamette Valley) that are considered incapable of supporting spotted owls. Including these areas in Zonation runs would give a false impression of habitat conservation block efficiency. That is, the algorithm would be able to remove large amounts of area (high elevation and valley areas) with no impact on the loss of spotted owl habitat value. Thus, we believed these areas should be masked out from the start. The GIS layer used to represent exclusion areas is the same one (mask) developed for the NWFP Monitoring Group (Davis and Dugger in press) and used in our MaxEnt modeling.

Selection of values for conservation value ranking: Zonation enables the user to specify the proportion of habitat value to display as maps of habitat conservation networks. Selection of the quantity of habitat value has a large influence on the size and distribution of habitat conservation networks. Because there is a near-infinite number of values that could be selected for evaluation, we compared results across a broad gradient of habitat values (20%, 30% 40%, 50%, 60%, 70%, and 80%), with the objective of identifying a smaller subset of reasonably diverse habitat conservation network scenarios for testing with the population model (see below). In addition, we compared habitat conservation networks from the above habitat values to the habitat values contained in existing networks such as spotted owl critical habitat (1992 and 2008) and the NWFP reserve network.

Precedence Masking allows the analyst to identify areas that must be or must not be included in the habitat conservation network. For example, existing protected areas such as Wilderness Areas and National Parks can be "forced" into the priority areas, regardless of their habitat value. Similarly, various land ownership categories can be "forced" out of priority areas. To accomplish this, the user identifies zones (land ownership, existing reserves, etc.) and ranks them by conservation priority (Zone 1, Zone 2, and so on) into a 'precedence mask'. In processing, Zonation removes the lowest value cells in Zone 1 first, , and continues by removing the next lowest value cell until all cells are removed in Zone 1 before moving on to Zone 2 and any potentially subsequent zones. Because the cells in Zone 2 are assigned a higher ranking, in terms of removal order, than those in Zone 1, they are disproportionately included in the solution. This process is repeated until all zones defined by the precedence mask have been fully evaluated. Zonation does not re-calculate or otherwise change the habitat value of a cell according to which zone it is in. Instead, identifying zones identifies discrete areas of the landscape that are to be given higher or lower priority of consideration for reasons other than the cells' habitat value.

The basis for precedence masking in Zonation is to allow factors such as land status to be incorporated into the landscape prioritization. For example, forcing existing National Parks and Wilderness Areas into habitat conservation networks would recognize that these areas exist as protected areas, and thus should be included in a habitat conservation networks regardless of their value to spotted owls. However, because we used Zonation to *help identify* areas estimated to provide the most conservation value for the spotted owl, we proceeded by first conducting an evaluation based purely on habitat value (unforced), and *then* evaluated how much overlap the resulting habitat conservation networks had with existing protected areas and other land designations or ownerships. Forcing existing reserves into priority areas will likely predispose Zonation to not find optimal solutions (*i.e.*, because some non-optimal areas are forced into the solution). For example, in areas such as the northern Cascades where high-value spotted owl habitat is relatively sparsely distributed, forcing Congressionally Reserved land allocations into priority areas resulted in an extremely inefficient network design (Figure C8).

Figure C-8. Comparison of Zonation 40% (orange) and 50% (yellow) solutions on all land ownerships (left) and with Congressional Reserves prioritized (right). Outlines of habitat conservation network solutions in the right frame correspond largely to National Park and National Forest boundaries.



After evaluating Zonation results employing a range of values for distributional smoothing, cell removal methods, ranking values, and land status and ownership prioritization, we selected habitat conservation network scenarios comprised of 30 percent, 50 percent, and 70 percent of habitat value as reference points. These scenarios sample along a gradient from somewhat smaller than the current habitat conservation network (NWFP) to a habitat conservation network approximately twice as large as the LSR network (Table C21). We recognize that the results of population modeling may indicate other Zonation scenarios that should or could be developed and tested (feedback loop in Figure C1). ***Also, it is important to recognize these scenarios are not recommendations for the specific size or location of habitat conservation blocks – they are only scenarios for the purpose of comparing to other scenarios to evaluate how they influence spotted owl population performance in the population simulation model.***

Settings and Values Used in Zonation

Distribution Smoothing: Home range area (2100 m radius)
Cell Removal Method: Add Edge points (2000 points/modeling region)
Exclusion Areas: Used NWFP non-capable habitat mask from NWFP Monitoring
Ranking Values: Used 30%, 50%, and 70% of habitat value
Precedence Masking: Land ownership scenarios evaluated include:

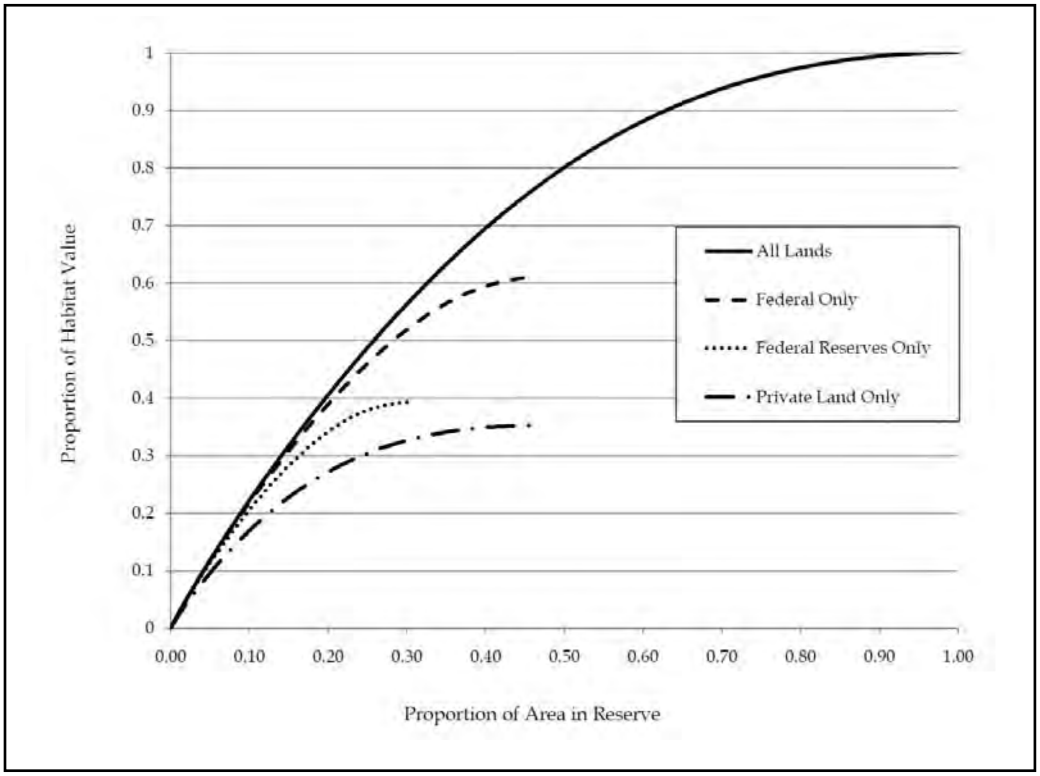
1) **No limit on inclusion** – No hierarchical masking - all land ownerships were allowed to be included and existing reserves were not forced into the priority areas. This scenario was chosen to represent the potential of the entire area to provide for spotted owls.

2) **Public lands only** – precedence masking was done such that non-public lands were removed first, and public lands were removed last. This had the effect of emphasizing reserves on public lands, but if the total amount of habitat value specified (*e.g.*, 50% or 70%) could not be acquired from cells in public lands, other lands could be included in the solution.

Maps depicting all of the initial Zonation scenarios are available at:
http://www.fws.gov/oregonfwo/Species/Data/NorthernSpottedOwl/Recovery/Library/Default.aspx#Files
Once there, click on "maps" and "AppendixCMaps.pdf" The layers can be turned on and off using the "layers" button in the upper left-hand corner.

Zonation outputs can be used to compare the contributions of different land classes (ownership, reserve status, etc.) based on the area and proportion of habitat value of each land class. Figure C9 depicts the relationship between area (proportion of the spotted owl's range) that could, hypothetically, be included in a habitat conservation network and the amount of spotted owl habitat value that various habitat conservation networks would contain among four categories: 1) all lands, which represents no limits on ownerships in the habitat conservation network; 2) Federal lands only, with no priority for currently existing reserves; 3) Federal reserves only, this scenario includes only NWFP reserves (Congressional Reserves and LSRs); and 4) private lands only; no reserves on Federal lands. These depictions are for demonstrative purposes only, not recommendations. They are essentially asking what would be the conservation value to spotted owls if habitat conservation areas were restricted to various land ownership categories. For example, private lands constitute about 45 percent of the spotted owl's range and provide roughly 35 percent of the rangewide habitat value (RHS), whereas the NWFP reserve network provides 40 percent of rangewide habitat value on 30 percent of the area (Figure C9).

Figure C-9. Relationship between proportion of various land ownerships/categories (no restriction, Federal lands only, Federal reserves only, or private lands only) included in a habitat conservation network and proportion of spotted owl habitat value included in the habitat conservation network.



While Zonation outputs do not evaluate or predict potential spotted owl population sizes associated with different habitat conservation network scenarios, they nonetheless permit comparison of the sizes of existing reserve or conservation networks to possible habitat conservation areas, and enable additional comparisons to be made in a GIS environment. For example, Table C21 shows a comparison of network size, percent of spotted owl training locations from the habitat modeling that falls within various habitat conservation network scenarios, and percent of the top two Zonation habitat value ranks among 10 habitat conservation network scenarios. Table C22 shows the relationship the proportion of RHS bins within each of 20 Zonation and 4 non-Zonation habitat conservation network scenarios. The results show the efficiency with which Zonation selects high RHS areas.

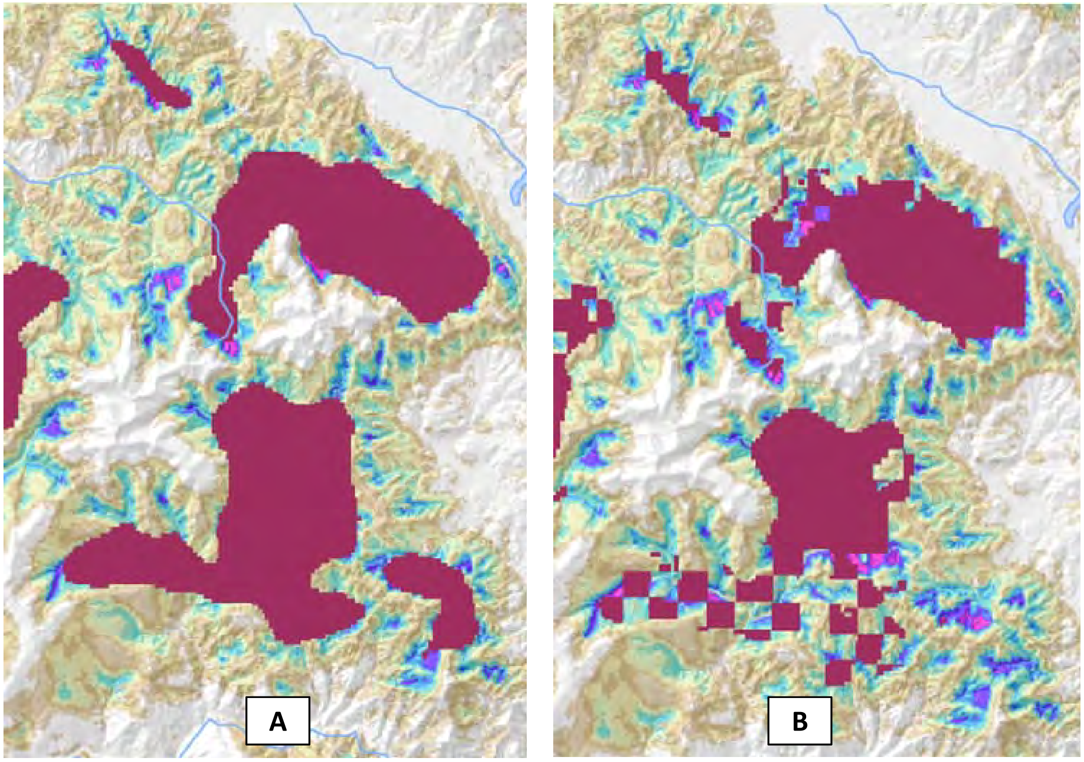
Table C-21. Comparison of area, percent of 1996 spotted owl sites used in model development, and percent of top 10% and 20% Zonation ranked habitat value for 10 spotted owl reserve scenarios.

Network scenario	Network scenario size (million hectares)	Percent of 1996 spotted owl sites	Percent of top 10% Zonation-ranked	Percent of top 25% Zonation-ranked
NWFP	6.63	46	56.7	55.2
MOCA	4.77	33	46.3	43.8
1992 Critical Habitat	5.75	44	57.3	55.4
2008 Critical Habitat	5.17	37	49.6	47.7
Z30 All lands	5.61	50	100	100
Z50 All lands	7.80	71	100	100
Z70 All lands	10.55	87	100	100
Z30 Public lands	5.57	51	94.9	91.3
Z50 Public lands	7.82	73	95.0	93.0
Z70 Public lands	11.24	88	98.9	98.0

Table C-22. Proportion of relative habitat suitability (RHS) bins represented among various habitat conservation network scenarios. Many more Zonation (Zall and Zpub) scenarios are presented in this table than in the remainder of the document. Zall = all lands available; public = Zpub lands prioritized in Zonation.

	Relative Habitat Suitability Bin									
Habitat Conservation Network Scenario	**0 - 10**	**10 - 20**	**20 - 30**	**30 - 40**	**40 - 50**	**50 - 60**	**60 - 70**	**70 - 80**	**80 - 90**	**90 - 100**
NWFP	0.22	0.26	0.31	0.36	0.41	0.46	0.51	0.57	0.63	0.58
MOCA	0.16	0.18	0.22	0.25	0.30	0.34	0.40	0.46	0.49	0.31
1992 Critical Habitat	0.17	0.22	0.28	0.33	0.38	0.44	0.50	0.57	0.66	0.57
2008 Critical Habitat	0.16	0.20	0.24	0.28	0.32	0.37	0.43	0.51	0.60	0.51
Z10all	0.00	0.00	0.02	0.03	0.07	0.16	0.33	0.54	0.70	0.89
Z10pub	0.00	0.01	0.02	0.04	0.08	0.16	0.30	0.51	0.68	0.83
Z20all	0.00	0.02	0.05	0.10	0.19	0.35	0.57	0.77	0.89	0.99
Z20pub	0.00	0.03	0.06	0.11	0.20	0.34	0.54	0.73	0.85	0.90
Z30all	0.01	0.05	0.11	0.20	0.33	0.53	0.74	0.89	0.95	1.00
Z30pub	0.01	0.06	0.13	0.21	0.34	0.51	0.70	0.83	0.90	0.91
Z40all	0.01	0.09	0.19	0.32	0.49	0.69	0.85	0.94	0.98	1.00
Z40pub	0.02	0.11	0.22	0.34	0.48	0.66	0.80	0.88	0.92	0.91
Z50all	0.02	0.15	0.30	0.46	0.63	0.81	0.92	0.98	0.99	1.00
Z50pub	0.04	0.21	0.35	0.47	0.61	0.75	0.85	0.90	0.92	0.91
Z60all	0.04	0.24	0.43	0.61	0.77	0.90	0.96	0.99	1.00	1.00
Z60pub	0.12	0.37	0.48	0.58	0.70	0.82	0.89	0.92	0.93	0.92
Z70all	0.08	0.38	0.59	0.75	0.87	0.95	0.99	1.00	1.00	1.00
Z70pub	0.25	0.47	0.59	0.70	0.81	0.90	0.94	0.97	0.98	1.00
Z80all	0.15	0.57	0.75	0.87	0.95	0.99	1.00	1.00	1.00	1.00
Z80pub	0.32	0.61	0.73	0.83	0.91	0.96	0.98	0.99	1.00	1.00
Z90all	0.31	0.80	0.91	0.97	0.99	1.00	1.00	1.00	1.00	1.00
Z90pub	0.47	0.79	0.88	0.95	0.98	1.00	1.00	1.00	1.00	1.00
Z100all	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Z100pub	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Figure C-10. Example Zonation output map of the Mount Ashland, OR, area, depicting 30 percent of habitat value in red on all lands (A) and on Federal lands only (B).



Modeling Process Step 3 - Develop a spatially explicit spotted owl population model that reliably predicts relative responses of spotted owls to environmental conditions, and use it to test the effectiveness of habitat conservation network scenarios designed in step 2 in recovering the spotted owl. The simulations from this spotted owl population model are not meant to be precise estimates of what will occur in the future, but provide information on comparative trends predicted to occur under differing habitat conservation scenarios.

To meet this objective, the modeling team elected to use a spatially explicit, individual-based modeling approach. While other approaches such as population level population viability analysis (PVA) and metapopulation models have been used for evaluating spotted owl populations, we required an approach that enabled comparison of a wide range of spatially explicit conditions such as variation in habitat conservation networks. Dunning *et al.* (1995) wrote the following regarding spatially explicit population models:

> *"Spatial models, structured and parameterized according to a species' life history, allow one to explore the efficiency of various reserve designs. The models can be*

> *used to estimate the potential effects on a species' persistence by systematically varying factors such as the percentage of the landscape that is suitable habitat, and the size, shape, and spacing of habitat patches. The addition of marginal (i.e., sink) habitat to a reserve can be assessed for negative effects on a managed population (Pulliam and Danielson 1991). These exercises can be done on artificial landscape maps to explore general reserve design principles (Lamberson et al. 1992, 1994) or on GIS-based maps that incorporate land-use and ownership constraints (Murphy and Noon 1992, Noon and McKelvey 1992)."*

Individual-based models (IBMs) allow for the representation of ecological systems in a manner consistent with the way ecologists view such systems as operating. That is, emergent properties such as population increases or declines are the result of a series of effects and interactions operating at the scale of individuals. Individuals select habitat based on what is available to them, disperse as a function of their individual circumstance (age), compete for resources, etc.

Grimm and Railsback (2005) noted that IBMs need to be simple enough to be practical, but have enough resolution to capture essential structures and processes. The spotted owl is perhaps the most studied raptor in the world, and thus there exists a tremendous quantity and quality of data (*e.g.*, vital rates are evaluated in a meta-analysis for several long-term demographic study areas every 5 years; *e.g.*, Anthony *et al.* 2006, Forsman *et al.* (2011)); habitat selection (see review by Blakesley 2004) has been thoroughly evaluated; large numbers of individuals have been followed during dispersal (Forsman *et al.* 2002); among many other aspects of the species' ecology. The spotted owl is therefore ideally suited for spatially explicit IBM. Bart (1995), however, noted that the question "Does the model improve our ability to make decisions?" needs to be explicitly considered. The modeling team believes that the spatially explicit IBM HexSim, which is parameterized largely with empirically-derived values from spotted owl studies, improves our ability to make land management decisions, and therefore we have decided to use this approach.

The HexSim Model:

HexSim (Schumaker 2011) was designed to simulate a population's response to changing on-the-ground conditions by considering how those conditions influence an organism's survival, reproduction, and ability to move around a landscape. The modeling team developed a HexSim spotted owl scenario based on the most up-to-date demographic data available on spotted owls (Forsman *et al.* 2011), published information on spotted owl dispersal, and home range size as well as on parameters for which less empirical information was available (see below). Initially, the HexSim spotted owl model allows users to evaluate the efficacy of existing conservation strategies, under currently-estimated barred owl impacts and with currently-estimated habitat conditions, to meet recovery goals. Subsequently, the model serves as a consistent framework into which variation in spatial data layers (*e.g.*, reserve or conservation block boundaries, different assumptions about habitat conditions (RHS) inside and outside of reserves or blocks, different assumptions about RHS change on public versus private lands, and different assumptions about the impact of barred owls among modeling regions) can be introduced. Comparison of estimates of simulated spotted owl population performance estimates across the range of scenarios incorporating variation in habitat conservation network sizes, habitat trends, and barred owl influence, can inform evaluations of habitat conservation networks and other conservation measures designed to lead to spotted owl recovery.

In very general terms, we tried to design the model to answer the following questions: (1) Given current circumstances (reserves, habitat, barred owls, spotted owl demographic rates, etc.), is recovery of the spotted owl likely in the foreseeable future?; (2) Given current estimates of habitat, barred owls, and spotted owl demographics, is recovery of the spotted owl likely in the foreseeable future under different habitat conservation network scenarios?; and (3) To what degree would management of habitat and barred owls contribute to or detract from reaching spotted owl recovery goals under a range of habitat conservation networks and management scenarios? Evaluation and ranking of the population simulation results from the model obtained across a range of habitat conditions, barred owl effects, and conservation network scenarios, and comparison with established recovery criteria, should provide important insight into these questions. **The HexSim model is available at: www.epa.gov/hexsim.**

HexSim Overview:

HexSim is a spatially explicit, individual-based computer model designed for simulating terrestrial wildlife population dynamics and interactions. HexSim is a generic life history simulator; it is not specifically a spotted owl model. HexSim was designed to quantify the cumulative impacts to wildlife populations of multiple interacting stressors.

HexSim simulations are built around a user-defined life cycle. This life cycle is the principal mechanism driving all other model processing and data needs. Users develop the life cycle when initially setting up a simulation. The life cycle consists of a sequence of life history events that are selected from a list. This event list includes survival, reproduction, movement, resource acquisition, species interactions, and many other actions. Users can impose yearly, seasonal, daily, or other time cycles on the simulated population. Each event can work with all, or just a segment of a population, and events can be linked to static or dynamic spatial data layers. Each life cycle event has its own data requirements. Simple scenarios may use few events with minimal parameterization and little spatial data. When more complexity is warranted, HexSim allows a great deal of data and behavior to be added to its simulations.

HexSim scenarios include descriptions of one or more populations, spatial data needs, life cycle definitions, event data, and basic simulation criteria such as the number of replicates and time steps. Each population is composed of individuals, and individuals have traits that can change probabilistically, or based on age, resource availability, disturbance, competition, etc. HexSim also includes optional genetics and heritable traits (though these were not used for the spotted owl model). The use of traits allows members of the simulated population to have unique properties that change in time and space. Traits also allow populations to be segregated into classes, such as males and females, fitness categories, disease categories, etc. Combinations of trait values can be used to stratify events such as survival, reproduction, movement, etc.

Traits are a fundamental part of HexSim scenarios. Traits can be used to control most life cycle events because events can be stratified by trait combinations. For example, a movement event might be set up to operate only on a fledgling stage class. Or a survival event might assign mortalities based on the values of a trait that reflects resource acquisition. In addition, one trait's values can also be influenced by multiple other traits, which makes it possible to set up stressor interactions and complex feedback loops. Traits can also be used to capture interactions such as parasitism, competition, mutualism, breeding, etc.

Overview of the Spotted Owl Scenario

Because females are the most influential sex in terms of population dynamics, the HexSim spotted owl scenario is a females-only model. The life cycle is simple except that the acquisition of resources by individual spotted owls is spatially stratified, and thus somewhat complex. The scenario depends on two static spatial data layers; one representing the distribution and relative suitability of habitat, and an "exclusion layer" to prevent spotted owls from moving out into the Pacific Ocean, or into areas outside of their geographic range .

An additional layer comprised of the boundaries of both the modeling regions and demographic study areas (DSAs were used to generate HexSim reports (*i.e.*, we extracted information about spotted owls in DSAs as well as within modeling regions and for all modeling regions overall), had no effect on the simulated population. All spatial data layers are converted to grids consisting of 86.6- ha hexagons. To the extent possible, simulation parameter values were estimated based on published empirical data.

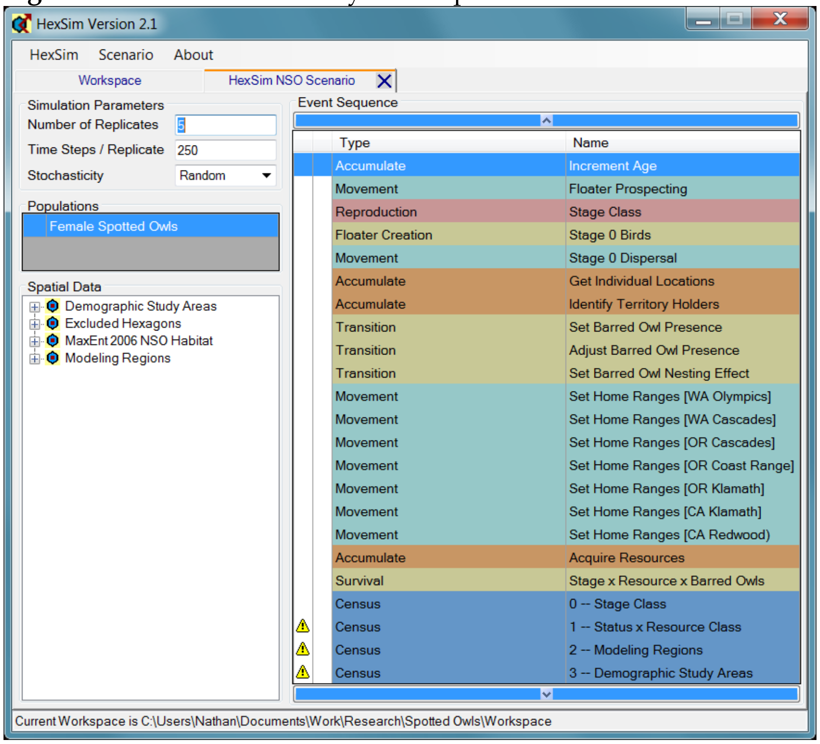
The HexSim simulations began with 10,000 spotted owls being virtually introduced into the study landscape. The initial population's ages were randomly distributed, and they were placed preferentially into areas of high RHS. Once initialization was complete, individual spotted owls were subjected to the event cycle shown in Figure C11. The year begins with each individual becoming a year older. Next, floaters (spotted owls without a territory) prospect for a territory. This is followed by reproduction and fledgling dispersal. Dispersing fledglings do not prospect for a territory.

We assumed that the RHS map developed in MaxEnt was a proxy for the amount of resources available to spotted owls within each hexagon. Because nesting spotted owls showed relatively strong selection for some RHS categories and against others (see Figure C5), we reasoned that this selection was based on a combination of factors (including, but not limited to, those we included as covariates in our models) that influence spotted owl natural selection. That is, spotted owls select some areas and avoid other areas in order to maximize their survival and reproductive success. Spatially-explicit data on competitors, prey, predators and other factors influencing spotted owls were unavailable, and thus we were unable to incorporate more direct measures of resource quantity and quality.

In the HexSim Spotted Owl Scenario, a primary influence of RHS on simulated spotted owl populations occurs in territory acquisition (occupancy). To the extent that some areas aren't selected by spotted owls (or disproportionately selected against), habitat suitability acts to limit survival and reproduction (*i.e.*, spotted owls don't survive or reproduce in areas that they don't occupy). Subsequent to territory establishment, resource acquisition (RHS values) determines the resource class a spotted owl is placed in, which influences survival rates. Reproduction was not influenced by resource acquisition, and thus was not influenced by habitat quality. Individual studies (*e.g.*, Franklin *et al*. 2000) and meta-analyses have reported influences of habitat on survival and in some cases fecundity (see Forsman *et al*. 2011).

We recognized the importance of dispersal and habitats used by dispersing spotted owls in developing habitat conservation planning models. However, relatively little is known about the characteristics of areas used by dispersing spotted owls. In the spotted owl modeling effort, the modeling team therefore elected not to define or attempt to model dispersal habitat, but instead to rely on reasonable assumptions about the influence of relative habitat suitability (for nesting) on successful dispersal. Success (survival) of spotted owls dispersing through variable landscapes may be influenced by factors similar to those affecting territorial spotted owls (*e.g.* availability of prey, cover from predation, thermal stress) albeit at a different scale. Because the RHS values generated by MaxEnt retain the full gradient of habitat suitability (*i.e.* not 'thresholded' or categorized), it is reasonable to assume that relative habitat suitability is correlated with relative success of dispersal occurring in those areas (pixels). In HexSim, dispersing spotted owls are allowed to disperse through the full range of RHS values, with some degree of repulsion to the lowest RHS values.

Figure C-11. HexSim event cycle for spotted owls.



After floater spotted owls finish prospecting for territories, the modeling region they are in is recorded. Then the determination of whether each territorial spotted owl is in the presence of a barred owl is made probabilistically, with the probability of being in the presence of a barred owl dependent on the modeling region (Table C25). The region-specific probabilities for spotted owl exposure to barred owls were based on the proportion of spotted owl territories where barred owls were detected each year on the 11 DSAs (see Appendix B; Forsman *et al*. 2011). This decision is only made once per "bird-territory" (*i.e.*, once the decision is made for an individual spotted owl at a territory, the barred owl presence/absence is fixed for that territory until another spotted owl takes over the territory). All non-territorial spotted owls are placed in an 'undetermined status' category until they obtain a territory. A newly territorial spotted owl that has this undetermined status is assigned a "barred owl present" or "barred owl absent" status, based on the barred owl encounter probability for that modeling region.

Next, spotted owls that have the "barred owl present" status are placed in either a "*nesting normal*" or "*nesting halted*" class. At present, every spotted owl is placed into the *nesting normal* class. If spotted owls were assigned to the *nesting halted* class, they would not reproduce. Unlike the barred owl presence/absence trait described above, the *nesting normal* vs. *nesting halted* decision could be revisited every year, for every territorial spotted owl. Spotted owl floaters do not reproduce, so although they are always assigned to the *nesting normal* category, this has no impact on the simulation results. We mention these features (even when they aren't used) that were built into the HexSim Spotted Owl Scenario model to show how the model can adapt to and incorporate new information when it becomes available.

In the HexSim simulation, barred owls affect spotted owls through survival only. However, the simulation has been developed to facilitate a barred owl impact on spotted owl reproduction. This feature has not yet been used. It would also be possible to have barred owls impact habitat selection by spotted owls, or site fidelity. Neither of these processes has been implemented. Reproductive rates were obtained from Table 3 of Forsman *et al*. (2011). Those estimates were for time periods as long as 1985 to 2008 and as short as 1992 to 2008. It is generally agreed that barred owl populations have increased in most areas of the spotted owl's range over that time. Thus, to the degree that barred owls have an influence on fecundity, that influence is incorporated into these estimates.

Spotted owl reproduction is stratified by both stage class and nesting status (see above). Spotted owls that are in the *nesting halted* class have 100% probability of producing a clutch of size 0. Otherwise, the reproductive rates vary by stage class.

Spotted owl survival is stratified by barred owl presence, stage class, and resource class. Spotted owls in the barred owl present class have lower survival rates. Those in the barred owl absent, or undetermined classes, have higher survival rates.

At present, barred owls are not explicitly simulated, but are instead captured probabilistically. Accounting for barred owl impacts on spotted owl habitat selection or site fidelity would require that barred owls be actually located on the simulated landscape, and possibly even fully simulated within HexSim. The modeling team felt that sufficient data did not exist range-wide to permit either option to be incorporated into the current simulations. When such data become available, they can be integrated into the framework we have developed.

Next, each spotted owl establishes a home range. The simulated spotted owls have small defended territories, but large overlapping home ranges. Home range size varies with modeling region. The spotted owls extract resources from their home ranges, and thus they experience competition for resources from conspecifics. Finally, resource acquisition and survival are simulated. Survival varies based on stage class, resource acquisition class, and exposure to barred owls.

Home range sizes were set to the mean of the available regional-specific estimates (see summary in Schilling 2009). Spotted owl survival rates were based on study area-specific estimates from Forsman *et al*. (2011), with adjustment for the impact of barred owls across all study areas as calculated from the survival meta-analysis model containing an additive barred owl effect, also from Forsman *et al.* (2011).

The Population Parameters

Three distinct component groups were involved in the specification of the HexSim spotted owl population. These involved a set of basic properties, the definition of several different population traits, and finally the establishment of rules for the spotted owl's use of space and resource needs. The basic properties were used to establish an initial population size of 10,000 spotted owls, and to define an exclusion layer. Individuals were initially placed into the best hexagons in the simulation landscape, but only one spotted owl was allowed per hexagon.

Seven traits were created as part of the spotted owl population definition. These traits track stage class, location (modeling region and possibly DSA), resource class, territory status (territorial vs. floater), exposure to barred owls, and barred owl impacts on spotted owl nesting. Table C23 shows each possible trait value.

The simulated spotted owls produced each year begin life at age zero, and stage class zero. Each year they transition into the next stage class. At age 3 they reach stage class three, which is the terminal stage class. The spotted owls always belong to one of three resource classes, depending on the amount of resources they are able to acquire from their home range. Resources are a function of the mean RHS of hexagons, derived from the MaxEnt models (see above). Spotted owls that acquire 2/3 or more of their resource target are placed in the high resource class. Those that attain less than 1/3 of their resource target are placed into the low resource class. All other spotted owls are placed into the medium resource class. Resource targets vary by modeling region, and are described below.

The territory status trait is used to record whether individual spotted owls own a territory, or are floaters. The barred owl presence trait categorizes individual spotted owls as being exposed, or unexposed, to a barred owl. This decision is made once for each territorial spotted owl. The barred owl nesting effect trait is used to assign a probability that exposure to a barred owl will cause a spotted owl to avoid nesting. This evaluation is repeated every year for every spotted owl.

Table C-23. Spotted owl scenario traits and value categories.

Trait	Values
Stage Class	Stage 0
	Stage 1
	Stage 2
	Stage 3
Resource Class	Low
	Medium
	High
Territory Status	Floater
	Territorial
Barred Owl Presence	Pending
	Absent
	Present
Barred Owl Nesting Effect	Normal
	Halted

Trait	Values
Modeling Region	North Coast Olympics
	Oregon Coast
	East Cascades South
	East Cascades North
	West Cascades North
	West Cascades Central
	West Cascades South
	Klamath East
	Klamath West
	Inner-California Coast Range
	Redwood Coast

Trait	Values
DSA	Cle Elum
	Coast Ranges
	HJ Andrews
	Klamath
	Olympic
	Rainier
	South Cascades
	Tyee
	Warm Springs
	Wenatchee
	Hoopa
	Marin
	NW California
	Simpson

The modeling region and demographic study area traits are used to track individual spotted owl locations. The 11 modeling regions are space-filling and non-overlapping. Each individual spotted owl occupies one modeling region at any one time. If a spotted owl territory spanned multiple modeling regions, it was assigned to the region in which the majority of its territory hexagons fell. The demographic study areas (DSAs) take up just a fraction of the landscape. So at any moment most spotted owls will not be in a DSA. Resource targets (explained below) and home range size vary by modeling region.

The population parameters also control individual's use of space. The simulated spotted owls had territory sizes of no more than three 86.6-hectare hexagons. This territory size represents a reasonable approximation of a spotted owl core area (see discussion of spatial scale above). Hexagons had to have at least a score of 35 (out of 90 possible) to be usable in forming a territory. We decided on a minimum score of 35 after evaluating the scores of hexagons overlaid on 3,790 spotted owl nest sites. We evaluated the score for the focal hexagon (the one in which the nest resided), the second, and third closest hexagons, as well as the mean scores of the first, second, and third hexagons. More than 75% of the nest sites were in hexagons with scores >35. Similarly, 73% of the spotted owl sites had a mean score >35 for the focal, second, and third closest hexagons. Although other scores might be reasonable, we reasoned that increasing the score would unreasonably inhibit settlement on suitable areas, whereas decreasing the score would result in unrealistic densities in areas with relatively low RHS. Territory size had little significance for the simulated population dynamics, as the spotted owls derive resources from their home ranges. The territories served as a core area around which home ranges could be constructed. Territories, in the HexSim simulations, were exclusively used areas, whereas the remainder of the home range area could overlap with that of neighboring spotted owls.

Each simulated spotted owl has a resource target, which controlled how much resource it must have access to in order to be placed into the highest resource class. The resource targets vary by modeling region. Spotted owls that acquire 2/3 or more of their resource target are placed into the high resource acquisition class. Those that attain less than 1/3 of their resource acquisition target are placed into the low resource acquisition class. All other spotted owls end up in the medium resource acquisition class. The resource targets are listed in Table C24.

Table C-24. Estimated resource targets based on RHS values at 3,790 spotted owl locations.

Modeling Region	Home Range Size ha (# hexagons)	Resource Target
North Coast Olympics	11,052 (128)	1250
East Cascades North	7,258 (84)	1000
West Cascades North	7,258 (84)	1250
West Cascades Central	7,258 (84)	1250
Oregon Coast	4,123 (48)	375
West Cascades South	3,949 (46)	375
Inner CA Coast Range	3,165 (37)	375
East Cascades South	3,033 (35)	750
Klamath East	3,033 (35)	375
Klamath West	3,033 (35)	375
Redwood Coast	1,173 (14)	250

The Event Sequence

There are 23 events in the HexSim spotted owl scenario. Not all of these events modify the population, and some have similar or related functions. These events are described in turn below. Each event is listed by type (*e.g.,* movement) and specific name (in square brackets).

Accumulate [Increment Age]

This event makes each individual one year older. As a result, stage 0 individuals will move into stage 1, stage 1 individuals will move into stage 2, and stage 2 individuals will move into stage 3.

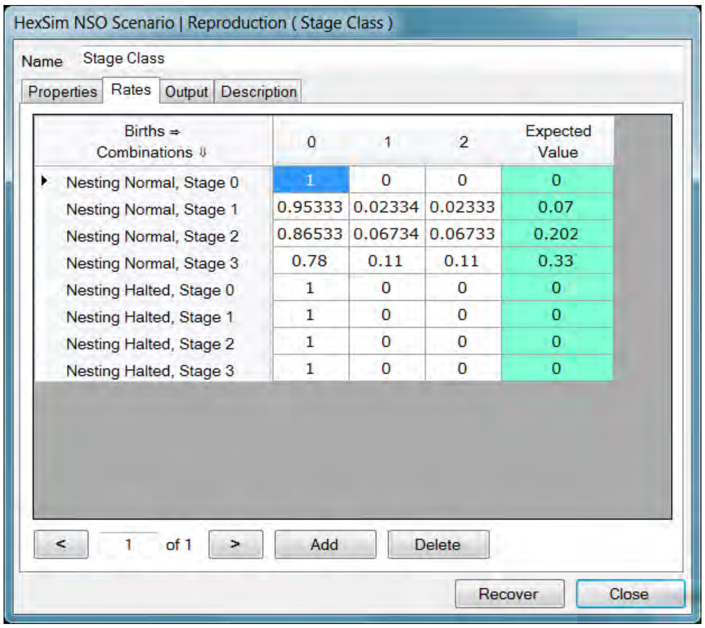
Movement [Floater Prospecting]

HexSim's movement event controls dispersal and prospecting behavior. But any one event may do either or both. This event only performs prospecting, but it does so for all spotted owls that are floaters (*i.e.,* those who do not own a territory). Individual floaters are allowed to search an area of up to 500 86.6 - hectare hexagons in search of a vacant area from which a territory could be constructed. The search strategy is imperfectly informed by resource availability. That is, spotted owls tended to construct home ranges from high RHS hexagons, but they did not select the best sites with certainty.

Reproduction [Stage Class]

HexSim's reproduction module is parameterized by assigning probabilities to each possible clutch size. Reproduction is also stratified by traits. In this case, the maximum clutch size was set to 2, and reproduction rates were varied by stage class, and based on the Barred Owl Nesting Effect trait values. The reproductive rates used in the event are shown in Figure C12. The unperturbed (by barred owls) reproductive rates were obtained from Table 3 of Forsman *et al.* (2011).

Figure C-12. Estimated spotted owl reproductive rates by stage class.



Births ⇒ Combinations ⇓	0	1	2	Expected Value
Nesting Normal, Stage 0	1	0	0	0
Nesting Normal, Stage 1	0.95333	0.02334	0.02333	0.07
Nesting Normal, Stage 2	0.86533	0.06734	0.06733	0.202
Nesting Normal, Stage 3	0.78	0.11	0.11	0.33
Nesting Halted, Stage 0	1	0	0	0
Nesting Halted, Stage 1	1	0	0	0
Nesting Halted, Stage 2	1	0	0	0
Nesting Halted, Stage 3	1	0	0	0

The column headings in Figure C12 correspond to clutch sizes. The rows contain all of the permutations of the two trait values. The right-most column shows the expected values, which, in a females-only model, equal fecundities. Individuals whose nesting has been halted by a barred owl are assigned a 100% probability of having a clutch size of zero. The same is true for stage class 0 individuals. Otherwise, the probabilities of having clutches of size 1 and 2 were set as equal as possible, to whatever value was necessary to produce the fecundity values reported in Forsman *et al.* (2011). Finally, the probability of having a clutch of size zero was set so that each row summed to exactly 1.0.

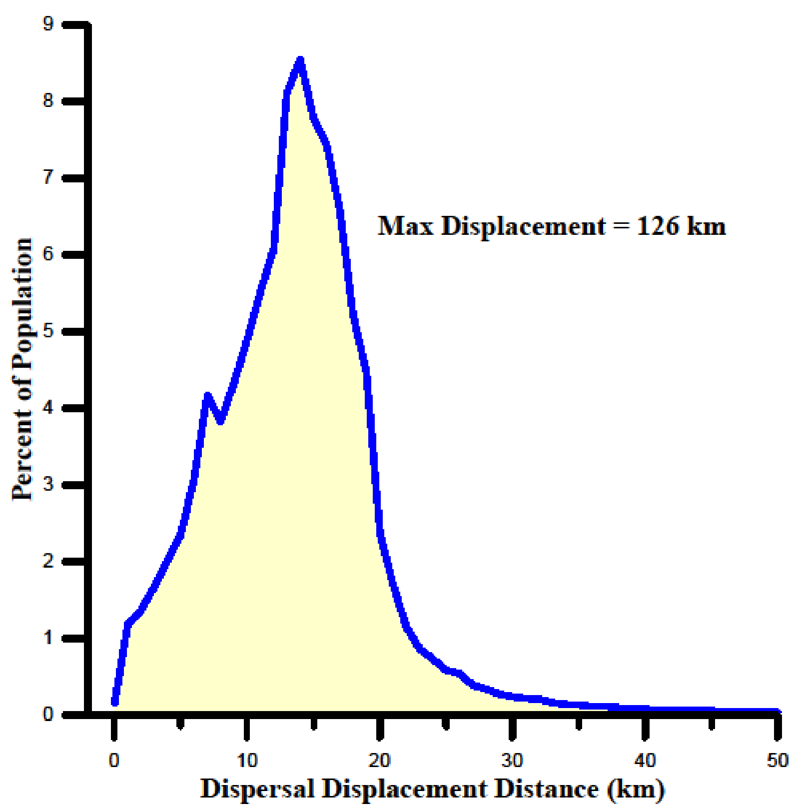
Floater Creation [Stage 0 Birds]

In HexSim, recruits become a co-owner of their mother's territory. They will disperse from their natal territory when forced to by a floater creation event at the end of Year 1. This floater creation event removes all stage 0 birds from their natal groups. These animals disperse in the next event.

Movement [Stage 0 Dispersal]

HexSim's movement event controls dispersal and prospecting behavior. Any one movement event may do either or both. This event strictly performs dispersal for stage class 0 spotted owls. The dispersing birds move with moderate auto-correlation until they encounter enough resource that a territory may be constructed (see above). Territory construction does not actually take place at this time. The dispersers are limited to moving 250 km total distance. The birds have a slight repulsion to lower RHS areas of the landscape, but are not prevented from moving into zero-valued hexagons. Figure C13 shows an example of the distribution of simulated dispersal displacement distances produced by this movement event. These data were gathered from five replicate simulations, for years 100-250. The total number of dispersal events in this period was approximately 852,000. The shape of this frequency distribution will change if either the rules for stopping (3 territory-quality hexagons encountered in succession) or the degree of autocorrelation (50%) are modified.

Figure C-13. Distribution of 852,000 simulated Year 1 dispersal distances.



Accumulate [Get Individual Locations]

This event records which modeling region each spotted owl is in. If an individual falls within a demographic study area then this event will captures that information, as well.

Accumulate [Identify Territory Holders]

This event updates a trait that segregates into two classes: floaters and territory-holders.

Transition [Set Barred Owl Presence]

This transition event assigns values to the Barred Owl Presence trait. Each modeling region was assigned a separate barred owl encounter probability, based on field data illustrating the proportion of spotted owl territories on DSAs where a barred owl was documented each year (Appendix B; Forsman *et al.* 2011). Using these probabilities, this event places each territorial spotted owl into one of two classes. The classes indicate whether the spotted owl is exposed to a barred owl or not. Once this determination is made for a specific spotted owl, it is not changed until that spotted owl dies or otherwise leaves the territory. The probabilities that were used are shown in Table C25.

Table C-25. Barred owl encounter probabilities estimated from Forsman *et al.* (2011).

Region	Encounter Probability
North Coast Olympics	0.505
East Cascades North	0.296
West Cascades North	0.320
West Cascades Central	0.320
Oregon Coast	0.710
West Cascades South	0.364
Inner CA Coast Range	0.213
East Cascades South	0.180
Klamath East	0.245
Klamath West	0.315
Redwood Coast	0.205

Transition [Adjust Barred Owl Presence]

This transition event simply removes the barred owl presence designation from floater spotted owls. This way, if a spotted owl was to give up its territory and leave, it would not retain its barred owl presence / absence designation. In the present scenario territorial spotted owls have perfect site fidelity, so this event has no impact.

Transition [Set Barred Owl Nesting Effect]

This transition event uses the barred owl presence trait to set the value of a barred owl nesting effect trait. This allows spotted owls that are exposed to a barred owl to be placed into a non-nesting category with some probability. As this probability increases from zero, barred owls have an increasingly strong influence over spotted owl nesting rates, and hence reproductive output. In these simulations, the barred owl effect on spotted owl nesting was set to zero.

Movement [Set Home Ranges]

Eight different movement events are used to set home range sizes differently based on modeling region. These movement events only establish home ranges for territorial spotted owls. The home range sizes used are listed in Table C26. Spotted owls acquire resources from their home ranges, and the home ranges for different birds may overlap; territories however, cannot overlap. This results in competition among spotted owls for resources. Spotted owl home ranges were always contiguous, but their shapes were not constrained. The home range sizes used were developed from the published results of many field studies, and were compiled by the modeling team.

Table C-26. Spotted owl home range sizes used in population modeling.

Region	Home Range Size (in hexagons)
North Coast Olympics	128
East Cascades North	84
West Cascades North	84
West Cascades Central	84
Oregon Coast	48
West Cascades South	46
Inner CA Coast Range	37
East Cascades South	35
Klamath East	35
Klamath West	35
Redwood Coast	14

Accumulate [Acquire Resources]

This "accumulate event" assigns individual spotted owls to a resource class, based on how much resource they acquire from their home ranges. Habitat suitability and quantity, plus competition with conspecifics will dictate what resource class individual spotted owls end up in.

Survival [Stage x Resource x Barred Owls]

The survival event is stratified by stage class, resource class, and exposure to barred owls (which is binary). The survival rates that were used are shown in Table C27. The derivation of these values is discussed in a separate section below.

Census [x 4]

Four census events are used to track the number of spotted owls by stage class, resource class, modeling region, and demographic study area.

Table C-27. Estimated survival rates of spotted owl based on stage class, resource class, and barred owl effect.

Without Barred Owls			With Barred Owls		
Stage Class	**Resource Class**	**Survival Rate**	**Stage Class**	**Resource Class**	**Survival Rate**
Stage 0	Low	0.366	Stage 0	Low	0.28
	Medium	0.499		Medium	0.413
	High	0.632		High	0.546
Stage 1	Low	0.544	Stage 1	Low	0.458
	Medium	0.718		Medium	0.632
	High	0.795		High	0.709
Stage 2	Low	0.676	Stage 2	Low	0.590
	Medium	0.811		Medium	0.725
	High	0.866		High	0.780
Stage 3	Low	0.819	Stage 3	Low	0.733
	Medium	0.849		Medium	0.763
	High	0.865		High	0.779

Spatial Data

The Baseline HexSim spotted owl scenario uses four different map files. All four maps are static (they do not change with time), and each is made up from 538,395 hexagons arranged in 1430 rows and 377 columns. Individual hexagons are 1000 meters in diameter, and 86.6 hectares in area. The spatial data were developed by sampling raster imagery, using a tool that is built into the HexSim model. The sampling process involves intersecting a grid of hexagonal cells with a raster image, and then computing a per-hexagon mean from a series of weights assigned to the land cover classes present in the raster data.

The habitat map (*MaxEnt 2006 NSO Habitat)* depicts spotted owl RHS values developed using MaxEnt in Step 1 (see above). In HexSim, each pixel was assigned a weight equal to its RHS score. Pixel scores ranged between zero and 97. Thus when the HexSim RHS map was constructed from this raster file, the largest possible hexagon score was 97.00; this upper limit was never realized because each hexagon's value represented an average of the pixels underneath it. The hexagons in the HexSim RHS map vary between 0.00 and 90.37. Hexagon scores were assumed to be proxies for the value of resources available to NSOs within the hexagon.

The habitat map (*MaxEnt 2006 NSO Habitat)* captures spotted owl resource quality, and was derived from RHS values developed using MaxEnt in Step 1 (see above). In HexSim, each land cover class was assigned a weight equal to its category ID. The category IDs ranged between zero and 97. Thus when the HexSim resource quality map was constructed from this raster file, the best possible hexagon score was 97.00; this upper limit was never realized because each hexagon's value represented an average of the pixels underneath it. The hexagons in the HexSim resource quality map vary between 0.00 and 90.37.

A map delineating the study area (*Excluded Hexagons)* was binary, with ones being assigned to each hexagon within the range of the spotted owl, and zeros elsewhere. Simulated spotted owls were not allowed to move into hexagons that were zero-valued in this map. This map included boundaries to the study area, such as the Pacific Ocean and other areas outside of spotted owl's range, or outside our area of inquiry (*e.g.*, the spotted owl's range in British Columbia).

The final two maps depict the locations of the modeling regions and DSAs. The map called *Modeling Regions* breaks the range of the spotted owl up into 11 different regions. This map was used to identify which region individual spotted owls occupied, because each modeling region had different resource requirements and home range sizes. Similarly, a map called D*emographic Study Areas* indicates the locations of 14 different DSAs.

Survival Rates

The survival event is stratified by stage class, resource class, and exposure to barred owls. To begin with, 9 survival rates (estimated apparent survival) were derived from Table 12 in Forsman *et al.* (2011). Because true adult survival is unknown we made the assumption that apparent adult survival is equal to, or a reliable surrogate for, true adult survival. These rates corresponded to the three oldest stage classes x 3 resource classes. Forsman *et al.* (2011) provided stage class-specific survival estimates for each of 11 DSAs. For each study area and stage class, mean apparent survival values for males and females were provided. We computed the mean of each pair and identified the smallest and largest of these mean values. For any given stage class, the smallest mean value was assigned to individuals in the low resource class. Likewise, the largest stage-specific mean value was assigned to individuals in the high resource class. The stage-specific survival rates for individuals in the medium resource class were set equal to the mean taken over all of the survival estimates present in Table 12 of Forsman *et. al* (2011) for that stage class. Through this process survival rates were obtained for stage 1-3 spotted owls in all three resource classes.

Stage class 0 survival estimates were taken from Franklin *et al*. (1999: 27-28). This is the final report titled "Range-wide status and trends in northern spotted owl populations" that was written after a major workshop held in Corvallis, Oregon, in 1999 to estimate demographic rates of the subspecies. The estimates of juvenile survival rates for three study areas from banding studies were adjusted to compensate for emigration rates, based on radio telemetry studies conducted by Eric Forsman (unpublished data). Mean, minimum and maximum juvenile survival rates were taken from this reference and used in the model. The mean value for Stage class zero was set to the midpoint between the minimum and maximum value.

Finally, survival rates were varied based on the presence or absence of barred owls, and the magnitude of their effect was based on the best meta-analysis model for survival with an additive barred owl covariate across all DSAs from Forsman *et al.* (2011). These values were stratified by both stage class and resource class.

Evaluation of Model Calibration

The HexSim model simulated a females-only population of spotted owls throughout their range. The principal metric used to evaluate the model was the simulated population size. The numbers of female spotted owls were tracked range-wide, per modeling region, and also per DSA. The model's performance was assessed by comparing all three measures of simulated population size to field data. We compared simulation year 50 HexSim estimates to field data for 8 DSAs. For this comparison, we used the HexSim simulations during which barred owl impacts were inserted during year (or time-step) 40. After barred owl impacts were incorporated at time-step 40, they remained constant for the remaining 210 time-steps. For these simulations we did not attempt to back-cast barred owl "invasion" dynamics. Our "scenario", therefore, predisposed barred owl impacts to occur all at once, not incremented. We determined by inspection that simulation year 50 most closely represented the present day.

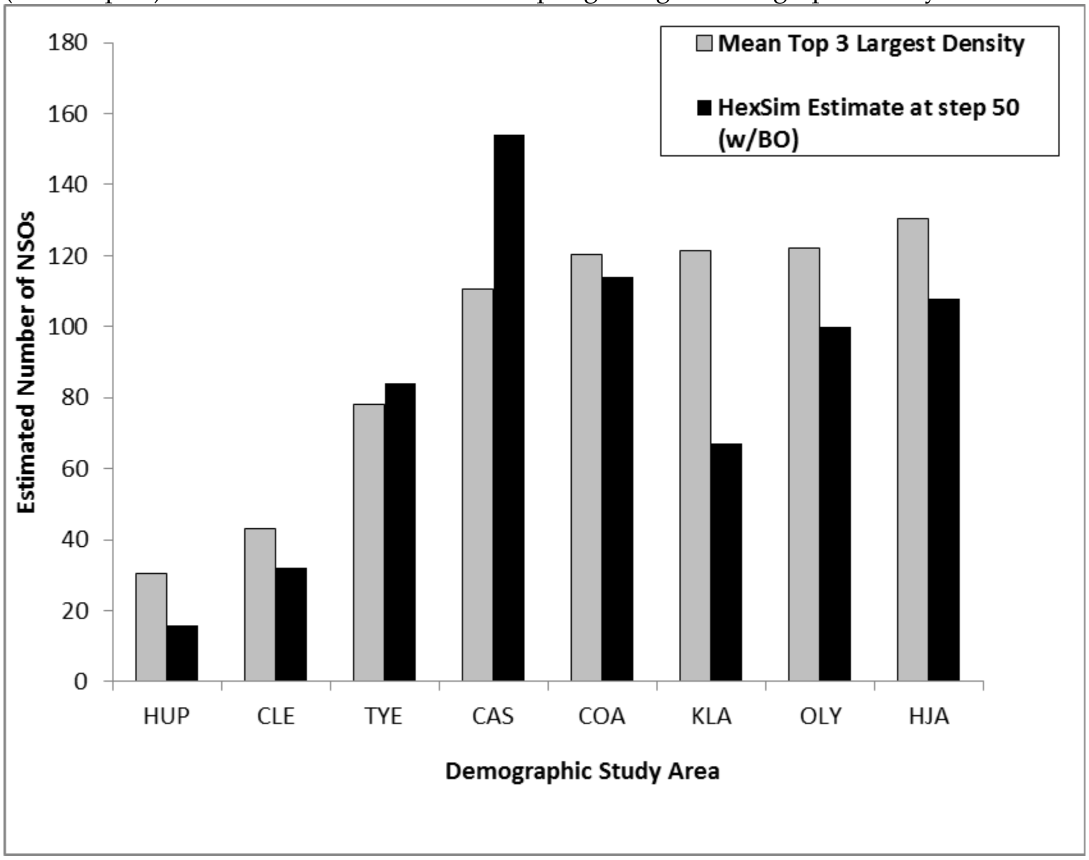
HexSim simulations are stochastic, and to quantify population size, the mean was taken from 5 replicate simulations. Each simulation was 250 time-steps (years) in duration. This does not suggest that spotted owl population sizes were forecasted 250 years into the future. Doing so would at minimum require performing the simulations with a series of maps illustrating habitat changes through time. In contrast, these initial simulations were performed with static data from year 0 to year 40, then (if changes were introduced) changes in barred owl or RHS were introduced and remained static until year 250. The length of the simulations (250 years) simply allowed a steady-state population size and trend to be estimated.

Most, but not all DSAs had data that could be used to approximate density of female spotted owls. Additionally, not all DSAs functioned as "density study areas", and they did not always sample spotted owls identically, nor present data consistently (among DSAs at least). Nonetheless, most DSA annual reports contained tables of historic data which revealed trends. For calibration purposes data from the following DSAs were used: Cle-Elum, Olympic, Oregon Coast, HJ Andrews, Tyee, Klamath, Cascades, and Hoopa. Several calibration iterations were performed by varying resource requirements one modeling region at a time.

Discrepancies in the fit between simulated and observed population size were addressed by varying the resource targets (described above). The resource targets were specified on a modeling-region basis, and they indicated how much resource an individual spotted owl living in a specific region would attempt to acquire. The resource targets were a proxy for resource availability, which varied from region to region and was not fully captured in the RHS maps. As the resource targets increased, individual spotted owl's needs for resources increased. An inability to acquire sufficient resources could cause spotted owls to drop into the lower resource acquisition classes, which would then lower their survival rates.

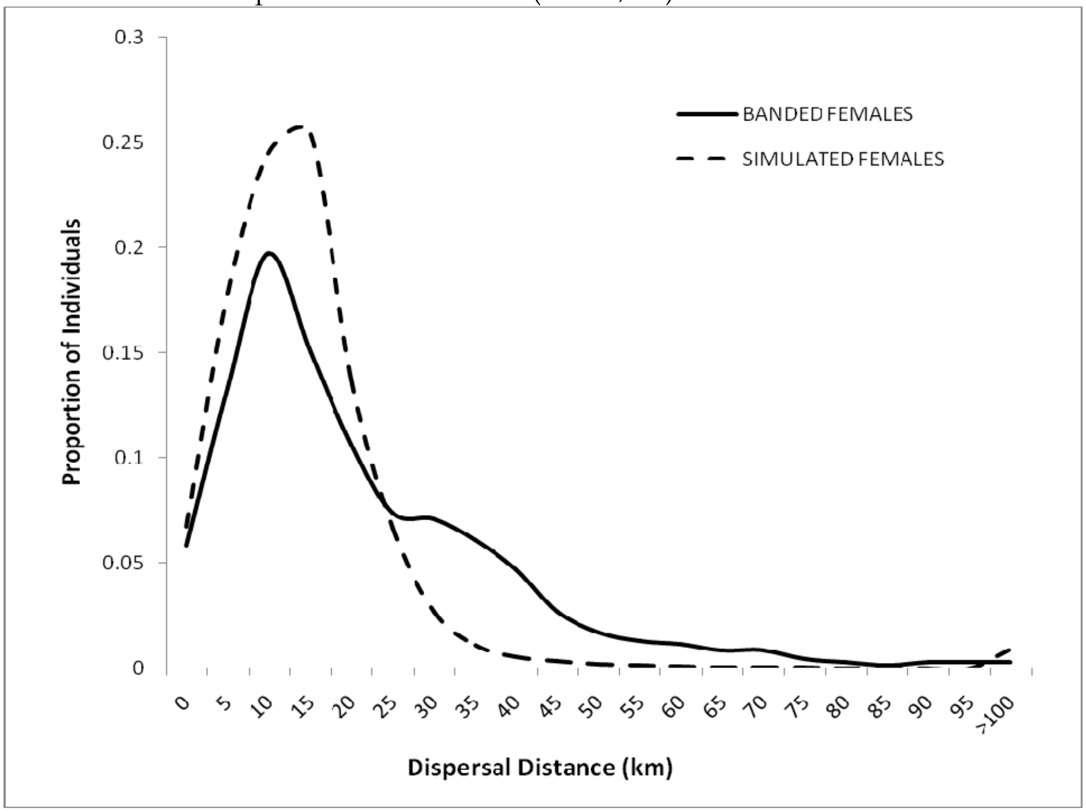
The Baseline HexSim simulations, in which barred owl impacts were introduced at time-step 40, then held static, produced an estimated total female spotted owl population size within the eight DSAs of 675. From field sampling, the total estimated female spotted owls in those DSAs based on the largest number recorded between 1996 and 2006 was 778. The average of the three highest density years from the annual reports (using only data from 1996-2006) for total estimated spotted owl females was 756. The mean of the highest three years (1996-2006) was selected instead of the highest single year in order to reduce the chance that a single year was uncharacteristic of the DSA (Figure C14). Differences in number of female spotted owls on the eight DSAs between those estimated from field sampling and those estimated from our HexSim runs ranged from 5% to 47%, with a mean absolute percentage difference of 26%. Subsequent changes to HexSim did not eliminate these differences.

Figure C-14. Model calibration: Comparison of simulated spotted owl population size (time step 50) to estimates based on field sampling in eight Demographic Study Areas.



Dispersal is a critical process through which landscape structure impacts spotted owl population size and meta-population structure, and is a primary concern in habitat conservation network design (Murphy and Noon 1992). Of particular importance is natal dispersal; the movements of juvenile spotted owls between their natal site and the site where they eventually establish breeding territories. We evaluated the performance of HexSim relative to natal dispersal by comparing graphs of simulated versus observed natal dispersal displacement distances (Figure C15). HexSim generates reports of annual dispersal events by non-territorial (juvenile and floater) spotted owls. The dispersal behavior of the simulated spotted owls was affected principally by landscape structure, the dispersal stopping criteria, and the amount of autocorrelation (both discussed above). Observed natal dispersal distances were estimated from movements of banded spotted owls (Forsman *et al.* 2002).

Figure C-15. Model calibration: Comparison of natal dispersal distances of banded female spotted owls (N= 328) from Forsman *et al.* (2002) to simulated natal dispersal distances for female spotted owls in HexSim (N=850,000).



Because our HexSim spotted owl scenario consists solely of females, we limited the comparison to banded female spotted owls. The distributions of natal dispersal distances for 328 banded female spotted owls were generally similar to 850,000 natal dispersal events recorded during a 250 time-step (years) HexSim simulation. The majority of both observed and simulated dispersal distances were between one and 25 km, however, about 10 % fewer simulated dispersal distances were greater than 10 km and 20% fewer were greater than 25 km.

Uncertainties and Limitations

An important goal of the spatial population modeling effort is to provide a tool to evaluate and compare the suitability of suites of habitat conservation network scenarios. Each scenario represents a unique ensemble of conditions that could affect future spotted owl population size and trends. The overall amounts of spotted owl habitat, the arrangement of habitat conservation networks, and barred owl influences will vary from scenario to scenario.

Several conclusions about each scenario could be drawn from the HexSim spotted owl simulations. Very specific results, such as estimates of absolute population size, will be the most sensitive to parameter uncertainties. Less specific conclusions, such as the relative differences between scenarios, will be increasingly robust. The HexSim simulations provide, at a minimum, a repeatable methodology for qualitatively ranking the efficacy of the habitat conservation scenarios. This analysis might also extend further, to include a quantification of individual reserve or block carrying capacities, and attendant probabilities of extinction. The conclusions that are drawn from a simulation model must balance concern over uncertainties with the desire to preserve a threatened species.

The HexSim spotted owl simulation model resulted from an attempt to construct the simplest model that could do a credible job of ranking habitat conservation network scenarios. HexSim makes adding realism relatively simple. But more life history detail does not automatically translate into more accurate forecasts. Realism comes at a cost since complex models have larger numbers of parameters, and thus greater data requirements.

There are many details that could be added to the existing HexSim simulation model. Examples include environmental stochasticity, the explicit modeling of spotted owl males (including mate-finding and pairing) and barred owl populations, genetics, disturbance regimes such as fire, etc. Some of these "enhancements" might provide more accurate forecasts of future spotted owl population sizes and probabilities of extinction, and decisions whether to incorporate some of them can be made in the future by model users depending on their specific needs. These enhancements, however, are not necessary in order to reliably rank habitat conservation network scenarios based on their likelihood of facilitating recovery of the spotted owl.

The modeling team considered several enhancements that could be added to the current HexSim spotted owl model. Some enhancements that might be made to the HexSim model are listed below.

Environmental Stochasticity

Incorporation of environmental stochasticity into HexSim scenarios will be necessary when estimates of population size or extinction probability need to be made. However, the addition of environmental stochasticity is unlikely to change the order in which habitat conservation network scenarios rank (*i.e.*, from least to most likely to recover the spotted owl). Developing a modeling process to determine the rank-ordering of scenarios was the modeling team's primary goal, and environmental stochasticity was left out of these simulations in order to limit the computational burden associated with that analysis. Environmental stochasticity should be added to the HexSim model before it is used to estimate population sizes or extinction rates. At that time, the more variable model could be used to test a subset of the rank-ordering results obtained without environmental stochasticity. Recent research into the effects of variability in climate on spotted owl demographic rates (Glenn *et al.* 2010) suggested adding realistic variation in annual temperature and precipitation would provide an important element of environmental stochasticity into HexSim simulations.

Effect of relative habitat suitability on reproductive rates

The HexSim spotted owl model links habitat to survival rates through resource acquisition. Individual spotted owls acquire resources from their simulated home ranges, and home ranges with higher RHS values provide greater resources. But home ranges overlap, and competition between spotted owls will lower resource availability. Resource acquisition, because it links landscape structure and intra-specific competition, is a more realistic driver of survival rates than habitat would be on its own. Resource acquisition could easily influence reproduction in exactly the same way that it influences survival. Unfortunately, the most recent meta-analysis (Forsman *et al.* 2011) was inconclusive regarding the role that habitat played in determining reproductive rates. For this reason, the modeling team elected to not vary spotted owl reproductive rates as a function of resource acquisition.

Effect of barred owls on reproductive rates

The HexSim spotted owl model includes the machinery necessary for barred owl influences to include a lowering of spotted owl reproductive rates. This is done by setting a probability that a spotted owl in the presence of a barred owl will nest. Each year, every affected territorial spotted owl will make an independent nesting decision, based on this probability. However, in the current model, the probability that a spotted owl in the presence of a barred owl will forgo nesting entirely is set to zero.

Modeling team members determined that range-wide empirical estimates were not sufficient to assign region-by-region probabilities for barred owl impacts on spotted owl reproduction. Such impacts could come in several forms. For example, the presence of a barred owl could cause a spotted owl to abandon its territory, to keep the territory but forgo nesting (or calling for a mate), or a barred owl could lower effective spotted owl reproductive rates by interfering with nest-tending or preying on spotted owl offspring.

In order to simulate territory abandonment, it would be necessary to explicitly model barred owl locations across the landscape. But sufficient data on barred owl locations and habitat associations were not available range-wide to permit doing more than setting region-by-region probabilities of barred owl occurrence. Simulating barred owl predation on spotted owl offspring runs the risk of double-counting this impact, since barred owl presence does lower survival rates in the HexSim spotted owl model. As described above, the model is able to simulate a lowering of spotted owl nesting rates (when in the presence of a barred owl). But sufficient data was not available range-wide to do more than speculate on the associated parameter values.

Interaction between habitat and barred owl effect

By incorporating the barred owl into the spotted owl scenario as a dynamic spatially explicit stressor, the influence of habitat on barred owl presence and barred owls effects to spotted owl occupancy (extinction rates), recruitment and survival could be more realistically simulated. While there is new information suggesting that habitat and barred owl effects may interact, the data necessary to develop reliable models of barred owl habitat suitability (and subsequently, distribution) are not available. For this reason, the modeling team elected not to attempt this. Moreover, outcomes of modeling region-specific simulations suggest that the current barred owl parameterization is realistic; low to intermediate barred owl encounter probabilities act to depress spotted owl populations but do not result in extinction.

Sensitivity analyses

When the HexSim spotted owl model is used to make estimates of population size, or probabilities of extinction, it will be necessary to also conduct a sensitivity analysis. The modeling team has conducted some work on a traditional sensitivity analysis. Whereas a traditional sensitivity analysis is focused on making small changes to individual parameter values, it would be instructive to complement this work with an assessment of the consequences of varying elements of the model structure itself. Examples of model design elements that might be varied include the lack of direct effects of resource acquisition on reproductive rates, the number of resource acquisition levels being simulated, and some of the behavioral features associated with dispersal and prospecting.

The most important parameters in any model of the spotted owl are going to be the survival and reproductive rates. The rates used in the HexSim survival and reproduction events have been derived from the most recent compendium of spotted owl field data (Forsman *et al.* 2011). Still, some uncertainty is introduced when these survival data are used to assign rates to spotted owls in three different resource acquisition classes, as that process involves extrapolation. We therefore elected not to use a larger number of resource acquisition classes. Likewise, the impact of barred owls on spotted owl reproduction is not perfectly understood, and certainly varies from region to region (as we represent in the HexSim scenarios).

One element of realism that the modeling team deemed necessary for this analysis was ensuring that the simulated spotted owls' home ranges and resource requirements varied by modeling region. The variation in home range size is supported by much published information (see review in Schilling 2009). The variation in resource requirements was used to account for regional differences in resource availability that were not captured in the MaxEnt resource map. In areas where the resource availability was known to be lower, spotted owls were assigned a higher resource requirement. The resource requirements were used as a fitting parameter that made it possible to adjust regional population sizes independently.

The HexSim spotted owl model described here is simple, but not overly so. It is likely the most realistic spatially-explicit individual-based spotted owl simulation that has been developed to-date. Its design and complexity mirror what is being asked of it. Additional complexity may be added at a future time as needed to meet the goals that accompany other planning exercises.

Testing Modeling Process Applications – Using the HexSim Spotted Owl Scenario model to compare the demographic effectiveness of various habitat conservation network scenarios and other recovery strategies:

For the Revised Recovery Plan, the modeling team's objective was to develop and test a modeling framework (Steps 1-3) that would support a wide variety of recovery actions, including evaluation of habitat conservation network scenarios. To facilitate the implementation of recovery actions contained in the Revised Recovery Plan, the modeling team established a process for developing scenarios and conducted preliminary population simulations to compare a sample of habitat conservation network scenarios in order to test the modeling framework's reliability. The results from these preliminary comparisons were necessary in order to obtain feedback on the overall framework and provided the basis for revisions to the HexSim model. This objective was completed as part of the recovery planning process. The following evaluation consists of the actual comparison of simulated spotted owl population responses among many alternative scenarios representing various recovery strategies and habitat conservation networks.

<u>Development of Scenarios for Evaluation and Comparison in HexSim</u>

An important use of the modeling framework is to simulate spotted owl population performance relative to three primary sources of variation: size (area) and distribution of habitat conservation networks; trends in habitat conditions inside and outside of the habitat conservation networks; and trends in the influence of barred owls. Considering the many possible variations in network designs, land ownership limitations, future habitat trends, and barred owl effects that could be evaluated, it is clear the number of scenarios needed to evaluate all of the possibilities could increase rapidly and become unfeasible. Instead, the modeling team developed an iterative process for evaluation of scenarios; establishing broad sideboards in earlier comparisons, then testing the models' sensitivity to habitat conditions and barred owl effects. The HexSim spotted owl model can also be used to evaluate the response of spotted owl populations to future climate scenarios.

To test the modeling framework's ability to evaluate the influence of habitat conservation network size (area) and spatial distribution on spotted owl population performance, we analyzed a subset of 10 habitat conservation network scenarios from Step 2 representing a wide range of sizes (proportions of "habitat value"), as well as existing habitat conservation networks (Table C28).

Table C-28. Initial set of habitat conservation networks evaluated in population modeling Rounds 1-3.

Network **scenario**	**Code**
Northwest Forest Plan Reserve Network	**NWFP**
Managed Owl Conservation Areas	**MOCA**
1992 Critical Habitat	**1992CH**
2008 Critical Habitat	**2008CH**
30% Zonation (All Lands Available)	**Z30all**
50% Zonation (All Lands Available)	**Z50all**
70% Zonation (All Lands Available)	**Z70all**
30% Zonation (Public Lands Only)	**Z30pub**
50% Zonation (Public Lands Only)	**Z50pub**
70% Zonation (Public Lands Only)	**Z70pub**

Maps depicting each of the network scenarios listed above are available at: http://www.fws.gov/oregonfwo/Species/Data/NorthernSpottedOwl/Recovery/Library/Default.aspx#Files
Once there, click on "maps" and "AppendixCMaps.pdf" The layers can be turned on and off using the "layers" button in the upper left-hand corner.

The habitat conservation networks listed in Table C28 form the basis for a series of comparisons in the population modeling environment (called Rounds) wherein different environmental conditions such as barred owl effects and habitat conditions are manipulated both spatially and temporally (scenarios). Each habitat conservation network that is subjected to different conditions is termed a habitat conservation network scenario. Rounds simply articulate the specific modifications that are made. The following paragraphs provide descriptions of the scenarios developed by the modeling team, and the results of HexSim runs for the scenarios in Rounds 1-3.

Interpreting HexSim results:

Each HexSim simulation run provides estimates of population size at any chosen time period as well as population trend over any range of time steps. Estimates are reported at both range-wide and regional scales. It is important to recognize that the results are intended to allow comparison of *relative population performance* among alternative habitat conservation network scenarios, not predictions of actual population size or trend in the future.

When a HexSim simulation starts, the number of individuals, age class distribution, spatial arrangement of territories, and other population attributes will have values that reflect the model's initial conditions. It takes many years for these artifacts to subside, and thus for the population's stable-state dynamics to become evident. Simulations were started with 10,000 female spotted owls, thus this initial period of transitory dynamics involved a period of rapid (apparent) population decline for the first 25 or 30 time-steps; typically subsiding by approximately time step 50. It is important not to confuse this decline with an observed or predicted loss in spotted owl numbers that has resulted from changing environmental conditions. We could have chosen to begin simulations with many fewer spotted owls than are known to currently exist in the landscape (say 250), and waited many time-steps for them to increase and reach some sort of equilibrium with their simulated landscape. That would have resulted in a rapid (apparent) population *increase*, but again would simply be the transitory dynamics involved with the starting population conditions. The point is that the first 25-30 time steps are not meant to be interpreted, but can be thought of as a "burn-in" period for the simulation whereby the simulated spotted owls equilibrate with the simulated environment.

Round 1: Baseline (2006) conditions

This was the simple "Baseline" scenario that was used to evaluate parameterization of the HexSim spotted owl scenario. This scenario assumes no change in habitat through time (2006 RHS map); therefore the 10 habitat conservation networks listed above are not compared (because nothing different happens inside and outside of habitat blocks in this scenario). Also, barred owl effects remain constant over time (either at zero or constant at their currently-estimated impacts, beginning at time step 40).

Figures C16 through C18 highlight differences in the relative influence of barred owls among modeling regions. Rangewide, barred owls act to depress spotted owl populations to roughly 50 percent of potential population size without barred owls (Figure C16). However, spotted owl populations in modeling regions with high barred owl encounter rates such as the Oregon Coast Ranges (P_{BO} = 0.710; figure C17) decline rapidly in comparison to modeling regions with low to intermediate barred owl encounter rates such as the Western Klamath (P_{BO} = 0.315; figure C18).

Figure C-16. Results of HexSim Round 1 model runs with five replicates each for "Without STVA" (barred owl) impacts and "With STVA" impacts for the spotted owl's entire geographic range in the U.S. The apparent within-year variation that appears in the figure is a function of an "even-odd" year effect on reproduction that was included in this version of the HexSim model.

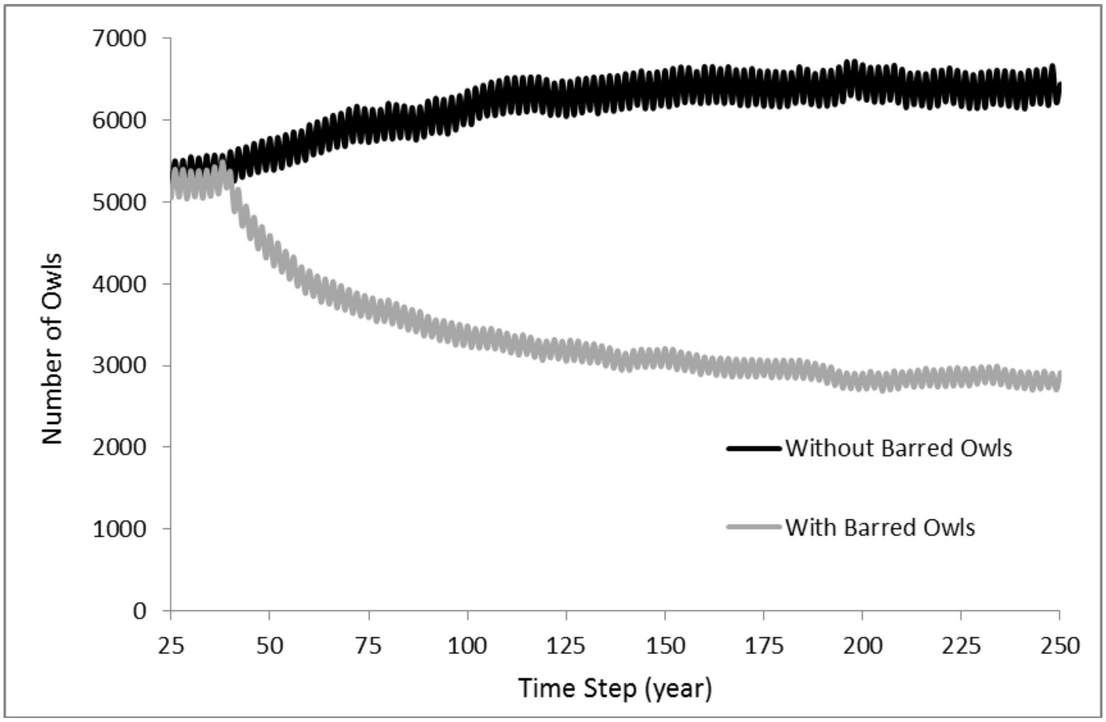


Figure C-17. Simulated Round 1 spotted owl population sizes in the Oregon Coast Ranges modeling region showing 1) current barred owl influence and 2) barred owl influence removed.

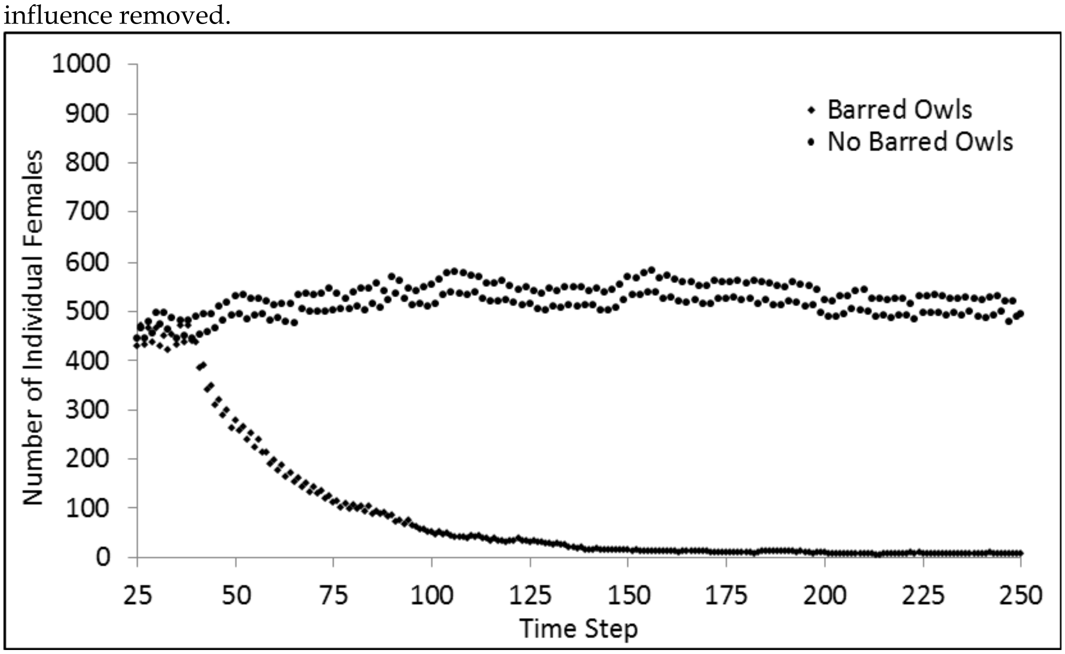
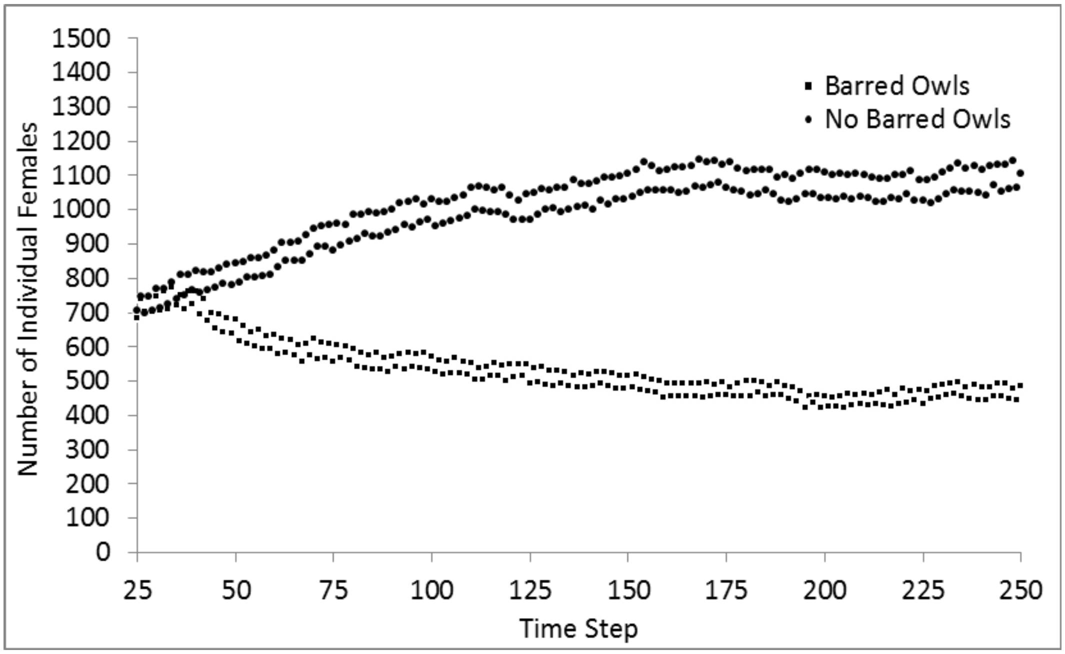


Figure C-18. Simulated Round 1 spotted owl population sizes in the Western Klamath modeling region showing 1) current barred owl influence, and 2) barred owl influence removed.



Round 2: Simulating a high degree of reliance on habitat conservation networks

Because the primary objective in this evaluation is to compare estimated spotted owl population performance across a range of habitat conservation network, the goal of Round 2 was to "isolate" the habitat conservation networks by devaluing non-network habitat suitability and holding habitat in networks at its 2006 estimated level throughout the simulation. In this scenario, we reduced relative habitat suitability (RHS) *outside* of habitat conservation networks to 34 (RHS=0.34); *just below* that needed for territory establishment; RHS within networks remained unchanged. The influence of barred owls was held to the currently-estimated encounter rates calculated from Forsman *et al.* (2011); the barred owl influence was slotted in at year 40. We repeated Round 2 with *No barred owl effect*, to evaluate the relative contribution of habitat and barred owl effects on simulated spotted owl population performance. The results of the Round 2 simulations allow for an evaluation of the relative influence of habitat conservation network size and distribution (relying primarily on public versus both public and private lands) and barred owls on spotted owl population performance – when the habitat conservation network provides nearly all nesting and roosting habitat.

Round 3: Simulating RA10 - retention of high-value habitat outside of habitat blocks

The goal of Round 3 was to evaluate the relative contribution of habitat conditions ***outside*** of habitat conservation networks to spotted owl populations; Scenarios R3S1 through R3S10 are intended to emulate the management approach of maintaining occupied spotted owl territories outside of network areas . RHS within habitat conservation networks was held constant, and areas of high RHS (>50) *outside* of networks (on public lands) were retained through time. Areas of RHS between 35 and 49 (outside of networks) were decremented to RHS 34. Scenarios R3S11 through R3S20 were similar but apply to *all* non-network lands (public and private). We repeated Round 3 with *No barred owl effect*, to evaluate the relative contribution of habitat and barred owl effects on simulated spotted owl population performance.

Figures C19 and C20 provide examples of different metrics that can be used to compare estimated spotted owl population outcomes among habitat conservation network scenarios, in this case Rounds 2 and 3 described above. Initial results using a wide range of population metrics can provide insights for meeting the recovery criteria established in the Revised Recovery Plan. Comparison of these estimates of spotted owl population performance across the range of scenarios can inform evaluation of habitat conservation networks designed to lead to spotted owl recovery.

Figure C19 provides results for the entire range of the spotted owl, but as described in Round 1 and evidenced in Figure C20, it is important to recognize that population outcomes may differ markedly among modeling regions.

Figure C-19. Comparison of percent population change (rangewide) between year 25 and year 250 under the scenarios in Rounds 2 and 3, with and without barred owl influence. MOCAs and critical habitat were not compared for Round 3.

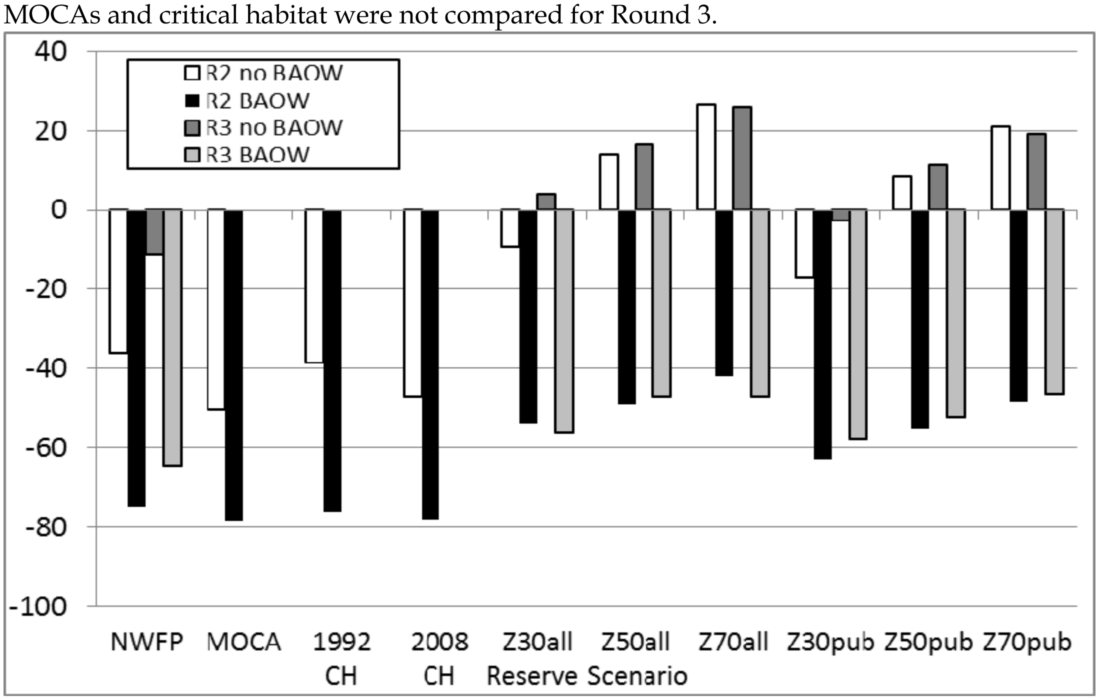
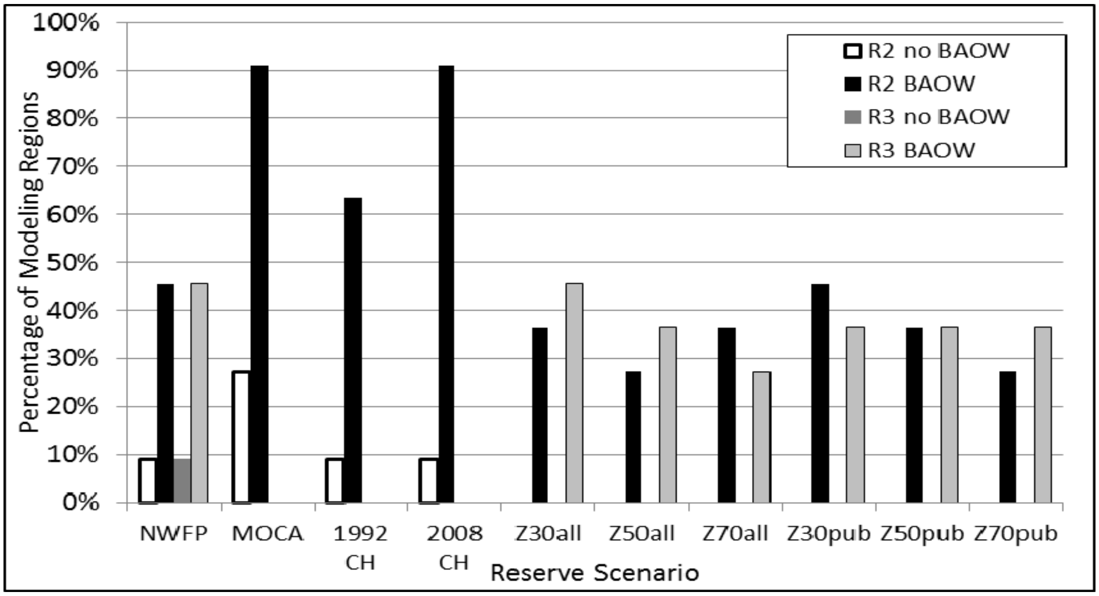


Figure C-20. Percentage of modeling regions whose simulated populations declined by more than 75% between years 25 and 250 (indication of extinction risk) under the scenarios in Rounds 2 and 3, with and without barred owl influence.



The interaction of network size with other conservation measures is highlighted in Figures C19 and C20. In Round 3 (simulated RA10 - retention of likely occupied, high-value habitat with RHS>50 in non-network areas), the amount of habitat "retained" is inversely proportional to the size of area within habitat conservation networks Subsequently, RA 10's benefit to simulated spotted owl populations is relatively less for larger habitat conservation network scenarios such as Z50 and Z70.

Conclusions:

The analysis presented in this appendix is intended to demonstrate how the three-part modeling framework can be used to evaluate spotted owl population response to a variety of environmental conditions such as habitat variation and barred owls. Although this initial analysis is intended to evaluate the modeling framework, it provides insight into factors influencing spotted owl populations and conservation planning for recovery of the spotted owl.

HexSim population simulations can be completed for the entire range of the spotted owl as well as for subsets of the species' range, such as individual modeling regions or DSAs. This capability enables evaluation of varying environmental conditions and subsequent population effects occurring in different parts of the species' range. For example, the relative effect of barred owls on spotted owl survival and subsequent population size varies among modeling regions, in accordance with different barred owl encounter rates (Table C29). Comparison of the relative differences between simulated spotted owl populations without barred owls and those resulting from different barred owl encounter rates among modeling regions (Figures C17 and C18) suggests there may be barred owl population levels (encounter rates) below which spotted owl populations remain stable (albeit at lower population sizes). Further evaluation of these relationships may inform planning of barred owl management scenarios.

Table C-29. Barred owl encounter probabilities estimated from Forsman *et al.* (2011).

Region	Encounter Probability
North Coast Olympics	0.505
East Cascades North	0.296
West Cascades North	0.320
West Cascades Central	0.320
Oregon Coast	0.710
West Cascades South	0.364
Inner CA Coast Range	0.213
East Cascades South	0.180
Klamath East	0.245
Klamath West	0.315
Redwood Coast	0.205

As shown in Figure C1, the modeling framework contains feedback loops that facilitate an iterative process, with each iteration informed by the results of previous scenarios and simulated population outcomes. This process enables an adaptive approach to developing and testing conservation measures. As new information from monitoring or other research becomes available, its influence on spotted owl conservation can be incorporated into subsequent evaluations in a consistent manner.

In sum, our goal was to develop a modeling framework that can be applied by interested parties to make better informed decisions concerning spotted owl management and recovery. The analyses described in this appendix represent a small subset of possible scenarios and are presented to test the framework and to give potential users of this approach some preliminary exposure to the models' potential utility. Future conservation planning for spotted owls will require development and evaluation of additional scenarios that are relevant to the management questions of particular interest to various stakeholders. These future planning efforts will likely address temporal factors such as changing barred owl populations, climate change, and future habitat change. They might also apply to private land managers who are evaluating different options within a Habitat Conservation Planning scenario, or Federal land managers who are considering recommendations for amending long-term forest management plans. Whatever the use to which this framework is applied, our goal was to provide managers with tools that will ultimately result in better informed decisions for spotted owl conservation.

Appendix D. References Cited

Literature Cited

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

Agee, J.K. 2002. The fallacy of passive management: managing for firesafe forest reserves. Conservation Biology in Practice 3:18–25.

Agee, J.K., and C.N. Skinner. 2005. Basic principles of forest fuel reduction treatments. Forest Ecology and Management 211:83–96.

Ager, A.A., M.A. Finney, B.K. Kerns and H. Maffei. 2007a. Modeling wildfire risk to northern spotted owl (*Strix occidentalis caurina*) habitat in Central Oregon, USA. Forest Ecology and Management 246:45–56.

Ager, A.A., A.J. McMahan, J.J. Barrett and C.W. McHugh. 2007b. A simulation study of thinning and fuel treatments on a wildland-urban interface in eastern Oregon, USA. Landscape and Urban Planning 80:292–300.

Akaike, H. 1974. A new look at statistical model identification. IEEE Transactions on Automatic Control. AU-19:716-722.

Allen, C.D., A.K. Macalady, H. Chenchouni, D. Bachelet, N. McDowell, M. Vennetier, T. Kitzberger, A. Rigling, D.D. Breshears, E.H Hogg, P. Gonzalez, R. Fensham, Z. Zhang, J. Castro, N. Demidova, J-H. Lim, G. Allard, S.W. Running, A. Semerci and N. Cobb. 2010. A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests. Forest Ecology and Management 259:660–684.

Allen, C.D., M. Savage, D.A. Kalk, K.F. Suckling, T.W. Swetnam, T. Schulke, P.B. Stacey, P. Morgan, M. Hoffman and J.T. Klingel. 2002. Ecological restoration of southwestern ponderosa pine ecosystems: a broad perspective. Ecological Applications 12(5): 1418–1433.

Alexander, J.D., N.E. Seavy, C.J. Ralph and B. Hogoboom. 2006. Vegetation and topographical correlates of fire severity from two fires in the Klamath-Siskiyou region of Oregon and California. International Journal of Wildland Fire 15:237–245.

Amman, G.D., and W.E. Cole. 1983. Mountain pine beetle dynamics in lodgepole pine forests. Part II: population dynamics. General Technical Report INT-GTR-145, Intermountain Forest and Range Experiment Station, U.S. Department of Agriculture, Forest Service, Portland, Oregon.

Amman, G.D., and J.A. Logan. 1998. Silvicultural control of mountain pine beetle: prescriptions and the influence of microclimate. American Entomologist 44:166–177.

Anderson, D.R., and K.P. Burnham. 1992. Demographic analysis of northern spotted owl populations. Pages 319–328 in Draft final recovery plan for the northern spotted owl. U.S. Fish and Wildlife Service, Portland, Oregon.

Andrews, L.S., J.P. Perkins, J.A. Thrailkill, N.J. Poage and J.C. Tappeiner, II. 2005. Silvicultural approaches to develop northern spotted owl nesting sites, central Coast Ranges, Oregon. Western Journal of Applied Forestry 20:13–27.

Anthony, R.G., and L.S. Andrews. 2004. Summary Report: Winter habitat use by spotted owls on USDI Bureau of Land Management Medford District Lands within the boundaries of the Timbered Rock Fire. Unpublished report, Oregon Cooperative Wildlife Research Unit, Corvallis, Oregon.

Anthony, R.G., and F.F. Wagner. 1999. Reanalysis of northern spotted owl habitat use on the Miller Mountain Study Area. Unpublished report. Submitted to Bureau of Land Management, Medford District and Forest and Rangeland Ecosystem Science Center, Biological Resources Division, U.S. Geological Survey.

Anthony, R.G., E.D. Forsman, A.B. Franklin, D.R. Anderson, K.P. Burnham, G.C. White, C.J. Schwarz, J. Nichols, J.E. Hines, G.S. Olson, S.H. Ackers, S. Andrews, B.L. Biswell, P.C. Carlson, L.V. Diller, K.M. Dugger, K.E. Fehring, T.L. Fleming, R.P. Gerhardt, S.A. Gremel, R.J. Gutiérrez, P.J. Happe, D.R. Herter, J.M. Higley, R.B. Horn, L.L. Irwin, P.J. Loschl, J.A. Reid and S.G. Sovern. 2006. Status and trends in demography of northern spotted owls, 1985–2003. Wildlife Monograph No. 163.

Anthony, R.G., M.A. O'Connell, M.M. Pollock and J.G. Hallett. 2003. Associations of mammals with riparian ecosystems in Pacific Northwest forests. Pp. 510–563 in C.J. Zabel and R.G. Anthony (editors), Mammal Community Dynamics: Management and Conservation in the Coniferous Forests of Western North America. Cambridge University Press, Cambridge, England.

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

Bailey, L.L., J.A. Reid, E.D. Forsman and J.D. Nichols. 2009. Modeling co-occurrence of northern spotted and barred owls: accounting for detection probability differences. Biological Conservation 142:2983–2989.

Baker, W.L. 1994. Restoration of landscape structure altered by fire suppression. Conservation Biology 8:763–769.

Baker, W.L., T.T. Veblen and R.L. Sherriff. 2007. Fire, fuels, and restoration of ponderosa pine-Douglas-fir forests in the Rocky Mountains, USA. Journal of Biogeography 4:251–269.

Barber, V.A., G.P. Juday and B.P. Finney. 2000. Reduced growth of Alaskan white spruce in the twentieth century from temperature-induced drought stress. Nature 405:668–673.

Barrowclough, G.F., and S. Coats. 1985. The demography and population genetics of owls, with special reference to the conservation of the spotted owl (*Strix occidentalis*). Pages 74–85 in R.J. Gutiérrez and A.B. Carey (editors), Ecology and management of the Spotted Owl in the Pacific Northwest. General Technical Report PNW-GTR-185, Pacific Northwest Research Station, U.S. Department of Agriculture, Forest Service, Portland, Oregon.

Barrowclough, G.F., and R. J. Gutiérrez. 1990. Genetic variation and differentiation in the spotted owl. Auk 107:737–744.

Barrowclough, G.F., J.G. Groth and R.J. Gutiérrez. 2005. Genetic structure, introgression and a narrow hybrid zone between northern and California spotted owls (*Strix occidentalis*). Molecular Ecology 14:1109–1120.

Barrowclough, G.F., R.J. Gutiérrez and J.G. Groth. 1999. Phylogeography of spotted owl (*Strix occidentalis*) populations based on mitochondrial DNA sequences: gene flow, genetic structure, and a novel biogeographic pattern. Evolution 53:919–931.

Barrows, C.W. 1981. Roost selection by spotted owls: an adaptation to heat stress. Condor 83:302–309.

Barrows, C., and K. Barrows. 1978. Roost characteristics and behavioral thermoregulation in the spotted owl. Western Birds 9:1–8.

Bart, J. 1995. Acceptance criteria for using individual-based models to make management decisions. Ecological Applications 5(2):411–420.

BCMFR (British Columbia Ministry of Forests and Range). Undated. An Introductory Guide to Adaptive Management for Project Leaders and Participants. Available on-line at <http://www.for.gov.bc.ca/hfp/amhome/Training/am-intro-guide.htm>. Accessed January 2, 2011.

Beaty, R.M., and A.H. Taylor. 2008. Fire history and the structure and dynamics of a mixed conifer forest landscape in the northern Sierra Nevada, Lake Tahoe Basin, California, USA. Forest Ecology and Management 255:707–719.

Bebi, P., D. Kulakowski and T.T. Veblen. 2003. Interactions between fire and spruce beetles in a Subalpine Rocky Mountain Forest Landscape. Ecology 84:362-371.

Beschta R.L., J.J. Rhodes, J.B. Kauffman, R.E. Gresswell, G.W. Minshall, J.R. Karr, D.A. Perry, F.R. Hauer and C.A. Frissell. 2004. Postfire management on forested public lands of the western United States. Conservation Biology 18:957–967.

Bevis, K.R., G.M. King and E.E. Hanson. 1997. Spotted owls and 1994 fires on the Yakama Indian Reservation. Pages 117–122 in J.M. Greenlee (editor), Proceedings of the First Conference on Fire Effects on Rare and Endangered Species and Habitats. International Association of Wildland Fire, Coeur d'Alene, Idaho.

Bigler, C., D. Kulakowski and T.T. Veblen. 2005. Multiple disturbance interactions and drought influence fire severity in Rocky Mountain Subalpine forests. Ecology 86:3018–3029.

Bigley, R., and J. Franklin. 2004. Habitat trends. Chapter 6 in S. Courtney (editor), Scientific evaluation of the status of the northern spotted owl. Sustainable Ecosystems Institute, Portland, Oregon.

Bingham, B.B., and B.R. Noon. 1997. Mitigation of habitat "take": Application to habitat conservation planning. Conservation Biology 11(1): 127-139.

Bingham, B., and B.R. Noon. 1998. The use of core areas in comprehensive mitigation strategies. Conservation Biology 12(1):241–243.Blakesley, J.A., W. LaHaye, J.M.M. Marzluff, B.R. Noon and S. Courtney. 2004. Demography. Chapter 8 in S. Courtney (editor), Scientific evaluation of the status of the northern spotted owl. Sustainable Ecosystems Institute, Portland, Oregon.

Blakesley, J.A., A.B. Franklin and R.J. Gutierrez. 1992. Spotted owl roost and nest site selection in northwestern California. Journal of Wildlife Management 56(2):388-392.

Blakesley, J.A. 2004. Habitat Associations. Chapter 5 *in* S.P. Courtney, J.A. Blakesley, R.E. Bigley, M.L. Cody, J.P. Dumbacher, R.C. Fleischer, A.B. Franklin, J.F. Franklin, R.J. Gutiérrez, J.M. Marzluff and L. Sztukowski. Scientific evaluation of the status of the northern spotted owl. Sustainable Ecosystems Institute, Portland, Oregon.

Blate, G.M., L.A. Joyce, J.S. Littell, S.G. McNulty, C.I. Millar, S.C. Moser, R.P. Neilson, K. O'Halloran and D.L. Peterson. 2009. Adapting to climate change in United States national forests. Unasylva 231/232. Vol. 60:57–62.

Bond, M.L., R.J. Gutiérrez, A.B. Franklin, W.S. LaHaye, C.A. May and M.E. Seamans. 2002. Short-term effects of wildfires on spotted owl survival, site fidelity, mate fidelity, and reproductive success. Wildlife Society Bulletin 30:1022–1028.

Bond, M.L., D.E. Lee, R.B. Siegel and J.P. Ward, Jr. 2009. Habitat use and selection by California spotted owls in a postfire landscape. Journal of Wildlife Management 73:1116–1124.

Bond, M.L., D.E. Lee and R.B. Siegel. 2010. Winter movements by California spotted owls in a burned landscape. Western Birds 41:174–180.

Bormann, B.T., R.W. Haynes and J.R. Martin. 2007. Adaptive management of forest ecosystems: did some rubber hit the road? BioScience 57:186–191.

Bormann, B.T., J.A. Laurence, K. Shimamoto, J. Thrailkill, J. Lehmkuhl, G. Reeves, A. Markus, D.W. Peterson and E.D. Forsman. 2008. A regional management study template for learning about postwildfire management. General technical Report PNW-GTR-777, Pacific Northwest Research Station, U.S. Department of Agriculture, Forest Service, Portland, Oregon.

Breiman, L. 2001. Statistical modeling: the two cultures. Statistical Science. 16(3):199-231.

Breshears, D.D., N.S. Cobb, P.M. Rich, K.P. Price, C.D. Allen, R.G. Balice, W.H. Romme, J.H. Kastens, M.L. Floyd, J.Belnap, J.J. Anderson, O.B. Myers and C.W. Meyer. 2005. Regional vegetation die-off in response to global-change-type drought. Proceedings of the National Academy of Sciences 102:15144–15148.

Brookes, M.H., R.W. Campbell, J.J. Colbert, R.G. Mitchell and R.W. Stark. (technical coordinators). 1987. Western spruce budworm. Technical Bulletin Number 1694. U.S. Department of Agriculture, Forest Service, Cooperative Research Station.

Brown, P.M., C.L. Wienk and A.J. Symstad. 2008. Fire and forest history at Mount Rushmore. Ecological Applications 18:1984–1999.

Buchanan, J.B. 2004. Managing habitat for dispersing northern spotted owls – are the current management strategies adequate? Wildlife Society Bulletin 32:1333–1345.

Buchanan, J.B. 2005. Barred Owl. Pages 218–219 in Birds of Washington: status and distribution. T. R. Wahl, B. Tweit, and S. G. Mlodinow (editors), Oregon State University Press, Corvallis.

Buchanan, J.B. 2009. Balancing competing habitat management needs for northern spotted owls and other bird species in dry forest landscapes. Pages 109–117 in: T.D. Rich, C. Arizmendi, D. Demarest, and C. Thompson (editors), Proceedings of the Fourth International Partners in Flight Conference: Tundra to Tropics. McAllen, Texas.

Buchanan, J., E. Hanson, D. Hays and L. Young. 1994. An evaluation of the Washington Forest Practices Board Wildlife Committee preferred alternative for a spotted owl protection rule. Washington Forest Practices Board Spotted Owl Scientific Advisory Group, Washington Department of Fish and Wildlife, Olympia, Washington.

Buchanan, J.B., L.L. Irwin and E.L. McCutchen. 1995. Within-stand nest site selection by spotted owls in the eastern Washington Cascades. Journal of Wildlife Management 59(2):301–310.

Burnham, K.P., D.R. Anderson and G.C. White. 1994. Estimation of vital rates of the northern spotted owl. Colorado Cooperative Fish and Wildlife Research Unit, Colorado State University, Ft. Collins, Colorado.

Caffrey, C. 2003. Determining impacts of West Nile Virus on crows and other birds. American Birds 57:12–13.

CFPR (California Forest Practice Rules). 2011. Title 14, California Code of Regulations, Chapters 4, 4.5, and 10. Compiled by The California Department of Foresty and Fire Protection Resource Management, Forest Practices Program. Sacramento, California.

Camp, A.E., C.D. Oliver, P.F. Hessburg and R.L. Everett. 1997. Predicting late-successional fire refugia from physiography and topography. Forest Ecology and Management 95:63–77.

Canadell, J.G., and M.R. Raupach. 2008. Managing forests for climate change mitigation. Science 320: 456–1457.

Carey, A.B. 1995. Sciurids in Pacific Northwest managed and old-growth forests. Ecological Applications 5(3):648–661.

Carey, A.B. 2000. Effects of new forest management strategies on squirrel populations. Ecological Applications 10(1):248–257.

Carey, A.B. 2003. Bioclomplexity and restoration of biodiversity in temperate coniferous forest: inducing spatial heterogeneity with variable-density thinning. Forestry 76:127–136.

Carey, A.B. 2007. AIMing for Healthy Forests: active, intentional management for multiple values. General Technical Report PNW-GTR-721, Pacific Northwest Research Station, U.S. Department of Agriculture, Forest Service, Portland, Oregon.

Carey, A.B., S.P. Horton and B.L. Biswell. 1992. Northern spotted owls: influence of prey base and landscape character. Ecological Monographs 62(2):223–250.

Carey, A.B., C.C. Maguire, B.L. Biswell and T.M. Wilson. 1999. Distribution and abundance of Neotoma in western Oregon and Washington. Northwest Science 73(2):65–80.

Carey, A.B., J.A. Reid and S.P. Horton. 1990. Spotted owl home range and habitat use in southern Oregon coast ranges. Journal of Wildlife Management 54:11–17.

Carroll, C. 2010. Role of climatic niche models in focal-species-based conservation planning: Assessing potential effects of climate change on northern spotted owls in the Pacific Northwest, USA. Biological Conservation 143:1432–1437.

Carroll, C., and D.S. Johnson. 2008. The importance of being spatial (and reserved): assessing northern spotted owl habitat relationships with hierarchical Bayesian models. Conservation Biology 22:1026–1036.

Carroll, C., J.R. Dunk and A. Moilanen. 2010. Optimizing resiliency of reserve networks to climate change: multispecies conservation planning in the Pacific Northwest. Global Change Biology 16:891-904.

Case, M.J., and D.L. Peterson. 2009. Growth-climate relations of lodgepole pine in the North Cascades National Park, Washington. Northwest Science 81:62–74.

Cayan, D.R., E.P. Maurer, M.D. Dettinger, M. Tyree and K. Hayhoe. 2008. Climate change scenarios for the California region. Climatic Change 87:S21–S42.

Charnley, S., E.M. Donogue, C. Stuart, C. Dillingham, L.P. Buttolph, W. Kay, R.J. McLain, C. Moseley, R.H. Philips and Lisa Tobe. 2006. Northwest Forest Plan–The First 10 Years (1994–2003): Socioeconomic Monitoring Results. General Technical Report PNW-GTR-649, Volume III, Pacific Northwest Research Station, U.S. Department of Agriculture, Forest Service, Portland, Oregon.

Chi, T., A. Henke, J. Smith and C. Brinegar. 2005. Spotted owl mitochondrial DNA haplotyping. San Jose State University. Unpublished results submitted to U.S. Fish and Wildlife Service.

Chutter, M.J., I. Blackburn, D. Bonin, J. Buchanan, B. Costanzo, D. Cunnington, A. Harestad, T. Hayes, D. Heppner, L. Kiss, J. Surgenor, W. Wall, L. Waterhouse and L. Williams. 2004. Recovery strategy for the northern spotted owl (*Strix occidentalis caurina*) in British Columbia. British Columbia Ministry of Environment, Victoria, Canada.

Clark, D.A. 2007. Demographic and habitat selection of northern spotted owls in post-fire landscapes of southwestern Oregon. Thesis, Oregon State University, Corvallis, Oregon.

Clark, D.A., R.G. Anthony and L.S. Andrews. 2011. Survival rates of northern spotted owls in post-fire landscapes of southwest Oregon. Journal of Raptor Research. 45:38-47.

Cohen, W.B., T.A. Spies, R.J. Alig, D.R. Oetter, T.K. Maiersperger and M. Fiorella. 2002. Characterizing 23 years (1972–95) of stand replacement disturbance in western Oregon forests with Landsat Imagery. Ecosystems 5:122–137.

Colgan, W., A.B. Carey, J.M. Trappe, R. Molina and D. Thysell. 1999. Diversity and productivity of hypogeous fungal sporocarps in a variably thinned Douglas-fir forest. Canadian Journal of Forest Research 29:1259–1268.

Collins, B.M., and S.L. Stephens. 2010. Stand-replacing patches within a 'mixed severity' fire regime: quantitative characterization using recent fires in a long-established natural fire area. Landscape Ecology. 25:927–939.

Colombaroli, D., and D.G. Gavin. 2010. Highly episodic fire and erosion regime over the past 2,000 y in the Siskiyou Mountains, Oregon. Available online at <www.pnas.org/cgi/doi/10.1073/pnas.1007692107>. Accessed 3 March 2011.

Conway, F.D.L., and G.E. Wells. 1994. Timber in Oregon: history and projected trends. Oregon State University Extension Service, EM 8544.

Courtney, S., and R. Gutiérrez. 2004. Chapter 11 in S. Courtney (editor), Scientific evaluation of the status of the northern spotted owl. Sustainable Ecosystems Institute, Portland, Oregon.

Courtney, S.P., J.A. Blakesley, R.E. Bigley, M.L. Cody, J.P. Dumbacher, R.C. Fleischer, A.B. Franklin, J.F. Franklin, R.J. Gutiérrez, J.M. Marzluff and L. Sztukowski. 2004. Scientific evaluation of the status of the northern spotted owl. Sustainable Ecosystems Institute, Portland, Oregon.

Crozier, M.L., M.E. Seamans, R.J. Gutiérrez, P.J. Loschl, R.B. Horn, S.G. Sovern and E.D. Forsman. 2006. Does the presence of barred owls suppress the calling behavior of spotted owls? Condor 108: 760–769.

Dale, V.H., L.A. Joyce, S. McNulty, R.P. Neilson, M.P. Ayres, M.D. Flannigan, P.J. Hanson, L.C. Irland, A.E. Lugo, C.J. Peterson, D. Simberloff, F.J. Swanson, B.J. Stocks and B.M. Wotton. 2001. Climate change and forest disturbances. BioScience 51:723–734.

Daley, C., D.R. Conklin and M.H. Unsworth. 2009. Short communication: local atmospheric decoupling in complex topography alters climate change impacts. International Journal of Climatology. Available online at <http://onlinelibrary.wiley.com/doi/10.1002/joc.2007/abstract>. Accessed 3 March 2011.

Dark, S.J., R.J. Gutiérrez and G.I. Gould, Jr. 1998. The Barred Owl (*Strix varia*) invasion in California. Auk 115:50–56.

Davies, B., S. Dettman, M. Goslin, M. Mertens and H. Silverman. 2011. Carbon Analysis of Proposed Forest Management Regimes on the Elliott State Forest. Ecotrust. Portland, OR. 36 pages.

Davis, R.J., and K.M. Dugger. In press. Habitat status and trend. In R. Davis (technical coordinator), Northwest Forest Plan—Status and Trend of Northern Spotted Owl Populations and Habitats from 1994 to 2008. General Technical Report PNW- GTR-###, Pacific Northwest Research Station, U.S. Department of Agriculture, Forest Service, Portland, Oregon.

Davis, R., and J. Lint. 2005. Habitat status and trends. Pages 21–82 in J. Lint, technical coordinator. Northwest Forest Plan—the first 10 years (1994–2003): status and trends of northern spotted owl populations and habitat. General Technical Report PNW-GTR-648, Pacific Northwest Research Station, U.S. Department of Agriculture, Forest Service, Portland, Oregon.

DellaSala, D.A., J.R. Karr, T. Schoennagel, D. Perry, R.F. Noss, D. Lindenmayer, R. Beschta, R.L. Hutto, M.E. Swanson and J. Evans. 2006. Post-fire logging debate ignores many issues. Science 314:51.

DellaSala, D.A., J.E. Williams, C. D Williams and J.F. Franklin. 2004. Beyond smoke and mirrors: a synthesis of fire policy and science. Conservation Biology 18:976–986.

Depro, B.M., B.C. Murray, R.J. Alig and A. Shanks. 2008. Public land, timber harvests, and climate mitigation: Quantifying carbon sequestration potential on U.S. public timberlands. Forest Ecology and Management 255:1122–1134.

Deubel, V., L. Fiette, P. Gounon, M.T. Drouet, H. Khun, M. Huerre, C. Banet, M. Malkinson and P. Despres. 2001. Variations in biological features of West Nile viruses. Annals of the New York Academy of Sciences 951:195–206.

Diller, L.V., and D.M. Thome. 1999. Population density of northern spotted owls in managed young-growth forests in coastal northern California. Journal of Raptor Research 33:275–286.

Donato, D.C., J.B. Fontaine, J.L. Campbell, W.D. Robinson, J.B. Kauffman and B.E. Law. 2006. Post-fire logging hinders regeneration and increases fire risk. Science 311:352.

Drever, C.R., G. Peterson, C. Messier, Y. Bergeron and M. Flannigan. 2006. Can forest management based on natural disturbances maintain ecological resilience? Canadian Journal of Forest Research 36:2285–2299.

Dugger, K.M., R.G. Anthony and L.S. Andrews. In Press. Transient dynamics of invasive competition: barred owls, spotted owls, habitat composition and the demons of competition present.

Dugger, K.M., R.G. Anthony and E.D. Forsman. 2009. Estimating northern spotted owl detection probabilites: updating the USFWS Northern Spotted Owl Survey Protocol. Final Report. Department of Fisheries and Wildlife, Oregon State University, Corvallis, Oregon.

Dugger, K.M., F. Wagner, R.G. Anthony and G.S. Olson. 2005. The relationship between habitat characteristics and demographic performance of northern spotted owls in southern Oregon. Condor 107:863–878.

Dukes, J.S., and H.A. Mooney. 1999. Does global change increase the success of biological invaders? Tree 14:135–139.

Dunk, J.R., W.J. Zielinski and H. Priestler. 2004. Predicting the occurrence of rare mollusks in northern California forests. Ecological Applications 14(3): 713-729.

Dunning, J.B., D.J. Stewart, B.J. Danielson, B.R. Noon, T.L. Root, R.H. Lamberson and E.E. Stevens. 1995. Spatially explicit population models: current forms and future uses. Ecological Applications 5:3-12.

Elith, J., C.H. Graham, R.P. Anderson, M. Dudik, S. Ferrier, A. Guisan, R.J. Hijmans, F. Huettmann, J.R. Leathwick, A. Lehmann, J. Li, L.G. Lohmann, B.A. Loiselle, G. Manion, C. Moritz, M. Nakamura, Y. Nakazawa, J. McC. Overton, A. Townsend Peterson, S.J. Phillips, K. Richardson, R. Scachetti-Pereira, R.E. Schapire, J. Sobero´n, S. Williams, M. S. Wisz and N.E. Zimmermann. 2006. Novel methods improve prediction of species' distributions from occurrence data. Ecography 29(2):129-151.

Elith, J., S.J. Phillips, T. Hastie, M. Dudik, Y.E. Chee and C.J. Yates. 2011. A statistical explanation of MaxEnt for ecologists. Diversity and distribution 17:43-57.

Elith, J., and J.R. Leathwick. 2009. Species distribution models: ecological explanation and prediction across space and time. Annual Review Ecology Evolution Systematics 40:677-697.

Elsner, M.M., L. Cuo, N. Voisin, J.S. Deems, A.F. Hamlet, J.A Vano, K.E.B. Michelson, S. Lee and D.P. Lettenmaier. 2009. Implications of 21st century climate change for the hydrology of Washington State. Pages 69–106 in M.M. Elsner, J. Littell and L.W. Binder (editors), The Washington climate change impacts assessment. Center for Science in the Earth System, Joint Institute for the Study of the Atmosphere and Oceans, University of Washington, Seattle.

Everett, R.L., R. Schellhaas, D. Keenum, D. Spurbeck and P. Ohlson. 2000. Fire history in the ponderosa pine/Douglas-fir forests on the east slope of the Washington Cascades. Forest Ecology and Management 129:207–225.

Feeney, S.R., T.E. Kolb, W.W. Covington and M.R. Wagner. 1998. Influence of thinning and burning restoration treatments on presettlement ponderosa pines at the Gus Pearson Natural Area. Canadian Journal of Forest Research. 28:1295–1306.

Fenger, M., J.B. Buchanan, T.J. Cade, E.D. Forsman, S.M. Haig, K. Martin and W.A. Rapley. 2007. Northern spotted owl population enhancement and recovery in British Columbia: proposed five-year action plan. Prepared by the Spotted Owl Population Enhancement Team for the government of British Columbia, Victoria, British Columbia, Canada.

Fettig, C.J., K.D. Klepzig, R.F. Billings, A.S. Munson, T.E. Nebeker, J.F. Negron and J.T. Nowak. 2007. The effectiveness of vegetation management practices for prevention and control of bark beetle infestations in coniferous forests of the western and southern United States. Forest Ecology and Management 238:24–53.

Fitzgerald, S.D., J.S. Patterson, M. Kiupel, H.A. Simmons, S.D. Grimes, C.F. Sarver, R.M. Fulton, B.A. Fulton, B.A. Steficek, T.M. Cooley, J.P. Massey and J.G. Sikarskie. 2003. Clinical and pathological features of West Nile Virus infection in native North American owls (family *Strigidae*). Avian Diseases 47:602–610.

Fleming, R.A., J-N. Candau and R.S. McAlpine. 2002. Landscape-scale analysis of interactions between insect defoliation and forest fire in central Canada. Climatic Change 55:251–272.

Forsman, E.D. 1975. A preliminary investigation of the spotted owl in Oregon. Thesis, Oregon State University, Corvallis.

Forsman, E.D. 1981. Molt of the spotted owl. Auk 98:735–742.

Forsman, E.D., R.G. Anthony, E.C. Meslow and C.J. Zabel. 2004. Diets and foraging behavior of northern spotted owls in Oregon. Journal of Raptor Research 38:214–230.

Forsman, E.D., R.G. Anthony, J.A. Reid, P.J. Loschl, S.G. Sovern, M. Taylor, B.L. Biswell, A. Ellingson, E.C. Meslow, G.S. Miller, K.A. Swindle, J.A. Thrailkill, F.F. Wagner and D.E. Seaman. 2002. Natal and breeding dispersal of northern spotted owls. Wildlife Monographs 149:1–35.

Forsman, E.D., R.G. Anthony, K.M. Dugger, E.M. Glenn, A.B. Franklin, G.C. White, C.J. Schwarz, K.P. Burnham, D.R. Anderson, J.D. Nichols, J.E. Hines, J.B. Lint, R.J. Davis, S.H. Ackers, L.S. Andrews, B.L. Biswell, P.C. Carlson, L.V. Diller, S.A. Gremel, D.R. Herter, J.M. Higley, R.B. Horn, J.A. Reid, J. Rockweit, J. Schaberl, T.J. Snetsinger and S.G. Sovern. 2011. Population demography of northern spotted owls: 1985–2008. Studies in Avian Biology. Cooper Ornithological Society.

Forsman, E.D., S. DeStefano, M.G. Raphael and R.J. Gutiérrez (editors), 1996. Demography of the northern spotted owl. Studies in Avian Biology No. 17.

Forsman, E.D, T.J. Kaminski, J.C. Lewis, K.J. Maurice, C. Ferland and E. M. Glenn. 2005. Home range and habitat use of northern spotted owls on the Olympic Peninsula, Washington. Journal of Raptor Research 39(4):356-377.

Forsman, E.D., E.C. Meslow and H.M. Wight. 1984. Distribution and biology of the spotted owl in Oregon. Wildlife Monographs 87:1–64.

Forsman, E.D., I.A. Otto, S.G. Sovern, M. Taylor, D.W. Hays, H. Allen, S.L. Roberts and D.E. Seaman. 2001. Spatial and temporal variation in diets of spotted owls in Washington. Journal of Raptor Research 35:141–150.

Foster, D.R., and D.A. Orwig. 2006. Preemptive and salvage harvesting of New England forests: when doing nothing is a viable alternative. Conservation Biology 20:959–970.

Franklin, A.B. 1992. Population regulation in northern spotted owls: theoretical implications for management. Pages 815–827 in D.R. McCullough and R.H. Barrett (editors), Wildlife 2001: populations. Elsevier Applied Sciences, London, England.

Franklin, A.B., D.R. Anderson, R.J. Gutiérrez and K.P. Burnham. 2000. Climate, habitat quality, and fitness in northern spotted owl populations in northwestern California. Ecological Monographs 70:539–590.

Franklin, A.B., K. P. Burnham, G.C. White, R.G. Anthony, E.D. Forsman, C. Schwarz, J.D. Nichols and J. Hines. 1999. Range-wide status and trends in northern spotted owl populations. Colorado Cooperative Fish and Wildlife Research Unit, Colorado State University, Fort Collins, Colorado.

Franklin, J., and S. Courtney. 2004. Evolution and effectiveness of strategies for conservation of northern spotted owl. Chapter 9 in S. Courtney (editor), Scientific evaluation of the status of the northern spotted owl. Sustainable Ecosystems Institute, Portland, Oregon.

Franklin, J.F., and C.T. Dyrness. 1973. Natural vegetation of Oregon and Washington. Oregon State University Press, Corvallis, OR. 452pp.

Franklin, J.F., D.R. Berg, A.B. Carey and R.A. Hardt. 2006. Chapter 5: Old-growth forests. Pages 97–121 in D. Apostol and M. Sinclair (editors), Restoring the Pacific Northwest: The Art and Science of Ecological Restoration in Cascadia. Island Press, Washington, D.C. 475 pp.

Franklin, J.F., D. Lindenmayer, J.A. MacMahon, A. McKee, J. Magnuson, D.A. Perry, R. Waide and D. Foster. 2000. Threads of Continuity. Conservation Biology in Practice 1:8–16.

Franklin, J.F., R.J. Mitchell and B.J. Palik. 2007. Natural disturbance and stand development principles for ecological forestry. General Technical Report NRS-GTR-19, Northern Research Station, U.S. Department of Agriculture, Forest Service, Newtown Square, Pennsylvania.

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

Fried, J.S., M.S. Torn and E. Mills. 2004. The impact of climate change on wildfire severity: a regional forecast for northern California. Climatic Change 4:169–191.

Funk, W.C., E.D. Forsman, M. Johnson, T.D. Mullins and S.M. Haig. 2010. Evidence for recent population bottlenecks in northern spotted owls (*Strix occidentalis caurina*). Conservation Genetics 11:1013–1021.

Gaines, W.L., R.J. Harrod, J. Dickinson, A.L. Lyons and K. Halupka. 2010. Integration of Northern spotted owl habitat and fuels treatments in the eastern Cascades, Washington, USA. Forest Ecology and Management 260:2045–2052.

Gaines, W.L., R.A. Strand and S.D. Piper. 1997. Effects of the Hatchery Complex Fires on northern spotted owls in the eastern Washington Cascades. Pages 123–129 in J.M. Greenlee (editor), Proceedings of the First Conference on Fire Effects on Rare and Endangered Species and Habitats. International Association of Wildland Fire, Coeur d'Alene, Idaho.

Gancz, A., I.K. Barker, R. Lindsay, A. Dibernardo, K. McKeever and B. Hunter. 2004. West Nile Virus outbreak in North American owls, Ontario, 2002. Emerging Infectious Diseases 10:2135–2142.

Ganey, J.L., R.P. Balda and R.M. King. 1993. Metabolic rate and evaporative water loss of Mexican spotted and great horned owls. Wilson Bulletin 105(4):645-656.

Garmendia, A.E., H.J. Van Kruiningen, R.A. French, J.F. Anderson, T.G. Andreadis, A. Kumar and A.B. West. 2000. Recovery and identification of West Nile virus from a hawk in winter. Journal of Clinical Microbiology 38:3110–3111.

Gärtner, S., K.M. Reynolds, P.F. Hessburg, S.S., Hummel and M. Twery. 2008. Decision support for evaluating landscape departure and prioritizing forest management activities in a changing environment. Forest Ecology and Management 256:1666–1676.

Gedalof, Z., D.L. Peterson and N.J. Mantua. 2005. Atmospheric, climatic, and ecological controls on extreme wildfire years in the northwestern United States. Ecological Applications 15:154–174.

Glenn, E.M. 2009. Local weather, regional climate, and population dynamics of northern spotted owls in Washington and Oregon. Dissertation, Oregon State University, Corvallis.

Glenn, E.M., R.G. Anthony and E.D. Forsman. 2010. Population trends in northern spotted owls: Associations with climate in the Pacific Northwest. Biological Conservation 143:2543-2552.

Glenn, E.M, M.C. Hansen and R.G. Anthony. 2004. Spotted owl home-range and habitat use in young forests of western Oregon. Journal of Wildlife Management 68:33–50.

Goheen, E.M., E. Hansen, A. Kanaskie, N. Osterbauer, J. Parke, J. Pscheidt and G. Chastagner. 2006. Sudden oak death and *Phytopthora ramorum*: a guide for forest managers, Christmas tree growers, and forest-tree nursery operators in Oregon and Washington. Oregon State University Extension Service, Central Point, Oregon.

Gomez, D.M., Anthony, R.G. and Hayes, J.P. 2005. Influence of thinning of Douglas-fir forests on population parameters and diet of northern flying squirrels: Journal of Wildlife Management 69:1670–1682.

Graumlich, L.J., L.B. Brubaker and C.C. Grier. 1989. Long-term trends in forest net primary productivity: Cascade Mountains, Washington. Ecology 70:405–410.

Gregory, R., D. Ohlson and J. Arvai. 2006. Deconstructing adaptive management: criteria for applications to environmental management. Ecological Applications 6:2411–2425.

Gremel, S. 2005. Factors controlling distribution and demography of northern spotted owls in a reserved landscape. Thesis, University of Washington, Seattle.

Grimm, V., and S.F. Railsback. 2005. Individual-Based Modeling and Ecology. Princeton: Princeton University Press. 480 pp.

Gubler, D.J. 2007. The continuing spread of West Nile Virus in the western hemisphere. Emerging Infections 45:1039–1046.

Gunderson, L. 1999. Resilience, flexibility and adaptive management– antidotes for spurious certitude? Conservation Ecology 3(1):7. <http://www.consecol.org/vol3/iss1/art7/>. Accessed 3 March 2011.

Gutiérrez, R.J., M. Cody, S. Courtney and A.B. Franklin. 2007. The invasion of barred owls and its potential effect on the spotted owl: a conservation conundrum. Biological Invasions 9:181–196.

Gutiérrez, R. J., M. Cody, S. Courtney and D. Kennedy. 2004. Chapter 7 in S. Courtney (editor), Scientific evaluation of the status of the northern spotted owl. Sustainable Ecosystems Institute, Portland, Oregon.

Gutiérrez, R.J. 1989. Hematozoa from the spotted owl. Journal of Wildlife Diseases 24:614–618.

Gutiérrez, R.J. 1996. Biology and distribution of the northern spotted owl. Studies in Avian Biology 17:2–5.

Gutiérrez, R.J., A.B. Franklin and W.S. LaHaye. 1995. Spotted owl (*Strix occidentalis*) in A. Poole and F. Gill (editors), The birds of North America, No. 179. The Academy of Natural Sciences and The American Ornithologists' Union, Washington, D.C.

Haig, S.M., T.D. Mullins and E.D. Forsman. 2004. Subspecific relationships and genetic structure in the spotted owl. Conservation Genetics 5:683–705.

Haig, S.M., R.S. Wagner, E.D. Forsman and T.D. Mullins. 2001. Geographic variation and genetic structure in spotted owls. Conservation Genetics 2:25–40.

Hamer, T.E. 1988. Home range size of the northern barred owl and northern spotted owl in western Washington. Thesis, Western Washington University, Bellingham.

Hamer, T.E., E.D. Forsman and E.M Glenn. 2007. Home range attributes and habitat selection of barred owls and spotted owls in an area of sympatry. Condor 109:750–768.

Hamer, T.E., E.D. Forsman, A.D. Fuchs and M.L. Walters. 1994. Hybridization between barred and spotted owls. Auk 111:487–492.

Hamer, T.E., D.L. Hays, C.M. Senger and E.D. Forsman. 2001. Diets of northern barred owls and northern spotted owls in an area of sympatry. Journal of Raptor Research 35:221–227.

Hamm, K.A., and L.V. Diller. 2009. Forest management effects on abundance of woodrats in northern California. Northwestern Naturalist 90:97-106.

Hansen, D.L., and M.J. Mazurek. 2010. Effects of forest thinning on northern spotted owls. Unpublished white paper.

Hanson, C.T., D.C. Odion, D.A. DellaSala and W.L. Baker. 2009. Overestimation of fire risk in the Northern Spotted Owl Recovery Plan. Conservation Biology 23:1314-1319.

Hanson, C.T., D.C. Odion, D.A. DellaSala and W.L. Baker. 2010. More-comprehensive recovery actions for northern spotted owls in dry forests: reply to Spies *et al.* Conservation Biology 24:334-337.

Hanson, E., D. Hays, L. Hicks, L. Young and J. Buchanan. 1993. Spotted owl habitat in Washington: a report to the Washington Forest Practices Board. Washington Forest Practices Board, Spotted Owl Advisory Group. Washington Department of Wildlife, Olympia.

Haugo, R.D., S.A. Hall, E.M. Gray, P. Gonzalez and J.D. Bakker. 2010. Influences of climate, fire, grazing, and logging on woody species composition along an elevation gradient in the eastern Cascades, Washington. Forest Ecology and Management 260: 2204-2213.

Healey, S.P., W.B. Cohen, T.A. Spies, M. Moeur, D. Pflugmacher, M.G. Whitley and M. Lefsky. 2008. The relative impact of harvest and fire upon landscape-level dynamics of older forests: lessons from the Northwest Forest Plan. Ecosystems 11: 1106-1119.

Heinrichs, J.H., D.H. Bender, D.L. Gummer and N.H. Schumaker. 2010. Assessing critical habitat: evaluating the relative contributions of habitats to population persistence. Biological Conservation 143:2229-2237.

Hemstrom, M., T. Spies, C. Palmer, R. Keister, J. Teply, P. McDonald and R. Warbington. 1998. Late-successional and old-growth forest effectiveness monitoring plan for the Northwest Forest Plan. General Technical Report PNW-GTR-438, Pacific Northwest Research Station, U.S. Department of Agriculture, Forest Service, Portland, Oregon. 37 p.

Henke, A.L., T.Y. Chi, J. Smith and C. Brinegar. 2005. Spotted owl (*Strix occidentalis*) microsatellite variation in California. Department of Biological Sciences, San Jose State University, San Jose, California.

Hershey, K.T., E.C. Meslow and F.L. Ramsey. 1998. Characterisics of forests at spotted owl nest sites in the Pacific Northwest. Journal Wildlife Management 62(4):1398-1410.

Herter, D.R., and L.L. Hicks. 2000. Barred owl and spotted owl populations and habitat in the central Cascade Range of Washington. Journal of Raptor Research 34:279–286.

Herter, D.R., L.L. Hicks, H.C. Stabins, J.J. Millspaugh, A.J. Stabins and L.D. Melampy. 2002. Roost site characteristics of northern spotted owls in the nonbreeding season in central Washington. Forest Science 48:437–446.

Hessburg, P.F., and J.K. Agee. 2003. An environmental narrative of Inland Northwest United States forests, 1800–2000. Forest Ecology and Management 178:23–59.

Hessburg, P.F., J.K. Agee and J.F. Franklin. 2005. Dry forests wildland fires of the inland Northwest USA: Contrasting the landscape ecology of the pre-settlement and modern eras. Forest Ecology and Management 211:117–139.

Hessburg, P.F., R.G. Mitchell and G.M. Filip. 1994. Historical and current roles of insects and pathogens in eastern Oregon and Washington forested landscapes. General Technical Report PNW-GTR-327, Pacific Northwest

Research Station, U.S. Department of Agriculture, Forest Service, Portland, Oregon.

Hessburg, P.F., K.M. Reynolds, R.B. Salter and M.B. Richmond. 2004. Using a decision support system to estimate departures of present forest landscape patterns from historical reference conditions. Pages. 158-175 in A.H. Perera, L.J. Buse and M.G. Weber (editors), Emulating Natural Forest Landscape Disturbances: Concepts and Applications. New York: Columbia University Press. 352 pp.

Hessburg, P.F., R.B. Salter and K.M. James. 2007. Re-examining fire severity relations in pre-management era mixed conifer forests: inferences from landscape patterns of forest structure. Landscape Ecology 22:5–24.

Hessburg, P.F., B.G. Smith, R.B. Salter, R.D. Ottmar and E. Alvarado. 2000. Recent changes (1930s–1990s) in spatial patterns of interior northwest forests, USA. Forest Ecology and Management 136:53–83.

Hessburg, P. F., R.B.Salter, M.B. Richmond and B.G. Smith. 2000. Ecological Subregions of the Interior Columbia Basin, USA. Applied Vegetation Science. 3(2): 163-180.

Hessl, A.E., D. McKenzie and R. Schellhaas. 2004. Drought and Pacific Decadal Oscillation linked to fire occurrence in the inland Pacific Northwest. Ecological Applications 14:425–442.

Heyerdahl, E.K., D. McKenzie, L.D. Daniels, A.E. Hessl, J.S. Littell and N.J. Mantua. 2008. Climate drivers of regionally synchronous fires in the inland Northwest (1651-1900). International Journal of Wildland Fire 17:40-49.

Hicke, J.A., and J.C. Jenkins. 2008. Mapping lodgepole pine stand structure susceptibility tomountain pine beetle attack across the western United States. Forest Ecology and Management 255:1536–1547.

Hicks, L.L., H.C. Stabins and D.R. Herter. 1999. Designing spotted owl habitat in a managed forest. Journal of Forestry 97:20-25.

Hirzel, A.H., G. LeLay, V. Helfer, C. Randin and A. Guisan. 2006. Evaluating the ability of habitat suitability models to predict species presence. Ecological Modelling 199:142-152.

Hoberg, E.P., G.S. Miller, E. Wallner-Pendleton and O.R. Hedstrom. 1989. Helminth parasites of northern spotted owls (*Strix occidentalis caurina*). Journal of Wildlife Diseases 25:246–251.

Holling, C.S. 1973. Resilience and stability of ecological systems. Annual Review of Ecology and Systematics 4:1–23.

Holling, C.S. (editor), 1978. Adaptive Environmental Assessment and Management. John Wiley & Sons. New York.

Holling, C.S. 1996. Surprise for science, resilience for ecosystems, and incentives for people. Ecological Applications 6:733–735.

Huang, J-G., Y. Bergeron, B. Denneler, F. Berninger and J. Tardif. 2007. Response of forest trees to increased atmospheric CO_2. Critical Reviews in Plant Sciences. 26:265-283.

Hubálek, Z., and J. Halouzka. 1999. West Nile fever—a reemerging mosquito-borne viral disease in Europe. Emerging Infectious Diseases 5:643–650.

Hummel, S., and J.K. Agee. 2003. Western spruce budworm defoliation effects on forest structure and potential fire behavior. Northwest Science 7:159-169.

Hunter, J.E., R.J. Gutierrez and A.B. Franklin. 1995. Habitat configuration around spotted owl nest sites in northwestern California. Condor 97:684-693.

Hurteau, M.D., G.W. Koch and B.A. Hungate. 2008. Carbon protection and fire risk reduction: toward a full accounting of forest carbon offsets. Frontiers in Ecology and the Environment 6:493-498.

Hutto, R.L. 2006. Toward meaningful snag-management guidelines for postfire salvage logging in North American conifer forests. Conservation Biology 20:984–993.

Hutto, R.L. 2008. The ecological importance of severe wildfires: some like it hot. Ecological Applicatoins. 8:1827-1834.

Innes, R.J., D.H. VanVuren, D.A. Kelt, M.L. Johnson, J.A. Wilson and P.A. Stine. 2007. Habitat associations of dusky-footed woodrats (*Neotoma fuscipes*) in mixed-conifer forest of the Northern Sierra Nevada. Journal of Mammalogy 88:1523-1531.

Irwin, L.L., D.F. Rock and G.P. Miller. 2000. Stand structures used by northern spotted owls in managed forests. Journal of Raptor Research 34:175–186.

Irwin, L.L., D. Rock and S. Rock. 2005. Adaptive management monitoring of spotted owls: annual progress report—August 2005. National Council for Air and Stream Improvement, unpublished report.

Irwin, L.L., D. Rock and S. Rock. 2008. Adaptive management monitoring of spotted owls: annual progress report—August 2008. National Council for Air and Stream Improvement, unpublished report.

Irwin, L.L., D. Rock and S. Rock. 2010. Adaptive management monitoring of spotted owls: annual progress report. Forthcoming. National Council for Air and Stream Improvement, unpublished report.

Ishak, H.D., J.P. Dumbacher, N.L. Anderson, J.J. Keane, G. Valkiunas, S.M. Haig, L.A. Tell and R.N.M. Sehgal. 2008. Blood parasites in owls with conservation implications for the spotted owl (*Strix occidentalis*). PLoS ONE 3 (5):e2304. Doi:10.1371/journal.pone.0002304.

Iverson, W.F. 1993. Is the barred owl displacing the spotted owl in western Washington? Thesis, Western Washington University, Bellingham, Washington.

Jenness, J.S., P. Beier and J.L. Ganey. 2004. Associations between forest fire and Mexican spotted owls. Forest Science 50:765–772.

Jenkins, M.J., E. Hebertson, W. Page and C.A. Jorgensen. 2008. Bark beetles, fuels, fires and implications for forest management in the intermountain west. Forest Ecology and Management 254:16–34.

Johnson, D.H. 2001. Validating and evaluating models. Pages 105–119 in T. M. Shenk and A. B. Franklin (editors), Modeling in natural resource management. Island Press, Covelo, California.

Johnson, K.N., and J.F. Franklin. 2009. Restoration of Federal forests in the Pacific Northwest: strategies and management implications. Unpublished manuscript. August 15, 2009. 120 pp. Available online at <http://www.cof.orst.edu/cof/fs/PDFs/RestorationOfFederalForestsInThePacificNorthwest.pdf>. Accessed 3 March 2011.

Johnson, K.N., J.F. Franklin, J.W. Thomas and J. Gordon. 1991. Alternatives for management of late successional forests of the Pacific Northwest. A report to the Agriculture and Merchant and Marine Fisheries Committees of the U.S. House of Representative. Scientific Panel on Late Successional Forest Ecosystems, Washington, D.C.

Joyce, L.A., G.M. Blate, J.S. Littell, S.G. McNulty, C.I. Millar, S.C. Moser, R.P. Neilson, K.A. O'Halloran and D.L. Peterson. 2008. Chapter 3 – National Forests. Pages 3-1 to 3-127 in S.H. Julius, J.M. West (editors), J.S. Baron, L.A. Joyce, P. Kareiva, B.D. Keller, M.A. Palmer, C.H. Peterson and J.M. Scott (authors), Preliminary review of adaptation options for climate-sensitive ecosystems and resources. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. U.S. Environmental Protection Agency, Washington, D.C., 873 pp.

JPL (Jet Propulsion Laboratory). 2008. Larger Pacific climate event helps current La Niña linger. Available online at <http://www.jpl.nasa.gov/news/news.cfm?release=2008–066>. Accessed 18 February 2011.

Karr, J.R., J.J. Rhodes, G.W. Minshall, F.R. Hauer, R.L. Beschta, C.A. Frissell and D.A. Perry. 2004. The effects of postfire salvage logging on aquatic ecosystems in the American west. BioScience 54:1029–1033.

Keane, R. E., R. Parsons and P.F. Hessburg. 2002. Estimating historical range and variation of landscape patch dynamics: Limitations of the simulation approach. Ecological Modeling 151: 29–49.

Keane, R.R., P.F. Hessburg, P. Landres and F.J. Swanson. 2009. The use of historical range and variability (HRV) in landscape management. Forest Ecology and Management 258:1025–1037.

Keeton, W.S., P.W. Mote and J.F. Franklin. 2007. Climate variability, climate change, and western wildfire with implications for the urban-wildland interface. Advances in the Economics of Environmental Resources 6:225–253.

Keith, H., B.G. Mackey and D.B. Lindenmayer. 2010. Re-evaluation of forest biomass carbon stocks and lessons form the world's most carbon-dense forests. Proceedings of the National Academy of Science (www.pnas.org/cgi/doi/10.1073/pnas.0901970106).

Kelly, E.G., and E.D. Forsman. 2003. Barred owl. Pages 320–322 in D. B. Marshall, M.G. Hunter and A.L. Contreras (editors), Birds of Oregon: a general reference. Oregon State University, Corvallis, Oregon.

Kelly, E.G., and E.D. Forsman. 2004. Recent records of hybridization between barred owls (*Strix varia*) and northern spotted owls (*S. occidentalis caurina*). Auk 121:806–810.

Kelly, E.G., E.D. Forsman and R.G. Anthony. 2003. Are barred owls displacing spotted owls? Condor 105:45–53.

Kennedy, R.S.H., and M.C. Wimberly. 2009. Historical fire and vegetation dynamics in dry forests of the interior Pacific Northwest, USA, and relationships to northern spotted owl (*Strix occidentalis caurina*) habitat conservation. Forest Ecology and Management 258:554–566.

Kennedy, R.E., Z. Yang and W.B. Cohen. 2010. Detecting trends in forest disturbance and recovery using yearly Landsat time series: 1. LandTrendr -

temporal segmentation algorithms. Remote Sensing of Environment 114(12): 2897-2910.

Kennedy, R.E., W.B. Cohen and T.A. Schroeder. 2007. Trajectory-based change detection for automated characterization of forest disturbance dynamics. Remote Sensing of Environment 110: 370-386.

King, G.M. 1993. Habitat characteristics of northern spotted owls in eastern Washington. Thesis, University of California, Berkeley.

King, G.M., K.R. Bevis, M.A. Rowe and E.E. Hanson. 1998. Spotted owls use of habitat impacted by 1994 fires on the Yakama Indian Reservation: three years post fire. Presented at the Second Fire Effects on Rare and Endangered Species Conference, March 29 – April 1, 1998. International Association of Wildland Fire, Coeur d'Alene, Idaho.

Klenner, W., R. Walton, A. Arsenault and L. Kremsater. 2008. Dry forests in the southern interior of British Columbia: historic disturbances and implications for restoration and management. Forest Ecology and Management. 256:1711–1722.

Klock, G.O. 1975. Impact of five postfire salvage logging systems on soils and vegetation. Journal of Soil and Water Conservation 30:78–81.

Kliejunas, J.T., B.W. Geils, J.M. Glaeser, E.M. Goheen, P. Hennon, M-S. Kim, H. Kope, J. Stone, R. Sturrock and S.J. Frankel. 2009. Review of literature on climate change and forest diseases of western North America. General Technical Report, PSW-GTR-225, Pacific Southwest Research Station, U.S. Department of Agriculture, Forest Service, Albany, California.

Kolb, T.E., K.M. Holmberg, M.R. Wagner and J.E. Stone. 1998. Regulation of ponderosa pine foliar physiology and insect resistance mechanisms by basal area treatments. Tree Physiology. 18:375–381.

Komar, N., N.A. Panella, J.E. Burns, S.W. Dusza, T.M. Mascarenhas and T.O. Talbot. 2001. Serologic evidence for West Nile virus infection in birds in the New York City vicinity during an outbreak in 1999. Emerging Infectious Diseases 7:621–625.

Krawchuk, M.A., M.A. Moritz, M. Parisien, J. Van Dorn and K. Hayhoe. 2009. Global pyrogeography: the current and future distribution of wildlife. PLos ONE 4(4): e5102. doi:10.1371/journal.pone.0005102.

Kroll, A.J., T.L. Fleming and L.L. Irwin. 2010. Site occupancy dynamics of northern spotted owls in the eastern Cascades, Washington, USA, 1990–2003. Journal of Wildlife Management 74:1264–1274.

Kuchler, A.W. 1977. The map of the natural vegetation of California. Pages 909-938 in M.G. Barbour and J. Major, editors, Terrestrial vegetation of California. Wiley-Interscience, reprinted by the California Native plant Society 1988, Sacramento, CA.

Kulakowski, D., and T.T. Veblen. 2007. Effect of prior disturbances on the extent and severity of wildfire in Colorado Subalpine forests. Ecology 88:759–769.

Kurz, W.A., C.C. Dymond, G. Stinson, G.J. Rampley, E.T. Neilson, A.L. Carroll, T. Ebata and L. Safranyik. 2008. Mountain pine beetle and forest carbon feedback to climate change. Nature 452:987–990.

LaHaye, W.S., and R.J. Gutiérrez. 1999. Nest sites and nesting habitat of the northern spotted owl in northwestern California. Condor 101:324-330.

LaHaye, W.S., R.J. Gutiérrez and J.R. Dunk. 2001. Natal dispersal of the spotted owl in southern California: Dispersal profile of an insular population. Condor 103:691–700.

Lamberson, R.H., R. McKelvey, B.R. Noon and C. Voss. 1992. A Dynamic Analysis of Northern Spotted Owl Viability in a Fragmented Forest Landscape. Conservation Biology 6(4):505-512.

Lamberson, R.H., B.R. Noon, C. Voss, and K.S. McKelvey. 1994. Reserve design for territorial species: the effects of patch size and spacing on the viability of the northern spotted owl. Conservation Biology 8(1):185-195.

Larsson, S., R. Oren, R.H. Waring and J.W. Barrett. 1983. Attacks of mountain pine beetle as related to tree vigor of ponderosa pine. Forest Science 29:395–402.

Latham, P., and J. Tappeiner. 2002. Response of old-growth conifers to reduction in stand density in western Oregon forests. Tree Physiology 2:137–146.

Latta, G., H. Temesgen, D. Adams and T. Barrett. 2010. Analysis of potential impacts of climate change on forests of the United States Pacific Northwest. Forest Ecology and Management 259: 720–729.

Lawler, J.J. 2009. Climate change adaptation strategies for resource management and conservation planning. Annals of the New York Academy of Sciences 1162:79–98.

Lee, D.C., and L.L. Irwin. 2005. Assessing risks to spotted owls from forest thinning in fire-adapted forests of the western United States. Forest Ecology and Management 211:191–209.

Lehmkuhl, J.F., K.D. Kistler and J.S. Begley. 2006a. Bushy-tailed woodrat abundance in dry forests of eastern Washington. Journal of Mammalogy 87:371–379.

Lehmkuhl, J.F., K.D. Kistler, J.S. Begley and J. Boulanger. 2006b. Demography of northern flying squirrels informs ecosystem management of western interior forests. Ecological Applications 16:584–600.

Lehmkuhl, J.F., L.E. Gould, E. Cazares and D.R. Hosford. 2004. Truffle abundance and mycophagy by northern flying squirrels in eastern Washington forests. Forest Ecology and Management 200:49–65.

Lehmkuhl, J.F., M. Kennedy, E.D. Ford, P.H. Singleton, W.L. Gaines and R.L. Lind. 2007. Seeing the forest for the fuel: Integrating ecological values and fuels management. Forest Ecology and Management 246:73–80.

Lenihan, J.M., D. Bachelet, R.P. Neilson and R. Drapek. 2008. Response of vegetation distribution, ecosystem productivity,and fire to climate change scenarios for California. Climatic Change 87:S215–S230.

Leskiw, T., and R.J. Gutiérrez. 1998. Possible predation of a spotted owl by a barred owl. Western Birds 29:225–226.

Levy, S. 1999. Owl vs. owl. Natural History 108:28–32.

Levy, S. 2004. Native incursions: avian range expansions imperil threatened species. BioScience 54:94–98.

Lindenmayer, D.B., and R.F. Noss. 2006. Salvage logging, ecosystem processes, and biodiversity conservation. Conservation Biology 20:949–958.

Lindenmayer, D.B., D.R. Foster, J.F. Franklin, M.L. Hunter, R.F. Noss, F.A. Schmiegelow and D. Perry. 2004. Salvage harvesting policies after natural disturbance. Science 303:1303.

Lindenmayer, D.B., P.J. Burton and J.F. Franklin. 2008. Salvage logging and its ecological consequences. Island Press, Washington, D.C.

Lindroth, R.L. 2010. Impacts of elevated atmospheric CO_2 and O_3 on forests: phytochemistry, trophic interactions, and ecosystem dynamics. Journal of Chemical Ecology 36:2–21.

Lint, J. 2005. Population status and trends. Pages 7–19 in J. Lint, technical coordinator. Northwest Forest Plan—the first 10 years (1994–2003): status and trends of northern spotted owl populations and habitat. General Technical Report PNW-GTR-648, Pacific Northwest Research Station, U.S. Department of Agriculture, Forest Service, Portland, Oregon.

Lint, J., B. Noon, R. Anthony, E. Forsman, M. Raphael, M. Collopy and E. Starkey. 1999. Northern spotted owl effectiveness monitoring plan for the Northwest Forest Plan. General Technical Report PNW-GTR-440, Pacific Northwest Research Station, U.S. Department of Agriculture, Forest Service, Portland, Oregon. 43 p.

Littell, J.S. 2009. "Climate change and the forest ecosystems of the Olympia Peninsula," a presentation given at Climate change impacts on Olympic Peninsula salmon, a workshop held at Olympic National Forest Headquarters in Olympia, Washington. Available online at < http://www.fs.fed.us/ccrc/video/olympic_littell.shtml>. Accessed 3 March 2011.

Littell, J.S., D.L. Peterson and M. Tjoelker. 2008. Douglas-fir growth in mountain ecosystems: water limits tree growth from stand to region. Ecological Monographs 78:349-368.

Littell, J.S., D. McKenzie, D.L. Peterson and A.L. Westerling. 2009. Climate and wildfire area burned in western U.S. ecoprovinces, 1916-2003. Ecological Applications 19:1003–1021.

Littell, J.S., E.E. Oneil, D. McKenzie, J.A. Hicke, J.A. Lutz, R.A. Norheim and M.M. Elsner. 2010. Forest ecosystems, disturbance, and climate change in Washington State, USA. Climate Change 102: 129-158.

Liu, Y., J. Stanturf and S. Goodrick. 2010. Trends in global wildfire potential in a changing climate. Forest Ecology and Management. 259:685-697.

Livezey, K.B. 2009a. Range expansion of Barred Owls, part I: chronology and distribution. American Midland Naturalist 161:49–56.

Livezey, K.B. 2009b. Range expansion of Barred Owls, part II: facilitating ecological changes. American Midland Naturalist 161:323–349.

Livezey, K.B., and T.L. Fleming. 2007. Effects of barred owls on spotted owls: the need for more than incidental detections and correlational analyses. Journal of Raptor Research 41:319–325.

Livezey, K.B., R.M. Engeman, D.F. Rock and D.A. Yasuda. 2007. Considering control of invasive barred owls to benefit California spotted owls: Possible justification and draft methods. Pages 72-81 in Witmer, G.W., W.C. Pitt and

K.A. Fegerstone, Editors, Managing vertebrate invasive species: Proceedings of an International Symposium. USDA APHIS/WS, National Wildlife Research Center, Fort Collins, CO.

Loehle, C. 2004. Applying landscape principles to fire hazard reduction. Forest Ecology and Management. 198:261-267.

Logan, J.A., and J.A. Powell. 2001. Ghost forests, global warming, and the mountain pine beetle (Coleoptera: Scolytidae). American Entomologist 47:160–172.

Logan, J.A., J. Regniere and J.A. Powell. 2003. Assessing the impacts of global warming on forest pest dynamics. Frontiers in Ecology and the Environment 1:130–137.

Long, J.N. 2009. Emulating natural disturbance regimes as a basis for forest management: A North American view. Forest Ecology and Management 257:1868–1873.

Luoma, D. L., J. M. Trappe, A.W. Claridge, K.M. Jacobs and E. Cazares. 2003. Relationships among fungi and small mammals in forested ecosystems. Pages 343–373 in C.J. Zabel and R.G. Anthony (editors), Mammal Community Dynamics in Western Coniferous Forests: Management and Conservation. Cambridge University Press, Cambridge, United Kingdom.

Luyssaert, S., E.-D. Schulze, A. Börner, A. Knohl, D. Hessenmöller, B.E. Law, P. Ciais and J. Grace. 2008. Old-growth forests as global carbon sinks. Nature 455:213–215.

Lynch, H.J., R.A. Renkin, R.L. Crabtree and P.R. Moorcroft. 2006. The influences of previous mountain pine beetle (*Dendroctonus ponderosae*) activity on the 1988 Yellowstone fires. Ecosystems 8:1318–1327.

Manter, D.K., P.W. Reeser and J.K. Stone. 2005. A climate-based model for predicting geographic variation in Swiss needle cast severity in the Oregon Coast Range. Phytopathology 95:1256–1265.

Mantua, N.J., S.R. Hare, Y. Zhang, J.M. Wallace and R.C. Francis. 1997. A Pacific interdecadal climate oscillation with impacts on salmon production. Bulletin of the American Meteorological Society 78:1069–1079.

Marra, P.P., S. Griffing, C. Caffrey, A.M. Kilpatrick, R. McLean, C. Brand, E. Saito, A.P. Dupuis, L. Kramer and R. Novak. 2004. West Nile Virus and wildlife. BioScience 54:393–402.

Marston, R.A., and D.H. Haire. 1990. Runoff and soil loss following the 1988 Yellowstone fires. Great Plains-Rocky Mountain Geographic Journal 18:1–8.

Martinson, E., P.N. Omi and W. Shepperd. 2003. Effects of fuel treatments on fire severity. Pages 96–126 in R.T. Graham (Technical Editor), Hayman fire case study. General Technical Report RMRS–GTR–114, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Ogden, Utah.

Mason, C.L., and B.R. Lippke. 2009. An investigation of the prospects for forests and the forest industry in Kittitas, Yakima, and Klickitat Counties. Unpublished report, September 2009. Lippke and Associates, 2600 Fairview Ave., Seattle, WA 98102. 62 pp.

Mazur, K.M., and P. C. James. 2000. Barred owl (*Strix varia*). In A. Poole (editor), The Birds of North America Online, No. 508. Cornell Lab of Ornithology, Ithaca, New York. Available online at <

http://bna.birds.cornell.edu/bna/species/508/articles/introduction>. Accessed 3 March 2011.

McIver J.D., and L. Starr (technical editors). 2000. Environmental effects of postfire logging: literature review and annotated bibliography. General Technical Report PNW-GTR-486, Pacific Northwest Research Station, U.S. Department of Agriculture, Forest Service, Portland, Oregon.

McKenzie, D, Z. Gedalof, D.L. Peterson and P. Mote. 2004. Climate change, wildfire, and conservation. Conservation Biology 18:890–902.

McKenzie, D., D.L. Peterson and J.J. Littell. 2009. Global warming and stress complexes in forests of western North America. Pages 319–338 in A. Bytnerowicz, M.J. Araugh, A.R. Riebau and C. Andersen (editors), Developments in Environmental Science, Volume 8. Elsevier, The Netherlands.

McLean, R.G., S.R. Ubico, S.E. Docherty, W.R. Hansen, L. Sileo and T.S. McNamara. 2001. West Nile Virus and transmission and ecology in birds. Annals of the New York Academy of Sciences 951:54–57.

McNab, H.W., and P.E. Avers. 1994. Ecological subregions of the United States: Section descriptions. Publication WO-WSA-5. USDA Forest Service, Washington, D.C.

Meiman, S., R. Anthony, E. Glenn, T. Bayless, A. Ellinson, M.C. Hansen and C. Smith. 2003. Effects of commercial thinning on home-range and habitat-use patterns of a male northern spotted owl: a case study. Wildlife Society Bulletin 31:1254–1262.

Meyer, J.S., L.L. Irwin and M.S. Boyce. 1998. Influence of habitat abundance and fragmentation on northern spotted owls in western Oregon. Wildlife Monographs 139:1–51.

Meyer, M.D., M.P. North and D.A. Kelt. 2005. Short-term effects of fire and forest thinning on truffle abundance and consumption by *Neotamias speciosus* in the Sierra Nevada of California. Canadian Journal of Forest Research 35:1061–1070.

Millar, C.I., N.L. Stephenson and S.L Stephens. 2007. Climate change and forests of the future: managing in the face of uncertainty. Ecological Applications 17:2145–2151.

Miller, G.S. 1989. Dispersal of juvenile spotted owls in western Oregon. Thesis, Oregon State University, Corvallis.

Miller, G.S., R.J. Small and E.C. Meslow. 1997. Habitat selection by spotted owls during natal dispersal in western Oregon. Journal of Wildlife Management 61:140–150.

Miller, G.S., S.K. Nelson and W.C. Wright. 1985. Two-year-old female spotted owl breeds successfully. Western Birds 16:69–73.

Mitchell, R.G., and H.K. Preisler. 1991. Analysis of spatial patterns of lodgepole pine attacked by outbreak populations of the mountain pine beetle. Forest Science 37:1390–1408.

Mitchell, S.R., M.E. Harmon and K.E.B. O'Connell. 2009. Forest fuel reduction alters fire severity and long-term carbon storage in three Pacific Northwest ecosystems. Ecological Applications 19:643–655.

Moen, C.A., A.B. Franklin and R.J. Gutiérrez. 1991. Age determination of subadult northern spotted owls in northwest California. Wildlife Society Bulletin 19:489–493.

Moilanen A., and H. Kujala. 2008. Zonation: software for spatial conservation prioritization. User Manual v2.0. Metapopulation Research Group, University of Helsinki, FI. Available at <http://www.helsinki.fi/bioscience/consplan/software/Zonation/index.html>. Accessed 3 March 2011.

Monsanto, P.G., and J.K. Agee. 2008. Long-term post-wildfire dynamics of coarse woody debris after salvage logging and implications for soil heating in dry forests of the eastern Cascades, Washington. Forest Ecology and Management 255:3952–3961.

Moritz, M.A., P.F. Hessburg and N.A. Povak. 2011. Native fire regimes and landscape resilience. Chapter 3 in: Ecological Studies Series, Volume 213, The Landscape Ecology of Fire, McKenzie, D., Miller, C., Falk, D.A. (editors), Springer-Verlag.

Morrison, M.L., B.G. Marcot and R.W. Mannan. 1992. Wildlife-habitat relationships: concepts and applications. Madison, WI: The University of Wisconsin Press. 364 p.

Mote, P.W., and E.P. Salathe Jr. 2010. Future climate in the Pacific Northwest. Climatic Change 102:29–50.

Mote, P.W., D.Gavin and A. Huyer. 2010. Climate change in Oregon's land and marine environments. Pages 1–45 in K.D. Dello and P.W. Mote (editors), Oregon Climate Assessment Report. Oregon Climate Change Research Institute. College of Oceanic and Atmospheric Sciences, Oregon Statue University, Corvallis.

Mote, P.W., A.F. Hamlet, M.P. Clark and D.P. Lettenmaier. 2005. Declining mountain snowpack in western North America. Bulletin of the American Meteorological Society 86:39–49.

Mote, P.W., W.S. Keeton and J.F. Franklin. 1999. Decadal variations in forest fire activity in the Pacific Northwest. Pages 155–156 in Proceedings of the 11th Conference on Applied Climatology, American Meteorological Society, Boston, Massachusetts.

Munro, J.A., and I. McTaggart-Cowan. 1947. A review of the bird fauna of British Columbia. Special Publication Number 2. Provincial Museum, Victoria, British Columbia, Canada.

Murphy, D.D., and B.R. Noon. 1992. Integrating scientific methods with habitat conservation planning: reserve design for northern spotted owls. Ecological Applications 2: 3-17.

Muzika, R.M., and A.M. Liebhold. 2000. A critique of silvicultural approaches to managing defoliating insects in North America. Agricultural and Forest Entomology 2:97–105.

Naficy, C., A. Sala, E.G. Keeling, J. Graham and T.H. DeLuca. 2010. Interactive effects of historical logging and fire exclusion on ponderosa pine forest structure in the northern Rockies. Ecological Applications 20:1851–1864.

Negron, J.F., and J.B. Popp. 2004. Probabililty of ponderosa pine infestation by mountain pine beetle in the Colorado Front Range. Forest Ecology and Management 191:17–27.

Neilson, R.P., J.M Lenihan, D. Bachelet, R.J. Drapek, D. Price and D. Scott. 2006. The potential for widespread, threshold dieback of forests in North America under rapid global warming. Pages 117–121 in L. Joyce, R. Haynes, R. White and R.J. Barbour (technical coordinators), Bringing climate change into natural resource management: proceedings. General Technical Report PNW-GTR-706, Pacific Northwest Research Station, U.S. Department of Agriculture, Forest Service, Portland, Oregon.

Nitschke, C.R. 2005. Does forest harvesting emulate fire disturbance? A comparison of effects on selected attributes in coniferous-dominated headwater systems. Forest Ecology and Management 214:305–319.

NMFS (National Marine Fisheries Service) and USFWS (U.S. Fish and Wildlife Service). 2010. Interim endangered and threatened species recovery planning guidance. Version 1.3. Silver Spring, Maryland.

NOAA (National Oceanic and Atmospheric Administration). 2011. Pacific Decadal Oscillation (PDO). Available online at <http://www.nwfsc.noaa.gov/research/divisions/fed/oeip/ca–pdo.cfm>. Accessed 18 February 2011.

Noon, B.R., and J.A. Blakesley. 2006. Conservation of the northern spotted owl under the Northwest Forest Plan. Conservation Biology 20:288–296.

Noon, B.R., and A.B. Franklin. 2002. Scientific research and the spotted owl (*Strix occidentalis*): Opportunities for major contributions to avian population ecology. Auk 119(2):311-320.

North, M., and W. Keeton. 2008. Emulating natural disturbance regimes: an emerging approach for sustainable forest management. Pages 341–372 in R. Lafortezza, J. Chen, G. Sanesi and T. Crow (editors), Landscape ecology: Sustainable management of forest landscapes. Springer-Verlag Press, The Netherlands.

North, M., P. Stine, W. Zielinski, K. O'Hara and S. Stephens. 2010. Harnessing fire for wildlife: fuels management in California's mixed-conifer forests. The Wildlife Professional. 4:30–33.

Noss, R.F., and D.B. Lindenmayer. 2006. Special section: the ecological effects of salvage logging after natural disturbance. Conservation Biology 20:946–948.

Noss, R.F., J.F. Franklin, W.L. Baker, T. Schoennagel and P.B. Moyle. 2006. Managing fire-prone forests in the western United States. Frontiers in Ecology and the Environment 4:481–487.

O'Hara, K.L. 2009. Multiaged silviculture in North America. Journal of Forest Science 55:432–436.

ODF (Oregon Department of Forestry). 2006. Forest Practices Administrative Rules and Forest Practices Act. Oregon Department of Forestry, Salem, Oregon.

Odion, D.C., E.J. Frost, J.R. Strittholt, J. Hong, D.A. DellaSala and M.A. Moritz. 2004. Patterns of fire severity and forest conditions in the western Klamath Mountains, California. Conservation Biology 18:927–936.

Odion, D.C., M.A. Moritz and D.A. DellaSalla. 2010. Alternative community states maintained by fire in the Klamath Mountains, USA. Journal of Ecology 98:96–105.

Ohmann, J.L., and M.J. Gregory. Predictive mapping of forest composition and structure with direct gradient analysis and nearest-neighbor imputation in coastal Oregon, U.S.A. Canadian Journal of Forest Research 32: 725-741.

Olsen, W.K., J.M. Schmid and S.A. Mata. 1996. Stand characteristics associated with mountain pine beetle infestations in ponderosa pine. Forest Science 42:310–327.

Olson, G.S., E.M. Glenn, R.G. Anthony, E.D. Forsman, J.A. Reid, P.J. Loschl and W.J. Ripple. 2004. Modeling demographic performance of northern spotted owls relative to forest habitat in Oregon. Journal of Wildlife Management 68:1039–1053.

Olson, G.S., R.G. Anthony, E.D. Forsman, S.H. Ackers, P.J. Loschl, J.A. Reid, K.M Dugger, E.M. Glenn and W.J. Ripple. 2005. Modeling of site occupancy dynamics for northern spotted owls, with emphasis on the effects of barred owls. Journal of Wildlife Management 69:918–932.

Omi, P.N., and E.J. Martinson. 2002. Effects of fuels treatment on wildfire severity. Final report submitted to the Joint Fire Science Program Governing Board.

Parker, T.J., K.M. Clancy and R.L. Mathiasen. 2006. Interactions among fire, insects and pathogens in coniferous forests of the interior western United States and Canada. Agricultural and Forest Entomology 8:167–189.

Pearce, J., and S. Ferrier. 2000. Evaluating the predictive performance of habitat models developed using logistic regression. Ecological Modelling 133:225–245.

Pearson, R.R., and K.B. Livezey. 2003. Distribution, numbers, and site characteristics of spotted owls and barred owls in the Cascade Mountains of Washington. Journal of Raptor Research 37:265–276.

Pearson, R.R., and K.B. Livezey. 2007. Spotted owls, barred owls, and Late-Successional Reserves. Journal of Raptor Research 41:156–161.

Perera, A.H., L.J. Buse and M.G. Weber (editors), 2004. Emulating Natural Forest Landscape Disturbances: Concepts and Applications. New York: Columbia University Press. 352 pp.

Perry, D.A., M.P. Amaranthus, J.G. Borchers, S.L. Borchers and R.E. Brainerd. 1989. Bootstrapping in ecosystems. BioScience 39:230–237.

Perry, D.A., P.F. Hessburg, C.N. Skinner, T.A. Spies, S.L. Stephens, A.H. Taylor, J.F. Franklin, B. McComb and G. Riegel. 2011. The ecology of mixed severity fire regimes in Washington, Oregon, and Northern California. Forest Ecology and Management, Volume 262, Issue 5, 1 September 2011, Pages 703-717.

Peterson, D.L., J.K. Agee, G.H. Aplet, D.P. Dykstra, R.T. Graham, J.F. Lehmkuhl, D.S. Pilliod, D.F. Potts, R.F. Powers and J.D. Stuart. 2009. Effects of timber harvest following wildfire in western North America. General Technical Report PNW-GTR-776, Pacific Northwest Research Station, U.S. Department of Agriculture, Forest Service, Portland, Oregon.

Peterson, G.D. 2002. Contagious disturbance, ecological memory, and the emergence of landscape pattern. Ecosystems 5:329–338.

Peterson, G., C.R. Allen and C.S. Holling. 1998. Ecological resilience, biodiversity, and scale. Ecosystems 1:6–18.

Phillips S.J., and M. Dudik. 2008. Modeling of species distributions with Maxent: new extensions and a comprehensive evaluation. Ecography 31:161–175.

Phillips, S.J., and J. Elith. 2010. POC plots: calibrating species distribution models with presence-only data. Ecology 91:2476-2484.

Phillips, S.J., R.P. Anderson and R.E. Schapire. 2006. Maximum entropy modeling of species geographic distributions. Ecological Modeling 190:231–259.

Phillips, S.J., M. Dudik, J. Elith, C.H. Graham, C.H., A. Lehmann, J. Leathwick and S. Ferrier. 2009. Sample selection bias and presence-only distribution models: implications for background and pseudo-absence data. Ecological Applications 19(1):181-197.

Pipkin, J. 1998. The Northwest Forest Plan revisited. U.S. Department of the Interior, Office of Policy Analysis, Washington, D.C., and Department of Forest Resources, Oregon State University, Corvallis.

Pollet, J., and P.N. Omi. 2002. Effect of thinning and prescribed burning on crown fire severity in ponderosa pine forests. International Journal of Wildland Fire 11:1–10.

Power, T.M. 2006. Public timber supply, market adjustments, and local economies: economic assumptions of the Northwest Forest Plan. Conservation Biology 20: 341–350.

Preisler, H.K., and R.G. Mitchell. 1993. Colonization patterns of the mountain pine beetle in thinned and unthinned lodgepole pine stands. Forest Science 39:528–545.

Prichard, S.J., D.L. Peterson and K. Jacobson. 2010. Fuel treatments reduce the severity of wildfire effects in dry mixed conifer forest, Washington, USA. Canadian Journal of Forest Research 40:1615–1626.

Raffa, K.F., B.H. Aukema, B.J. Bentz, A.L. Carroll, J.A. Hicke, M.G. Turner and W.H. Romme. 2008. Cross-scale drivers of natural disturbances prone to anthropogenic amplification: the dynamics of bark beetle eruptions. BioScience 58:501–517.

Raettig, T.L., and H.H. Christensen. 1999. Timber harvesting, processing, and employment in the Northwest Economic Initiative Region: changes and economic assistance. General Technical Report PNW-GTR-465, Volume III, Pacific Northwest Research Station, U.S. Department of Agriculture, Forest Service, Portland, Oregon.

Rand, A.L. 1944. Birds of the Alaska highway in British Columbia. Canadian Field-Naturalist 58:111–125.

Ransome, D.B., and T.P. Sullivan. 2002. Short-term population dynamics of *Glaucomys sabrinus* and *Tamiasciurus douglasii* in commercially thinned and unthinned stands of coastal coniferous forest. Canadian Journal of Forest Research 32:2043–2050.

Ransome, D.B., and T.P. Sullivan. 1997. Food limitation and habitat preference of *Glaucomys sabrinus* and *Tamiasciurus hudsonicus*. Journal of Mammalogy 78:538–549.

Ransome, D.B., P.M.F. Lindgren, D.S. Sullivan and T.P. Sullivan. 2004. Long-term responses of ecosystem components to stand thinning in young lodgepole pine forest. I. Population dynamics of northern flying squirrels and red squirrels. Forest Ecology and Management 202:355–367.

Raphael, M.G. 1987. Wildlife-tan oak associations in Douglas-fir forests of northwestern California. Pages 183–189 in T.R. Plumb and N.H. Pillsbury (technical coordinators), Proceedings of the symposium on multiple-use management of California's hardwood resources; 1986. General Technical Report PSW-GTR-100. Pacific Southwest Research Station, U.S. Department of Agriculture, Forest Service, Albany, California.

Raphael, M.G. 2006. Conservation of listed species: the northern spotted owl and marbled murrelet. Chapter 7 in R.W. Haynes, B.T. Bormann, D.C. Lee and J.R. Martin (technical editors), Northwest Forest Plan—the first 10 Years (1994–2003): synthesis of monitoring and research results. General Technical Report PNW-GTR-651, Pacific Northwest Research Station, U.S. Department of Agriculture, Forest Service, Portland, Oregon.

Raphael M.G., K.S. McKelvey and B.M. Galleher. 1998. Using geographic information systems and spatially explicit population models for avian conservation: a case study. Pages 65-74 in J.M. Marzluff, R. Sallabanks, editors. Avian conservation: research and management. Island Press, Washington.

Raymond, C.L., and D.L. Peterson. 2005. Fuel treatments alter the effects of wildfire in a mixed-evergreen forest, Oregon, USA. Canadian Journal of Foresst Research 35:2981–2995.

Reed, J.M., H.R. Akcakaya, M. Burgman, D. Bender, S.R. Beissinger and J.M. Scott. 2006. Critical Habitat. Pages 164–177 in J.M. Scott, D.D. Goble and F.W. Davis (editors). The Endangered Species Act at Thirty; Conserving Biodiversity in Human-Dominated Landscapes, Volume 2. Island Press Washington, DC. 360 pp.

Reeves, G.H., P.A. Bisson, B.E. Rieman and L.E. Benda. 2006. Postfire logging in riparian areas. Conservation Biology 20:994–1004.

Reinhardt, E.D., R.E. Keane, D.E. Calkin and J.D. Cohen. 2008. Objectives and considerations for wildland fuel treatment in forested ecosystems of the interior western United States. Forest Ecology and Management 256:1997-2006.

Rhodes, J.J., and W.L. Baker. 2008. Fire probability, fuel treatment effectiveness and ecological tradeoffs in western U.S. public forests. The Open Forest Science Journal 1:1–7.

Ricklefs, R.E., Z. Naveh and R.E. Turner. 1984. Conservation of ecological processes. The Environmentalist 4, supplement 8:6–16.

Roberts, S., and J. van Wagtendonk. 2006. The effects of fire on California spotted owls and their prey in Yosemite National Park, California. Extended abstract from Third International Fire Ecology and Management Congress. November 13-17, 2006. Association for Fire Ecology, San Diego, California.

Roberts, S.L., J.W. van Wagtendonk, A.K. Miles and D.A. Kelt. 2011. Effects of fire on spotted owl site occupancy in a late-successional forest. Biological Conservation 144:610–619.

Rogers, T.H. 1966. The fall migration: northern Rocky Mountain-Intermountain region. Audubon Field Notes 20:74.

Roloff, G.J., S.P. Mealey, C. Clay, J. Barry, C. Yanish and L. Neuenschwander. 2005. A process for modeling short- and long-term risk in the southern Oregon Cascades. Forest Ecology and Management 211:166–190.

Romme, W.H., J. Clement, J. Hicke, D. Kulakowski, L.H. MacDonald, T.L. Schoennagel and T.T. Veblen. 2006. Recent forest insect outbreaks and fire risk in Colorado Forests: a brief synthesis of relevant research. Colorado State University, Fort Collins.

Rosenberg, D. K., and R.G. Anthony. 1992. Characteristics of northern flying squirrel populations in young second- and old-growth forests in western Oregon. Canadian Journal of Zoology 70:161–166.

Rosenberg, D.K., and K.S. McKelvey. 1999. Estimation of habitat selection for centralplace foraging animals. Journal of Wildlife Management 63:1028–1038.

Russell, R.E., V.A. Saab, J.G. Dudley and J.J. Rotella. 2006. Snag longevity in relation to wildfire and postfire salvage logging. Forest Ecology and Management 232:179–187.

Safranyik, L., and A.L. Carroll. 2006. The biology and epidemiology of the mountain pine beetle in lodgepole pine forests. Pages 3–66 in S. Safranyik and B. Wilson, The mountain pine beetle: a synthesis of biology, management and impacts on lodgepole pine. Natural Resources Canada, Canadian Forest Service, Victoria, British Columbia.

Sakai, H.F., and B.R. Noon. 1993. Dusky-footed woodrat abundance in different-aged forests in northwestern California. Journal of Wildlife Management 57:373–382.

Salathe, E.P. Jr., R. Steed, C.F. Mass and P.H. Zahn. 2008. A high-resolution climate model for the U.S. Pacific Northwest: mesoscale feedbacks and local responses to climate change. Journal of Climate 21:5708–5726.

Salathe, E.P, L. R. Leung, Y. Qian and Y. Zhang. 2009. Regional climate model projections for the State of Washington. Pages 45–67 in M. M. Elsner, J. Littell, and L.W. Binder (editors), The Washington climate change impacts assessment. Center for Science in the Earth System, Joint Institute for the Study of the Atmosphere and Oceans, University of Washington, Seattle.

Schilling, J.W. 2009. Demography, home range, and habitat selection of northern spotted owls in the Ashland Watershed. M.Sc. Thesis, Oregon State University, Corvallis, OR. 129 pp.

Schmid, J.M., and S.A. Mata. 2005. Mountain pine beetle-caused tree mortality in partially cut plots surrounded by unmanaged stands. Research Paper RMRS-RP-54. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, Colorado.

Schmidt, D.A., A.H. Taylor and C.N. Skinner. 2008. The influence of fuels treatment and landscape arrangement on simulated fire behavior, Southern Cascade range, California. Forest Ecology and Management. 255:3170-3184.

Schmidt, K. 2006. Northern spotted owl monitoring and inventory, Redwood National and State Parks, 2005 annual report. Redwood National and State Parks, Orick, California.

Schoennagel, T., T.T. Veblen and W.H. Romme. 2004. The interaction of fire, fuels, and climate across Rocky Mountain forests. BioScience 54:661–676.

Schulte, L.A., R.J. Mitchell, M.L. Hunter, Jr., J.F. Franklin, R.K. McIntyre and B.J. Palik. 2006. Evaluating the conceptual tools for forest biodiversity conservation and their implementation in the U.S. Forest Ecology and Management. 232:1-11.

Schulze, E.-D., C. Wirth and M. Heimann. 2000. Managing forests after Kyoto. Science 289: 2058–2059.

Schumaker, N.H. 2008. HexSim (Version 1.3.6.9). U.S. Environmental Protection Agency, Environmental Research Laboratory, Corvallis, Oregon. Available online at <http://www.epa.gov/hexsim>. Accessed on 3 March 2011.

Schwind, B. (compiler). 2008. Monitoring trends in burn severity: report on the Pacific Northwest and Pacific Southwest fires—1984 to 2005. Available online at < http://mtbs.gov/reports/MTBS_pnw-psw_final.pdf>. Accessed on 3 March 2011.

SEI (Sustainable Ecosystems Institute). 2008. Scientific review of the draft northern spotted owl Recovery Plan and reviewer comments. Sustainable Ecosystems Institute, Portland, Oregon. 150 pp.

Seymour, R., and M. Hunter. 1999. Principles of ecological forestry. Pages XX in M. Hunter (editor), Managing Biodiversity in forested ecosystems. Cambridge University Press, Cambridge, United Kingdom.

Shafer, S.L., M.E. Harmon, R.P. Nieilson, R. Seidl, Brad St. Clair and A. Yost. 2010. The potential effects of climate change on Oregon's vegetation. Pages 173–208 in K.D. Dello and P.W. Mote (editors), Oregon Climate Change Research Institute (2010), Oregon Climate Assessment Report. College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis.

Shindler, B., and K. Aldred Cheek. 1999. Integrating citizens in adaptive management: a propositional analysis. Conservation Ecology 3:9. Available online at <http://www.consecol.org/vol3/iss1/art9/>. Accessed 3 March 2011.

Shore, T.L., L. Safranyik and R.J. Whitehead. 2006. Principles and concepts of management. Pages 117–121 in S. Safranyik and B. Wilson, The mountain pine beetle: a synthesis of biology, management and impacts on lodgepole pine. Natural Resources Canada, Canadian Forest Service, Victoria, British Columbia.

Simard, M., W.H. Romme, J.M. Griffin and M.G. Turner. 2011. Do mountain pine beetle outbreaks change the probability of active crown fire in lodgepole pine forests? Ecological Monographs 81:3–24.

Singleton, P.H., J.F. Lehmkuhl, W.L. Gaines and S.A. Graham. 2010. Barred owl space use and habitat selection in the eastern Cascades, Washington. Journal of Wildlife Management 74:285–294.

Sisco, C.L. 1990. Seasonal home range and habitat ecology of spotted owls in northwestern California. Thesis, Humboldt State University, Arcata, California.

Skinner, C.N. 1995. Change in spatial characteristics of forest openings in the Klamath Mountains of northwestern California, USA. Landscape Ecology 10:219–228.

Skinner, C.N., and A.H. Taylor. 2006. Southern Cascades bioregion. Pages 195–224 in N.G. Sugihara, J.W. van Wagtendonk, K.E. Shaffer, J. Fites-Kaufman and A.E. Thode (editors), Fire in California's Ecosystems. University of California Press, Berkeley.

Skinner, C.N., A.H. Taylor and J.K. Agee. 2006. Klamath Mountains bioregion. Pages 170–194 in N.G. Sugihara, J.W. van Wagtendonk, K.E. Shaffer, J. Fites-Kaufman and A.E. Thode (editors), Fire in California's Ecosystems. University of California Press, Berkeley.

Smith, F.A. 1997. *Neotoma cinerea*. Mammalian Species 564:1–8.

Solis, D.M. 1983. Summer habitat ecology of spotted owls in Northwestern California. Thesis, Humboldt State University, Arcata, California.

Solis, D.M., and R.J. Gutiérrez. 1990. Summer habitat ecology of northern spotted owls in northwestern California. Condor 92:739–748.

Sovern, S.G., E.D. Forsman, B.L. Biswell, D.N. Rolph and M. Taylor. 1994. Diurnal behavior of the spotted owl in Washington. Condor 96:200–202.

Spies, T.A., M.A. Hemstrom, A. Youngblood and S. Hummel. 2006. Conserving old-growth forest diversity in disturbance-prone landscapes. Conservation Biology 20:351–362.

Spies, T.A., T.W. Geisen, F.J. Swanson, J.F. Franklin, D. Lach and K.N. Johnson. 2010a. Climate change adaptation strategies for federal forests of the Pacific Northwest, USA: ecological, policy, and socio-economic perspectives. Landscape Ecology 25:1185–1199.

Spies, T.A., J.D. Miller, J.B. Buchanan, J.F. Lehmkuhl, J.F. Franklin, S.P. Healey, P.F. Hessburg, H.D. Safford, W.B. Cohen, R.S.H. Kennedy, E.E. Knapp, J.K. Agee and M. Moeur. 2010b. Underestimating risks to the northern spotted owl in fire-prone forests: response to Hanson *et al.* Conservation Biology 24:330–333.

Spracklen, D.V., L.J. Mickley, J.A. Logan, R.C. Hudman, R. Yevich, M.D. Flannigan and A.L. Westerling. 2009. Impacts of climate change from 2000 to 2050 on wildfire activity and carbonaceous aerosol concentrations in the western United States. Journal of Geophysical Research. Volume 114, D20301, doi:10.1029/2008JDO10966.

Stalberg, D., K.E. Fehring, L.Y. Pomara, N. Nur, D.B. Adams, D. Hatch, G.R. Geupel and S. Allen. 2009. Modeling nest-site occurrence for the northern spotted owl at its southern limit in central California. Landscape and Urban Planning 90:76-85.

Stankey, G.H., B.T. Bormann, C. Ryan, B. Shindler, V. Sturtevant, R.N. Clark and C. Philpot. 2003. Adaptive management and the Northwest Forest Plan: rhetoric and reality. Journal of Forestry 101:40–46.

Stankey, G.H., R.N. Clark and B.T. Bormann. 2005. Adaptive management of natural resources: theory, concepts, and management institutions. General Technical Report PNW-GTR-654, Pacific Northwest Research Station, U.S. Department of Agriculture, Forest Service, Portland, Oregon.

Stein, B.A. 2010. "Assessing vulnerability to climate change: , a key tool for adaptation planning," a webinar presentation given as part of the National Wildlife Federation-U.S. Fish and Wildlife Service climate change and wildlife webinar series, "Safeguarding Wildlife from Climate Change," January 28, 2010, National Conservation Training Center, U.S. Fish and Wildlife Service, Shepherdstown, WV.

Stephens, S.L., and L.W. Ruth. 2005. Federal forest-fire policy in the United States. Ecological Applications. 15:532-542.

Stephens, S.L., D.L. Fry and E. Franco-Vizcaino. 2008. Wildfire and forests in northwestern Mexico: the United States wishes it had similar fire problems. Ecology and Society 13:10.

Stephens, S.L., C.I. Millar and B.M. Collins. 2010. Operational approaches to managing forests of the future in Mediterranean regions within a context of changing climates. Environmental Research Letters. Volume 5(2). doi: 10.1088/1748-9326/5/2/024003. Available online at <http://iopscience.iop.org/1748-9326/5/2/024003>. Accessed on 3 March 2011.

Strittholt, J.R., D.A. DellaSalla and H. Jiang. 2006. Status of mature and old-growth forest in the Pacific Northwest. Conservation Biology 20:363–374.

Stewart, I.T., D.R. Cayan and M.D. Dettinger. 2005. Changes toward earlier streamflow timing across western North America. Journal of Climate 18:1136–1155.

Su, Q., D.A. MacLean and T.D. Needham. 1996. The influence of hardwood content on balsam fir defoliation by spruce budworm. Canadian Journal of Forest Research 26:1620–1628.

Sun, Y., S. Solomon, A. Dai and R.W. Portmann. 2007. How often will it rain? Journal of Climate 20:4801–4818.

Sundquist, E.T., K.V. Ackerman, N.B. Bliss, J.M. Kellndorfer, M.C. Reeves and M.G. Rollins. 2009. Rapid assessment of U.S. forest and soil organic carbon storage and forest biomass carbon sequestration capacity: U.S. Geological Survey Open-File Report 2009–1283, 15 p. Available online at <http://pubs.usgs.gov/ofr/2009/1283. Accessed 3 March 2011.

Swanson, M.E, J.F. Franklin, R.L Beschta, C.M. Crisafulli, D.A. DellaSala, R.L Hutto, D.B. Lindenmayer and F.J. Swanson. 2010. The forgotten stage of forest succession: early-successional ecosystems on forest sites. Frontiers in Ecology and the Environment. doi: 10.1890/090157.

Swetnam, T.W., and A.M. Lynch. 1989. A tree-ring reconstruction of western spruce budworm history in the southern Rocky Mountains. Forest Science 35:962–986.

Swetnam, T.W., and A.M. Lynch. 1993. Multicentury, regional scale patterns of western spruce budworm outbreaks. Ecological Monographs 63:399–424.

Swindle, K.A., W.J. Ripple, E.C. Meslow and D. Schafer. 1999. Old forest distribution around spotted owl nests in the central Cascade Mountains, Oregon. Journal of Wildlife Management 63:1212–1221.

Sztukowski, L., and S. Courtney. 2004. Chapter Four: Prey in S.P. Courtney, J.A. Blakesley, R.E. Bigley, M.L. Cody, J.P. Dumbacher, R.C. Fleischer, A.B. Franklin, J.F. Franklin, R.J. Gutierrez, J.M. Marzluff and L. Sztukowski (authors), Scientific evaluation of the status of the northern spotted owl. Sustainable Ecosystems Institute. Portland, Oregon.

Taylor, A.H. 2000. Fire regimes and forest changes along a montane forest gradient, Lassen Volcanic National Park, southern Cascade Mountains, USA. Journal of Biogeography 27:87–104.

Taylor, A.H., and C.N. Skinner. 1998. Fire history and landscape dynamics in a late-successional reserve in the Klamath Mountains, California, USA. Forest Ecology and Management 111:285–301.

Taylor, A.H., and C.N. Skinner. 2003. Spatial patterns and controls on historical fire regimes and forest structure in the Klamath Mountains. Ecological Applications 13:704–719.

Taylor, S.W., A.L. Carroll, R.I. Alfaro and L. Safranyik. 2006. Forest, climate and mountain pine beetle outbreak dynamics in western Canada. Pages 67–94 in L. Safranyik and B. Wilson (editors), The Mountain Pine Beetle: A Synthesis of Biology, Management, and Impacts on Lodgepole Pine. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, British Columbia.

Thomas, J.W., E.D. Forsman, J.B. Lint, E.C. Meslow, B.R. Noon and J. Verner. 1990. A conservation strategy for the northern spotted owl. Interagency Scientific Committee to Address the Conservation of the Northern Spotted Owl. U.S. Forest Service, U.S. Bureau of Land Management, U.S. Fish and Wildlife Service, and U.S. National Park Service, Portland, Oregon.

Thomas, J.W., J.F. Franklin, J. Gordon and K.N. Johnson. 2006. The Northwest Forest Plan: origins, components, implementation experience, and suggestions for change. Conservation Biology 20:277–287.

Thomas, J.W., M.G. Raphael, R.G. Anthony, E.D. Forsman, A.G. Gunderson, R.S. Holthausen, B.G. Marcot, G.H. Reeves, J.R. Sedell and D.M. Solis. 1993. Viability assessments and management considerations for species associated with late-successional and old-growth forests of the Pacific Northwest. U.S. Department of Agriculture, Forest Service, Portland, Oregon.

Thome, D.M., C.J. Zabel and L.V. Diller. 1999. Forest stand characteristics and reproduction of northern spotted owls in managed north-coastal California forests. Journal of Wildlife Management 63(1):44-59.

Thompson, J.R., and T.A. Spies. 2009. Vegetation and weather explain variation in crown damage within a large mixed-severity wildfire. Forest Ecology and Management. 258:1684-1694.

Thompson, J.R., and T.A. Spies. 2010. Factors associated with crown damage following recurring mixed-severity wildfires and post-fire management in southwestern Oregon. Landscape Ecology. 25:775-789.

Thompson J.R., T.A. Spies and L.M. Ganio. 2007. Reburn severity in managed and unmanaged vegetation in a large wildfire. Proceedings of the National Academy of Sciences 104:10743–10748.

Turner, M.G., and W.H. Romme. 1994. Landscape dynamics in crown fire ecosystems. Landscape Ecology 9:59–77.

Turner, M.G., W.H. Romme and R.H. Gardner. 1999. Prefire heterogeneity, fire severity, and early post–fire plant reestablishment in Subalpine forests of

Yellowstone National Park, Wyoming. International Journal of Wildland Fire 9:21–36.

USDA (U.S. Department of Agriculture). 2010. The Okanogan-Wenatchee National Forest Restoration Strategy: adaptive ecosystem management to restore landscape resiliency. U.S. Forest Service, Pacific Northwest Region. September 2010. 99 pp.

USDA (U.S. Department of Agriculture), and USDI (U.S. Department of the Interior). 1994a. 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. U.S. Forest Service and U.S. Bureau of Land Management, Portland, Oregon.

USDA (U.S. Department of Agriculture), and USDI (U.S. Department of the Interior). 1994b. Final supplemental environmental impact statement on management of habitat for late-successional and old-growth forest related species within the range of the northern spotted owl. U.S. Forest Service and U.S. Bureau of Land Management, Portland, Oregon.

USDA (U.S. Department of Agriculture), U.S. Department of the Interior, U.S. Department of Commerce, and U.S. Environmental Protection Agency. 1993. Forest ecosystem management: an ecological, economic and social assessment. Report of the Forest Ecosystem Management Assessment Team. U.S. Forest Service, Portland, Oregon.

USFS (U.S. Forest Service). 2003. Final environmental impact statement for the Gotchen risk reduction and restoration project. Mt. Adams Ranger District, Skamania and Yakima Counties, Washington. USDA Forest Service, Gifford Pinchot National Forest, Vancouver, WA. October 2003. 329 pp + appendices.

USFWS (U.S. Fish and Wildlife Service) and NMFS (National Marine Fisheries Service. 1998. Endangered species consultation handbook; procedures for conducting consultation and conference activities under section 7 of the Endangered Species Act. Washington, DC. 133 pp. + appendices.

USFWS (U.S. Fish and Wildlife Service). 1983a. Endangered and threatened species listing and recovery priority guidelines. Federal Register 48:43098–43105.

USFWS (U.S. Fish and Wildlife Service). 1983b. Endangered and threatened species listing and recovery priority guidelines: correction. Federal Register 48:51985.

USFWS (U.S. Fish and Wildlife Service). 1987. The northern spotted owl status review. U.S. Fish and Wildlife Service, Portland, Oregon.

USFWS (U.S. Fish and Wildlife Service). 1989. The northern spotted owl; a status review supplement. U.S. Fish and Wildlife Service, Portland, Oregon.

USFWS (U.S. Fish and Wildlife Service). 1990a. The 1990 status review: northern spotted owl: *Strix occidentalis caurina*. U.S. Fish and Wildlife Service, Portland, Oregon. 95 pp.

USFWS (U.S. Fish and Wildlife Service). 1990b. Endangered and threatened wildlife and plants: determination of threatened status for the northern spotted owl. Federal Register 55:26114–26194.

USFWS (U.S. Fish and Wildlife Service). 1992a. Endangered and threatened wildlife and plants: determination of critical habitat for the northern spotted owl. Federal Register 57:1796–1838.

USFWS (U.S. Fish and Wildlife Service). 1992b. Draft final recovery plan for the northern spotted owl. U.S. Fish and Wildlife Service, Portland, Oregon.

USFWS (U.S. Fish and Wildlife Service). 1994. Letter from D.C. Frederick (USFWS) to J. Belcher (Washington Department of Natural Resources) dated February 1, 1994, regarding correction to spotted owl home-range data for the Olympic Peninsula. U.S. Fish and Wildlife Service, Olympia, Washington.

USFWS (U.S. Fish and Wildlife Service). 1995. Endangered and threatened wildlife and plants; proposed special rule for the conservation of the northern spotted owl on non-Federal lands. Federal Register 60:9483–9527.

USFWS (U.S. Fish and Wildlife Service). 2003. Endangered and threatened wildlife and plants; 12-month finding for a petition to list the California Spotted Owl (*Strix occidentalis occidentalis*). Federal Register 68:7580–7608.

USFWS (U.S. Fish and Wildlife Service). 2004. Northern spotted owl: Five Year Review Summary and Evaluation. U.S. Fish and Wildlife Service, Portland, Oregon.

USFWS (U.S. Fish and Wildlife Service). 2007. 2007 Draft Recovery Plan for the Northern Spotted Owl, *Strix occidentalis caurina*: Merged Options 1 and 2. Portland, Oregon.

USFWS (U.S. Fish and Wildlife Service). 2008a. Endangered and threatened wildlife and plants: revised designation of critical habitat for the northern spotted owl. Federal Register 73(157): 47326–47522.

USFWS (U.S. Fish and Wildlife Service). 2008b. Final Recovery Plan for the Northern Spotted Owl (*Strix occidentalis caurina*). Portland, Oregon.

USFWS (U.S. Fish and Wildlife Service). 2009. (Draft) Rising to the challenge: strategic plan for responding to accelerating climate change. U.S. Fish and Wildlife Service, Washington D.C.

USFWS (U.S. Fish and Wildlife Service). 2010a. Draft Protocol for Surveying Proposed Management Activities that May Impact Northern Spotted Owls. Portland, Oregon.

USFWS (U.S. Fish and Wildlife Service). 2010b. LCC information bulletin #1: form and function. Office of the Science Advisor, Washington, D.C.

USFWS (U.S. Fish and Wildlife Service). 2011. Protocol for Surveying Proposed Management Activities that May Impact Northern Spotted Owls. Portland, Oregon.

Van Mantgem, P.J., N.L. Stephenson, J.C. Byrne, L.D. Daniels, J.F. Franklin, P.Z. Fule, M.E. Harmon, A.J. Larson, J.M. Smith, A.H. Taylor and T.T. Veblen. 2009. Widespread increase of tree mortality rates in the western United States. Science 323:521–524.

Walters 1986. Adaptive management of renewable resources. McMillan, New York. USA.

Walters 1997. Challenges in adaptive management of riparian and coastal ecosystems. Conservation Ecology 1:1. Available online at <http://www.consecol.org/vol1/iss2/art1/>. Accessed on 3 March 2011.

Ward, J.W. Jr. 1990. Spotted owl reproduction, diet and prey abundance in northwest California. Thesis, Humboldt State University, Arcata, California.

Ward, J.W. Jr., R.J. Gutiérrez and B.R. Noon. 1998. Habitat selection by northern spotted owls: the consequences of prey selection and distribution. Condor 100:79–92.

Warren, D.L., and S.N. Seifert. 2011. Environmental niche modeling in MaxEnt: The importance of model complexity and the performance of model selection criteria. Ecological Applications 21:335–342.

Washington Forest Practices Board. 1996. Permanent rules for the northern spotted owl. Washington Department of Natural Resources, Olympia.

Waters, J.R., and C.J. Zabel. 1995. Northern flying squirrel densities in fir forests of northeastern California. Journal of Wildlife Management 59:858–866.

Waters, J.R., K.S. McKelvey, C.J. Zabel and W.W. Oliver. 1994. The effects of thinning and broadcast burning on sporocarp production of hypogeous fungi. Canadian Journal of Forest Research 24:1516–1522.

Weathers, W.W., P.J. Hodum and J.A. Blakesley. 2001. Thermal ecology and ecological energetics of the California spotted owl. Condor 103:678–690.

Weatherspoon, C.P., and C.N. Skinner. 1995. An assessment of factors associated with damange to tree crowns from the 1987 wildfires in northern California. Forest Science 41:430–451.

Westerling, A.L., and B.P. Bryant. 2008. Climate change and wildfire in California. Climatic Change 2008. 87:S231–S249.

Westerling, A.L., H.G. Hidalgo, D.R. Cayan and T.W. Swetnam. 2006. Warming and earlier spring increase western U.S. forest wildfire activity. Science. 313:940-943.

Whitehead, R.J., L. Safranyik and T.L. Shore. 2006. Preventative Management. Pages 173–192 in L. Safranyik and B. Wilson (editors), The Mountain Pine Beetle: A Synthesis of Biology, Management, and Impacts on Lodgepole Pine. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, British Columbia.

Whitlock, C., S.L. Shafer and J. Marlon. 2003. The role of climate and vegetation change in shaping past and future fire regimes in the northwestern U.S. and the implications for ecosystem management. Forest Ecology and Management. 178:5–21.

Whittaker, J.B. 1999. Impacts and responses at population level of herbivorous insects to elevated CO2. European Journal of Entomology 96:149–156.

Wiedinmyer, C., and M.D. Hurteau. 2010. Prescribed fire as a means of reducing forest carbon emissions in the western United States. Environmental Science and Technology 44:1926–1932.

Wildavsky, A. 1988. Searching for Safety. Transaction Publishers. New Brunswick, New Jersey. Williams, C.K., and T.R. Lillybridge. 1983. Forested plant associations of the Okanogan National Forest. U.S. Forest Service R6-ECOL-132-1983, Pacific Northwest Region, Portland, Oregon.

Williams, D.F., J. Verner, H.F. Sakai and J.R. Waters. 1992. General biology of major prey species of the California spotted owl. Pages 207–221 in J. Verner, K.S. McKelvey, B.R. Noon, R.J. Gutiérrez, G.I. Gold, Jr., and T.W. Beck (technical coordinators), The California spotted owl: a technical assessment of its current status. General Technical Report PSW-GTR-133, Pacific Southwest Research Station, U.S. Department of Agriculture, Forest Service, Albany, California.

Williams, B.K., R.C. Szaro and C.D. Shapiro. 2009. Adaptive Management: the U.S. Department of the Interior technical guide. Adaptive management working group. U.S. Department of the Interior, Washington, D.C.

Wilson, T. 2010. Limiting factors for northern flying squirrels (*Glaucomys sabrinus*) in the Pacific Northwest: a spatio-temporal analysis. Disseration, Union Institute and University, Cincinnati, Ohio.

Wimberly, M.C., T.A. Spies and E. Nonaka. 2004. Using criteria based on natural fire regime to evaluate forest management in the Oregon Coast Range of the United States. Pages 146–157 in A.H. Perera, L.J. Buse, M.G. Weber (editors), Emulating Natural Forest Landscape Disturbances: Concepts and Applications. New York: Columbia University Press.

Wisz, M.S., R.J. Hijmans, J. Lis, A.T. Peterson, C.H. Graham and A. Guisan. 2008. Effects of sample size on the performance of species distribution models. Diversity and Distributions 14:763-773.

Wright, C.S., and J.K. Agee. 2004. Fire and vegetation history in the eastern Cascade Mountains, Washington. Ecological Applications 14:443–459.

Yin, X. 1999. The decay of forest woody debris: numerical modeling and implications based on some 300 data cases from North America. Oecologia121:81–98.

Zabel, C.J., J.R. Dunk H.B. Stauffer, L.M. Roberts, B.S. Mulder and A. Wright. 2003. Northern spotted owl habitat models for research and management application in California (USA). Ecological Applications 13:1027–1040.

Zabel, C.J., K.M. McKelvey and J.P. Ward, Jr. 1995. Influence of primary prey on home-range size and habitat-use patterns of northern spotted owls (*Strix occidentalis caurina*). Canadian Journal of Zoology 73:433–439.

Zabel, C.J., K.S. McKelvey and J.D. Johnston. 1992. Patterns of habitat use by California spotted owls in logged forests of the northern Sierra Nevada. Pages 165–174 in J. Verner, K.S. McKelvey, B.R. Noon, R.J. Gutiérrez, G.I. Gold, Jr., and T.W. Beck (technical coordinators), The California spotted owl: a technical assessment of its current status. General Technical Report PSW-GTR-133, Pacific Southwest Research Station, U.S. Department of Agriculture, Forest Service, Albany, California.

Personal Communications Cited

Buchanan, Joe. 2010. Washington Department of Fish and Wildlife. Email to Brendan White, U.S. Fish and Wildlife Service, Oregon Fish and Wildlife Office, Portland, dated July 26, 2010.

Diller, Lowell. 2010. Green Diamond Resource Company. Email to Kent Livezey, U.S. Fish and Wildlife Service, Western Washington Fish and Wildlife Office, Lacey, dated April 1, 2010.

Forsman, Eric. 2006. U.S. Forest Service, Pacific Northwest Research Station, Corvallis, Oregon. Email to Paul Phifer, U.S. Fish and Wildlife Service, Regional Office, Portland, dated August 30, 2006.

Loschl, Peter, and Eric Forsman. 2006. U.S. Forest Service, Pacific Northwest Research Station, Corvallis, Oregon. Email addressed to Kent Livezey, U.S. Fish and Wildlife Service, Washington Fish and Wildlife Office, dated September 8, 2006.

Storm, Rex. 2007. Infrastructure issues and their policy solutions on Oregon federal forestlands. Public comment by Rex Storm, Certified Forester, Associated Oregon Loggers, Inc., before the November 5, 2007, meeting of the Federal Forestland Advisory Committee, Salem, Oregon. 5 pp.

Carrier, Michael. 2010. Letter from Michael Carrier, Natural Resource Policy Director, Office of Governor Ted Kulongoski, Oregon, to U.S. Senator Ron Wyden. June 4, 2010. 9 pp.

Appendix E. Comments and Responses to Comments on the Draft Revised Recovery Plan

A complete list of the comments on the draft Revised Recovery Plan and the responses to those comments can be found at the following web site:

http://www.fws.gov/oregonfwo/Species/Data/NorthernSpottedOwl/Recovery/Plan/

Appendix F. Scientific Names for Common Names Used in the Text

Following is a list of scientific names for common names of plants and animals used in the text.

Trees

White fir	*Abies concolor*
Grand fir	*Abies grandis*
Shasta red fir	*Abies magnifica shastensis*
Western larch	*Larix occidentalis*
Tanoak	*Lithocarpus densiflorus*
Pinyon pine	*Pinus edulis*
Ponderosa pine	*Pinus ponderosa*
Sugar pine	*Pinus lambertiana*
Bishop pine	*Pinus muricata*
Lodgepole pine	*Pinus contorta*
Douglas-fir	*Pseudotsuga menziesii*
Coast redwood	*Sequoia sempervirens*
Western redcedar	*Thuja plicata*
Western hemlock	*Tsuga heterophylla*
Mountain hemlock	*Tsuga mertensiana*

Mammals

Tree voles	*Arborimus longicaudus, A. pomo*
Red-backed voles	*Clethrionomys* spp.
Northern flying squirrel	*Glaucomys sabrinus*
Snowshoe hare	*Lepus americanus*
Dusky-footed wood rat	*Neotoma fuscipes*
Bushy-tailed wood rat	*Neotoma cinerea*
Gophers	*Thomomys* spp.

Birds

Northern goshawk	*Accipiter gentilis*
Red-tailed hawk	*Buteo jamaicensis*
Great horned owl	*Bubo virginianus*
Eastern screech-owl	*Otus asio*
Northern spotted owl	*Strix occidentalis caurina*
California spotted owl	*Strix occidentalis occidentalis*
Mexican spotted owl	*Strix occidentalis lucida*
Barred owl	*Strix varia*

Other species

Bark beetle	*Dendroctonus* spp.
Mountain pine beetle	*Dendroctonus ponderosae*

Spruce beetle	*Dendroctonus rufipennis*
Western spruce budworm	*Choristoneura occidentalis*
West Nile virus	*Flavivirus*
Avian influenza	*Orthomyxoviridae*
Swiss needle cast	*Phaeocryptopus gaeumannii*
Sudden oak death	*Phytopthora ramorum*
Avian malaria	*Plasmodium* spp.
Truffles	*Tuber* spp.

Appendix G. Glossary of Terms

Many of these terms have a long history and various meanings in regard to spotted owl biology and management. This glossary defines the context in which they are used in this document.

Activity Center: Spotted owls have been characterized as central-place foragers, where individuals forage over a wide area and subsequently return to a nest or roost location that is often centrally-located within the home range (Rosenberg and McKelvey 1999). Activity centers are location or point within the core use area that represent this central location. Nest sites are typically used to identify activity centers, or in cases where nests have not been identified, breeding season roost sites or areas of concentrated nighttime detections may be used to identify activity centers.

Adaptive Management: Adaptive management is a systematic approach for improving resource management by learning from the results of explicit management policies and practices and applying that learning to future management decisions.

Conserve: To preserve to use, or manage wisely.

Core Use Area: An area of concentrated use within a home range that receives disproportionally high use (Bingham and Noon 1993), and commonly includes nest sites, roost sites, and foraging areas close to the activity center. Core use areas vary geographically, and in relation to habitat conditions. This is a biological definition of core use area and is not the same as a 70-acre core as defined by the Oregon Forest Practices Act nor is it equivalent to the 100-acre LSRs referred to as northern spotted owl cores on Federal lands.

Dispersal Habitat: Juvenile spotted owls often must disperse through a range of forest types prior to finding NRF habitat on which to establish a territory. These forest types include nesting, roosting, and foraging habitat in addition to forest that meets the definition of dispersal habitat. The Interagency Scientific Committee (ISC) defined dispersal habitat as forest stands with average tree diameters ≥11 inches and conifer overstory trees with closed canopies (>40 percent canopy closure in moist forests and >30 in dry forests) and with open space beneath the canopy to allow spotted owls to fly can provide the minimum conditions needed for successful dispersal (Thomas *et al.* 1990:310). We acknowledge that this definition primarily applies to moist forests in Oregon and Washington and may not capture the full range of dispersal habitat conditions in Northern California or drier forests across the range of the spotted owl.

Early-seral Forest: Stage of forest development that includes seedling, sapling, and pole-sized trees.

Foraging Habitat: Foraging habitat is defined as lands that provide foraging opportunities for spotted owls, but without the structure to support nesting and roosting (USFWS 1992b). Spotted owls often forage in forest conditions that meet the definition of nesting/roosting habitat, but also use a broader range of forest types for foraging. This definition identifies habitat that functions as foraging habitat, but does not meet requirements for nesting or roosting.

Habitat-capable Area: Forests below the elevation limits of occupancy by territorial spotted owls that are capable of growing and sustaining structural (Davis and Lint 2005) and ecological conditions of spotted owl habitat.

High-Quality Habitat: Older, multi-layered structurally complex forests that are characterized as having large diameter trees, high amounts of canopy cover, and decadence components such as broken-topped live trees, mistletoe, cavities, large snags, and fallen trees. This is a subset of spotted owl habitat and specific characteristics may vary due to climatic gradients and abiotic factors across the range.

High-Value Habitat: Habitat that is important for maintaining spotted owls on landscapes. Includes areas meeting definition of high-quality habitat, but also areas with current and historic use by spotted owls that may not meet the definition of high-quality habitat.

Historical Site: Sites that contained spotted owls in the past. These may be currently unoccupied or sites where spotted owls were detected in the past, but not surveyed more recently.

Home Range: The area in which a spotted owl conducts its activities during a defined period of time (USFWS 1992b) that provides important habitat elements for nesting, roosting, and foraging. Home range sizes vary generally increase from south to north and vary in relation to habitat conditions and prey availability and composition.

Known Spotted Owl Site: An occupied spotted owl site or a spotted owl site where spotted owls were documented to be present in the past.

Late-seral Forest: Stage in forest development that includes mature and old-growth forest (USDA *et al.* 1993). The appearance and structure of these forests will vary across the range of the spotted owl, particularly in the dry forest provinces.

Long-term: For the purposes of planning and managing the spotted owl and its forest habitat, a time frame estimated to be greater than 30 years at a minimum and usually referring to time periods ranging from 50 years to several centuries. Use of this term can be context dependent and relative, for example, when referring to gradual demographic changes in a spotted owl population or the development of late-successional habitat conditions.

Manage: To make and act upon decisions about which actions to take, if any, regarding a particular issue, area of land, etc. This may include a decision to take no action.

Mature Forest: Forests where the annual net rate of growth has peaked. Stand age, diameter of dominant trees, and stand structure at maturity vary by forest types and local site conditions. Mature stands generally contain trees with a smaller average diameter, less age-class variation and less structural complexity than old growth stands of the same forest type (USDA *et al.* 1993). The appearance and structure of these forests will vary across the range of the spotted owl, particularly in the dry forest provinces. Mature stages of some forests provide NRF habitat for spotted owls. However, mature forests are not always spotted owl habitat, and spotted owl habitat is not always mature forest.

Mid-seral Forest: Intermediate stages of tree growth between early-seral and late-seral. The appearance and structure of these forests will vary across the range of the spotted owl, particularly in the dry forest provinces.

Nesting and Roosting Habitat: Habitat that provides nesting and roosting opportunities for spotted owls. Important stand elements may include high canopy closure, a multi-layered, multi-species canopy with larger overstory trees and a presence of broken-topped trees or other nesting platforms (*e.g.,* mistletoe clumps (USFWS 1992b). The appearance and structure of these forests will vary across the range of the spotted owl, particularly in the dry forest provinces.

Occupied Site: Any location where territorial spotted owls are known to be present.

Old-growth Forest: Old-growth forests are forests that have accumulated specific characteristics related to tree size, canopy structure, snags and woody debris and plant associations. Ecological characteristics of old-growth forests emerge through the processes of succession. Certain features - presence of large, old trees, multilayered canopies, forest gaps, snags, woody debris, and a particular set of species that occur primarily in old-growth forests - do not appear simultaneously, nor at a fixed time in stand development. Old-growth forests support assemblages of plants and animals, environmental conditions, and ecological processes that are not found in younger forests (younger than 150-250 years) or in small patches of large, old trees. Specific attributes of old-growth forests develop through forest succession until the collective properties of an older forest are evident.

Protect: Guard or shield from loss.

Provincial: This is a qualifying term used with home range and core use area to reflect the fact that both vary in size according to latitude, amount of available habitat, prey availability, and forest structure and composition. Typically, home range and core use area sizes increase from south to north, and decrease as amount of high-quality habitat available to spotted owls increases.

Restoration: The recovery of vegetative structure, species composition, and self-regulating ecological processes at multiple spatial and temporal scales with the intent to provide for long-term ecological sustainability and ecological integrity.

Resilience: Resilience refers to the capacity of an ecosystem to not only accommodate gradual changes but to return toward a prior condition after disturbances including fire, extreme weather events, and climate change.

Retain: To keep.

Short-term: For the purposes of planning and managing the spotted owl and its forest habitat, a time frame estimated to be less than a few decades and usually between one to ten years. Use of this term can be context dependent and relative, for example, when referring to immediate changes in a forest stand due to a wildfire or vegetation treatment, or the behavioral response of individual spotted owls to habitat alteration or the removal of barred owls from a spotted owl territory.

Snag: Any standing dead or partially dead tree. A hard snag is composed primarily of sound (merchantable) wood while a soft snag is composed of wood in advanced stages of decay and deterioration, and is not generally merchantable.

Spotted Owl Site: Any location where territorial spotted owls are known to be present, were historically present, or may be present in unsurveyed habitat. Spotted owl sites can be identified through surveys where spotted owls were detected (USFWS 2010). In cases where survey data are unavailable, spotted owl sites can be identified by 1) conducting surveys, or 2) using a modeling approach that uses habitat and landscape characteristics to identify areas with a high probability of being occupied by spotted owls.

Uncharacteristic Wildfire – Fires that threaten the loss of key ecological attributes and functions, due primarily to the diminishment of natural landscape resilience mechanisms.

Unoccupied Site: Site where spotted owls were detected in the past, but more recent surveys have not detected owls. Surveys are required to establish unoccupied status, and criteria for determining unoccupied status are presented in the 2010 (2011) Northern Spotted Owl Survey Protocol (USFWS 2011).

Viable Population - a self-sustaining population with a high probability of survival despite the foreseeable effects of demographic, environmental and genetic stochasticity and of natural catastrophes.

Appendix H. Contributors To The 2008 Recovery Plan

A Recovery Plan for the Northern Spotted Owl (2008 Recovery Plan) was prepared with the assistance of a Recovery Team representing Federal agencies, State governments, and other affected and interested parties, as well as the assistance of a contractor (Sustainable Ecosystems Institute or SEI) and published May 14, 2008. The Recovery Team members served as independent advisors to the Service for the development of the 2007 Draft Recovery Plan. The 2008 Recovery Plan did not necessarily represent the view or official position of any individual or organization—other than that of the Service—involved in its development. Additional valuable support was provided by three work groups of Federal and State agency scientists and academic researchers.

The Service gratefully acknowledges the effort and commitment of the many individuals involved in the conservation and recovery of the northern spotted owl who participated in the preparation of the 2008 Recovery Plan. Without their individual expertise and support, this Revised Recovery Plan would not have been possible as it is the culmination of many years of labor.

The Service began preparing a recovery plan for the spotted owl in April 2006. To advise the Service, a Recovery Team was initially appointed which was supported by an Interagency Support Team (IST) and led by a Recovery Plan Project Manager. During the development of the 2007 Draft Recovery Plan, the Recovery Team convened several panels of experts to advise them and provide information on scientific and land management issues (noted as Scientist and Implementer Panelists below). The Service is indebted to all of the individuals for the guidance provided during the preparation of the 2007 Draft Plan. Their names, affiliations, and roles are listed below.

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The 2007 Draft Recovery Plan generated more than 75,800 public comments. To evaluate scientific and management issues highlighted during the comment period, the Service contracted with an independent consultant (SEI) to provide assistance. In addition, the Service appointed three scientific work groups to evaluate comments and provide guidance on the best science concerning the three major areas of concern raised during the comment period: spotted owl habitat, fire, and barred owls. Based on this input, and comments from the public, the Service finalized the 2008 Recovery Plan. We thank all of these individuals; they are listed below.

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