Chapter 6: Other Species and Biodiversity of Older Forests

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Introduction

This chapter focuses mostly on terrestrial conditions of species and biodiversity associated with late-successional and old-growth forests in the area of the Northwest Forest Plan (NWFP). We do not address the northern spotted owl (*Strix occidentalis caurina*) or marbled murrelet (*Brachyramphus marmoratus*)—those species and their habitat needs are covered in chapters 4 and 5, respectively. Also, the NWFP's Aquatic and Riparian Conservation Strategy and associated fish species are addressed in chapter 7, and early-successional vegetation and other conditions are covered more in chapters 3 and 12.

We begin by summarizing a set of questions provided by management. We then review the state of knowledge of species, biodiversity, and ecosystem conditions gained from studies conducted since the 10-year synthesis of monitoring and research results (Haynes et al. 2006). We review agency programs on other species and biodiversity of older forests of the Pacific Northwest, including implementation of the NWFP Survey and Manage standards and guidelines, the Interagency Special Status and Sensitive Species Program (ISSSSP), and other biodiversity consortia. We then review new findings on selected individual species and groups of species including fungi, lichens, bryophytes, and plants, as well as invertebrates. We also summarize findings on amphibians, reptiles, and birds, and on selected carnivore species including fisher (*Pekania pennanti*), marten (*Martes americana*), and wolverine (*Gulo gulo*), and on red tree voles (*Arborimus longicaudus*) and bats. We close the section with a brief review of the value of early-seral vegetation environments. We next review recent advances in development of new tools and datasets for species and biodiversity conservation in late-successional and old-growth forests, and then review recent and ongoing challenges and opportunities for ameliorating threats and addressing dynamic system changes. We end with a set of management considerations drawn from research conducted since the 10-year science synthesis and suggest areas of further study.

The general themes reviewed in this chapter were guided by a set of questions provided by the U.S. Forest Service Pacific Northwest Region (Region 6) and Pacific Southwest Region (Region 5). The scientific publications we review were selected based on the specific subjects listed above, as pertinent to science findings on other species and biodiversity of late-successional and old-growth forest ecosystems in the area of the NWFP in the Pacific Northwest, United States. We include selected references on studies outside the NWFP and Pacific Northwest and references dating prior to the previous NWFP science synthesis, when such studies are nonetheless pertinent to understanding biological and ecological topics within the NWFP and Pacific Northwest. We also address selected topics such as early-successional forest ecosystems and effects of wildfire, fire suppression, and climate change, as guided by the availability of recent literature on NWFP species and biodiversity; these topics, raised by managers, are also covered more fully in other chapters of this science synthesis. The final chapter of this synthesis discusses the conceptual and practical implications of new science findings, remaining scientific uncertainties and research needs, and overall conclusions.

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Setting and Background

Originally, the NWFP was developed as an ecosystem management plan to provide for the full suite of biodiversity at all taxonomic and functional levels, particularly in late-successional and old-growth environments, under an adaptive learning and management approach. The first decade of the NWFP, however, focused on the status of species; no biodiversity monitoring program per se was instituted under the NWFP (Marcot and Molina 2006). Since then, a broad assumption has been made that older-forest biodiversity in its full capacity would be provided by two complementary approaches of managing for "coarse filter" elements such as the dispersion and distribution of late-successional forest reserves and aquatic and riparian corridors, along with managing for "fine filter" elements of habitat needs of selected, individual late-successional and old-growth-associated species. The combined coarse- and fine-filter approach is intended to provide the same level of protection as would management and monitoring directed at specific biodiversity elements such as ecosystem processes of nutrient cycling, species' ecological functions, and population genetics and viability (e.g., Noss 1990). A current challenge is to test this assumption within the changing tapestry of ecological processes and disturbance-influenced ecosystems of the Northwest.

The 2012 planning rule for guiding land and resource management plans on national forests differs from the 1982 rule that was in place when the NWFP was first instituted and that guided the NWFP. The 2012 planning rule puts more weight on coarse-filter approaches and on ecological integrity (based in part on natural range of variation) but still calls for both coarse- and fine-filter approaches. In the Forest Service's evaluations of the alternatives to the planning rule (USDA FS 2012), the terms coarse filter and fine filter are referred to extensively as "well-developed concept[s] in the scientific literature [with] broad support from the scientific community and many stakeholders." However, the debate continues on an appropriate balance between coarse-filter (ecosystem and biodiversity) and fine-filter (species-specific) planning direction (Hayward et al. 2016,[2] Schultz et al. 2013).

Also, although not part of the NWFP per se, some previous elements of the U.S. Forest Service' Forest Inventory and Analysis (FIA) program[3]—which have since been drastically reduced or are no longer being carried out—provided much-needed information for monitoring biodiversity of trees, vegetation, and lichens.[4] The FIA program has become a de facto biodiversity monitoring program, at least for selected vegetation and floral elements.

In the previous science synthesis, Marcot and Molina (2006) concluded that NWFP directions for establishing effectiveness monitoring of forest biodiversity elements for other than selected species remained mostly unmet (beyond the FIA-identified biodiversity indicators). This remains true today, but much information has been provided by research studies and gathered by agency programs on basic occurrence, distribution, and ecology of rare and poorly known late-successional and old-growth-associated species. The 2006 synthesis also provided the following suggestions:

- Engage research partnerships to fill key information gaps on rare and little-known late-successional and old-growth species.
- Clarify objectives and expectations of implementing a coarse- and fine-filter conservation approach to managing for viable and persistent species populations.
- Validate the use of surrogates (e.g., indicator and focal species) for species and conservation objectives.
- Develop and maintain databases from ongoing inventory, survey, and any monitoring programs.

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[2] Hayward, G.D.; Flather, C.H.; Rowland, M.M.; Terney, R.; Mellen-Mclean, K.; Malcolm, K.D.; McCarthy, C.; Boyce, D.A. 2016. Applying the 2012 planning rule to conserve species: a practitioner's reference. Unpublished paper. On file with: Bruce Marcot, Forestry Sciences Laboratory, 620 SW Main, Portland, OR 97205. 78 p.

[3] http://www.fia.fs.fed.us/.

[4] McCune, B. Personal communication. Professor, Department of Botany and Plant Pathology, Oregon State University, 2082 Cordley Hall Corvallis, OR 97331-2902. http://bmccune.weebly.com/.

- Develop, test, and implement species survey designs.
- Explore habitat modeling and decision-support tools to meet some conservation objectives.
- Develop and implement an effectiveness monitoring framework.

The current synthesis determines the degree to which these suggestions have been met.

New Learning and Recent Issues

Much has been learned since the 2006 synthesis (Haynes et al. 2006) about conditions and dynamics of forest ecosystems and their organisms in the Pacific Northwest and throughout the West. The issue of climate change and its known and projected impacts on systems has become a foremost research topic (Bagne et al. 2011, Vose et al. 2012). Occurrence and effects of large-scale wildfire have become major issues of research and management focus (Sheehan et al. 2015, Wimberly and Liu 2014). Studies on the effect of fire suppression on vegetation succession are needed, however, as are studies examining how suppression activities affect subsequent fire behavior but also how it changes vegetation conditions as habitat for many species (see chapter 3). Concern over invasive species also has elevated (Jones et al. 2010, Wilson et al. 2009; also see chapter 3). We address these and other issues in sections that follow.

Additionally, of increased focus is how early-successional vegetation provides habitats for many species (Hagar 2007, Swanson et al. 2011). Another topic of continued interest is the importance of conditions in the managed-forest matrix and connectivity of late-successional and old-growth forests and late-successional reserves (LSRs) in the face of fire, climate change, and increased pressure on matrix-land resources (Suzuki and Olson 2008, Wilson and Puettmann 2007). As well, the roles and conditions of rare and little-known species have been addressed (Raphael and Molina 2007). In general, much more detailed information is now available on vertebrates than on most other species groups.

Guiding Questions

This chapter reviews the scientific understanding of the ecology and conservation of species associated with late-successional and old-growth forests. We summarize science findings on the conservation strategy of the NWFP and its provision for these species; scientific progress since the previous NWFP evaluations (Diaz and Haynes 2002, Haynes and Perez 2001, Haynes et al. 2006); and the outcome of the NWFP Survey and Manage program.

We review advancements on science and conservation through the following questions:

- What is the current scientific understanding of the rarity of late-successional and old-growth-associated species?
- Is forest management under the NWFP providing habitat for rare and uncommon species as planned? Are rare and uncommon species maintaining populations under NWFP management? How effective are the management recommendations for habitat conservation in retaining these species across treated landscapes?
- Have we accumulated enough information to change the management status of these species? Are there species originally ranked as having low potential for persistence that are now of less concern, particularly with the reduction in harvest levels of late-successional and old-growth forest that has occurred under the NWFP? Are there late-successional and old-growth species originally ranked as high persistence or not initially identified as conservation concerns that have been added to lists of species of concern?
- What are results of research on the effects of prescribed fire and wildfire on rare and uncommon late-successional and old-growth species?
- What are results of research on the effectiveness of site buffers as compared with landscape-scale habitat management for ensuring late-successional and old-growth species persistence, dispersal, and habitat connectivity?
- How has the ISSSSP served to provide information on late-successional and old-growth-associated species under the NWFP?

- Does the current list of special status and sensitive species adequately represent rare late-successional and old-growth species with risks to population persistence?
- What are new issues related to conservation of biodiversity in the NWFP area?

Agency Programs on Other Species and Biodiversity of Older Forests

Survey and Manage Program

Following the 1993 report of the Forest Ecosystem Management Assessment Team or FEMAT (1993), and as part of the initial creation of the NWFP, the NWFP Survey and Manage program was instituted in 1993 as part of a final environmental impact statement and record of decision for amendments to U.S. Department of Agirculture (USDA) Forest Service and U.S. Department of the Interior (USDI) Bureau of Land Management (BLM) planning documents for federal public lands within the range of the northern spotted owl. The Survey and Manage program was then amended by a 2001 record of decision for amendment to the Survey and Manage, protection buffer, and other mitigation measures standards and guidelines. The amendment established (1) an annual species review panel process to evaluate monitoring and research findings and to recommend to the regional forester of Region 6 appropriate conservation categories for all late-successional and old-growth-associated species not otherwise provided for by the NWFP guidelines, and (2) a set of site survey protocols[5] and management recommendations for detecting and conserving sites with rare and little-known species under the NWFP. The annual species review sessions were designed as rigorous, 10-person panels consisting of 5 biologists and 5 managers and used a Bayesian network decision modeling construct to help evaluate knowledge and explicitly represent uncertainty of each species in documented, repeatable procedures (Marcot et al. 2006). Mostly because of high costs and administrative complexities, no formal annual species review has been conducted since 2003.

The Survey and Manage program was established under the NWFP as a means of collecting information on, and providing appropriate conservation direction for, rare and poorly known late-successional and old-growth-associated species under the precautionary principle (resisting implementation of untested or disputed activities that may have adverse effects) and an adaptive management process (Marcot et al. 2006, Molina et al. 2003, USDA and USDI 2001). From the initial list of 1,120 late-successional and old-growth-associated species evaluated by FEMAT (1993), various mitigation means under the NWFP Survey and Manage program narrowed the list in 2001 to 296 individual species and 4 arthropod species groups. The Survey and Manage program was then abolished, and, under a management policy decision of the agencies, 152 of the 296 species were moved to the USDA Forest Service Sensitive Species program and the USDI BLM Special Status Species program, but the court then mandated that the Survey and Manage record of decision be reinstated. Eventually, the two agencies' species programs were merged into the ISSSSP, discussed more fully below, which has since held the responsibility for evaluation of late-successional and old-growth species in the region. Also in the interim, a set of new national forest planning regulations have been instituted that provide impetus for considering other species, biodiversity, ecosystems, dynamics, and functions of both older and early-seral forests (Schultz et al. 2013). We discuss these updates to Forest Service and BLM planning guidelines and regulations further below.

The Survey and Manage program has had an unstable existence, having been established in 1994 (USDA and USDI 1994) with corrections to its standards and guidelines published in 2001 (USDA and USDI 2001), abolished by the agencies in 2004 (USDA and USDI 2004), reinstated by the court in 2006, again abolished by the agencies in 2007, challenged in 2008, and with a court ruling in 2009 that the 2007 Forest Service environmental impact statement was flawed and the court subsequently approving a settlement agreement in 2011. The timber industry then challenged the settlement agreement in 2011 (and subsequently dropped their appeal in 2015), the Ninth Circuit Court of Appeals reversed and remanded the approval of the settlement

[5] http://www.blm.gov/or/plans/surveyandmanage/protocols/.

agreement in 2013, and then in 2014, the 2007 records of decision were vacated.

Vacatur of the two 2007 records of decision (in 2007, BLM and the Forest Service each issued separate records of decision) has had the effect of returning the agencies to the status quo in existence prior to the 2007 records of decision. The status quo existing before the 2007 records of decision was defined by three previous court rulings, as follows. First is the 2006 court order reinstating the 2001 record of decision, including any amendments or modifications that were in effect as of March 21, 2004. This ruling incorporated the 2001, 2002, and 2003 annual species review changes. Second was the 2006 court-ordered categories of activities that could proceed without conducting predisturbance surveys or site management for species: (1) thinning in forests less than 80 years old; (2) replacement or removal of water culverts; (3) activities for improvement of riparian and stream areas; and (4) treatment of hazardous fuels, including use of prescribed fire; these reinstatements were retained in the later court rulings mentioned above. Third was the 2006 court ruling that vacated the 2001 and 2003 annual species review category change and subsequent removal of reference to the red tree vole in a portion of its range, returning the species to its prior monitoring status throughout its range.

At present, oversight of the Survey and Manage standards and guidelines implementation is consigned to staff members within the ISSSSP (Region 6 and Oregon BLM) and the Region 5 regional wildlife program manager within the Ecosystem Conservation staff. These individuals coordinate revision of management recommendations and survey protocols, assist field specialists in implementing the standards and guidelines, resolve issues between Survey and Manage species management and meeting other resource objectives, coordinate data management between the agencies preparing for an Annual Species Review, stay abreast of taxonomic updates, and coordinate methods for filling information gaps. To clarify, Forest Service Region 5 is not formally a part of the ISSSSP, which is unique to Forest Service Region 6 and Oregon-Washington BLM.

The list of late-successional and old-growth-associated species as provided by FEMAT (1993) had been evaluated by the Forest Service and BLM under the Survey and Manage program's annual species reviews, using a set of published guidelines (table 6-1) to determine species' potential need for more specific and additional conservation. Based on an evaluation of the occurrence of, and scientific knowledge on, the species, about 400 species of amphibians, bryophytes, fungi, lichens, mollusks, vascular plants, arthropod functional groups, and one mammal were deemed to be potentially at-risk, and the rest of the species were deemed to be adequately provided under the NWFP guidelines; the genealogy through 2006 of the many species lists are covered by Marcot and Molina (2006) and Molina et al. (2006). The annual species reviews developed and adopted use of a Bayesian network decision modeling approach to help wade through the complex evaluation guidelines (table 6-1) and to document results on each species (Marcot et al. 2006).

Under the Survey and Manage program, about 68,000 sites with presence of Survey and Manage species were identified by surveys, and new ecological knowledge was gained on about 100 species leading to their being removed from the protection list (Molina et al. 2006). Additionally, a set of field and management guides were produced on aquatic and terrestrial mollusks and fungi,[6] and guidelines were published on assessing rare species of lichens (Edwards et al. 2004), fungi (Castellano et al. 2003, Molina 2008), and other taxa. Eventually, the high cost of maintaining the Survey and Manage program, running into several tens of millions of dollars, with its annual species reviews and all other activities associated with compiling scientific and monitoring information on late-successional and old-growth-associated species, was a factor considered by managers in their decision to abolish the program and enfold it into the ISSSSP.

Understanding the distributions and disturbance responses of rare species is a perennial problem in ecology, the main issues of which include securing adequate sample sizes for statistical analyses (Cunningham and Lindenmayer 2005). Methods for increasing confidence in such studies include stratifying samples, such as demonstrated by Edwards et al. (2005) with five rare epiphytic macrolichens in the Pacific Northwest United States.

[6] http://www.blm.gov/or/plans/surveyandmanage/field.php.

Table 6-1—Guidelines for determining whether late-successional and old-growth forest (late-successional and old-growth)-associated species under the Northwest Forest Plan (NWFP) may need additional conservation consideration, as required under the Survey and Manage program 2001 record of decision (USDA and USDI 2001)

Evaluation category[a]	Description in record of decision (USDA and USDI 2001)
1. Geographic range	The species must occur within the NWFP area or near the NWFP area and have potentially suitable habitat within the NWFP area.
2. Late-successional and old-growth association	A species is considered to be closely associated with late-successional and old-growth forests if it meets at least one of the following criteria: • The species is significantly more abundant in late-successional and old-growth forest than in young forest, in any part of its range. • The species shows association with late-successional and old-growth forest and may reach highest abundance there, and the species requires habitat components that are contributed by late-successional and old-growth forest. • The species is associated with late-successional and old-growth forest, based on field study, and is on a federal U.S. Fish and Wildlife Service (USFWS) list or state threatened or endangered list; the USFWS candidate species list; a Bureau of Land Management or Forest Service special status species list in California, Oregon, or Washington; or is listed by the states of California, Oregon, or Washington as a species of special concern or as a sensitive species. • Field data are inadequate to measure strength of association with late-successional and old-growth forest; the species is listed as a federal USFWS threatened and endangered species; and the Forest Ecosystem Management Assessment Team suspected, or the panel doing the final placement in Species Review Process suspects, that it is associated with late-successional and old-growth forest.
3. Plan provides for persistence	The reserve system and other standards and guidelines of the NWFP do not appear to provide for a reasonable assurance of species persistence. Criteria indicating a concern for persistence, i.e., one or more of the following criteria must apply: • Low to moderate number of likely extant known sites/records in all or part of a species range. • Low to moderate number of individuals. • Low to moderate number of individuals at most sites or in most populations. • Very limited to somewhat limited range. • Distribution within habitat is spotty or unpredictable in at least part of its range. • Very limited to somewhat limited habitat. Criteria indicating little or no concern for persistence, usually, most of the following criteria must apply: • Moderate to high number of likely extant sites/records. • Sites are relatively well distributed within the species range. • High proportion of sites and habitat in reserve land allocations; or limited number of sites within reserves, but the proportion or amount of potential habitat within reserves is high and there is a high probability that the habitat is occupied. • Matrix standards and guidelines or other elements of the NWFP provide a reasonable assurance of species persistence.
4. Data sufficiency	Information is insufficient to determine whether Survey and Manage basic criteria are met, or to determine what management is needed for a reasonable assurance of species persistence.

Table 6-1—Guidelines for determining whether late-successional and old-growth forest (late-successional and old-growth)-associated species under the Northwest Forest Plan (NWFP) may need additional conservation consideration, as required under the Survey and Manage program 2001 record of decision (USDA and USDI 2001) (continued)

Evaluation category[a]	Description in record of decision (USDA and USDI 2001)
5. Practicality of survey	Surveys are considered "practical" if all of the following criteria apply: • The taxon appears annually or predictably, producing identifying structures that are visible for a predictable and reasonably long time. • The taxon is not so minuscule or cryptic as to be barely visible. • The taxon can authoritatively be identified by more than a few experts, or the number of available experts is not so limited that it would be impossible to accomplish all surveys or identifications for all proposed habitat-disturbing activities in the NWFP area needing identification within the normal planning period for the activity. • The taxon can be readily distinguished in the field and needs no more than simple laboratory or office examination to confirm its identification. • Surveys do not require unacceptable safety (5a) or species risks. • Surveys can be completed in two field seasons (about 7 to 18 months). • Credible survey methods for the taxon are known or can be developed within a reasonable time period, i.e., about 1 year.
6a. Relative rarity	The species is relatively rare and all known sites or population areas are likely to be necessary to provide reasonable assurance of species persistence, as indicated by one or more of the following: • The species is poorly distributed within its range or habitat. • Limited dispersal capability on federal lands. • Reproduction or survival not sufficient. • Low number of likely extant sites/records on federal lands indicates rarity. • Limited number of individuals per site. • Declining population trends. • Low number of sites in reserves or low likelihood of sites or habitat in reserves. • Highly specialized habitat requirements (narrow ecological amplitude). • Declining habitat trend. • Dispersal capability limited relative to federal habitat. • Habitat fragmentation that causes genetic isolation. • Microsite habitat limited. • Factors beyond management under the NWFP affect persistence, but special management under the NWFP will help persistence.
6b. Relative uncommonness	The species is relatively uncommon rather than rare, and not all known sites or population areas are likely to be necessary for reasonable assurance of persistence, as indicated by one or more of the following: • A higher number of likely extant sites/records does not indicate rarity of the species. • Low to high number of individuals/site. • Less restricted distribution pattern relative to range or potential habitat. • Moderate to broad ecological amplitude. • Moderate to high likelihood of sites in reserves. • Populations or habitats are stable.

[a] If criteria for any evaluation category were met, then the species may be further considered for needing additional conservation beyond what the NWFP generally provides; such further consideration was addressed during annual species reviews under the NWFP Survey and Manage program.

Interagency Special Status and Sensitive Species Program

The ISSSSP[7] was formed in 2005 as an interagency Forest Service Region 6 and BLM Oregon/Washington program for regional-level approaches for conservation and management of rare (but neither federally listed threatened nor endangered) species that would meet criteria for the two agencies' lists of special status species and sensitive species. Its geographic and ecological scope includes and exceeds that of the NWFP and late-successional and old-growth forests in Washington and Oregon. The ISSSSP is not a reformulation of the NWFP Survey and Manage program, although it has taken on some of those functions pertaining to evaluation of the conservation status of species, development of some species survey and monitoring protocols, and other items. The ISSSSP addresses species across Forest Service and BLM lands in Oregon and Washington (but not California), implementing the Forest Service sensitive species policy (FSM 2670) and BLM special status species policy (BLM 6840) and providing oversight of the Survey and Manage standards and guidelines. Criteria for determining Forest Service sensitive species are quite different from the Survey and Manage species criteria discussed above (also see table 1).

California, particularly northwest California within the NWFP area, does not have an organization equivalent to the ISSSSP, which is a collaboration unique to Washington and Oregon. In California, instead, the Forest Service Region 5 implements the national Forest Service sensitive species policy (FSM 2670) and results are overseen by various Forest Service regional office staff for the entire state, not just for the NWFP area and the six national forests therein. California BLM includes lands within the NWFP area, and those are overseen by the BLM Redding Resource Area, Arcata Resource Area, and the Kings Range National Conservation Area, all within the BLM Ukiah District.

The ISSSSP has produced a wide array of products related to conservation of rare, nonlisted species. Products include species fact sheets, conservation assessments, conservation strategies, inventory reports, inventory and survey protocols and methods workshops, and results of studies. The most recent program update[8] (June 2015) mentions reorganization of the program's conservation and inventory information on bats and fungi (covered below). The ISSSSP partners with and supports a variety of research and academic institutions to provide key information on rare species of conservation concern within its geographic venue.

Unique among federal land management agencies, the ISSSSP has developed criteria used in common with Forest Service and BLM for including species on sensitive and special status lists. The ISSSSP considers species for such listing by using independent information from the Oregon Biodiversity Information Center[9] Washington Natural Heritage Program[10] and NatureServe. [11]

The current list of Survey and Manage species[12] dates to December 2003 and includes 298 species: 189 fungi, 15 bryophytes, 40 lichens, 12 vascular plants, 36 snails and slugs (mollusks), 4 amphibians, 1 mammal (red tree vole, treated below), and 1 bird (great gray owl, *Strix nebulosa*).

Implications of Forest Service and BLM Planning Directions

The current planning rule for the U.S. Forest Service (2012: 21174)[13] states that its intent is

> ... to provide for the diversity of plant and animal communities, and keep common native species common, contribute to the recovery of threatened and endangered species, conserve proposed and candidate species, and maintain species of conservation concern within the plan area, within Agency authority and the inherent capability of the land.

[7] http://www.fs.fed.us/r6/sfpnw/issssp/.

[8] http://www.fs.fed.us/r6/sfpnw/issssp/documents3/update-2015-06.pdf.

[9] http://inr.oregonstate.edu/orbic.

[10] http://www.dnr.wa.gov/natural-heritage-program.

[11] http://www.natureserve.org/.

[12] http://www.blm.gov/or/plans/surveyandmanage/files/sm-fs-enc3-table1-1-dec2003wrtv.pdf.

[13] http://www.fs.usda.gov/detail/planningrule/home/?cid=stel-prdb5359471.

The rule establishes guidelines and mandates for ecological sustainability, particularly for ecosystem integrity defined as the maintenance or restoration of terrestrial and aquatic ecosystems and watersheds, and their structure, function, composition, and connectivity. The rule also explicitly adopts a coarse- and fine-filter approach (further discussed below) to managing for diversity of plant and animal communities beginning with maintaining or restoring the diversity of ecosystem and habitat types including rare aquatic and terrestrial plant and animal communities, as well as identifying species of conservation concern to be designated by the responsible official, in coordination with the regional forester, based on scientific information. In the Pacific Northwest, the Forest Service is currently producing a draft list of potential species of conservation concern to facilitate efficiencies when the region undergoes plan revision under the 2012 planning rule.

Additional parts of the 2012 planning rule for the Forest Service provide guidance on monitoring, which it defines as "a systematic process of collecting information to evaluate effects of actions or changes in conditions or relationships" (USDA FS 2012:21271). The planning rule also provides guidance on managing ecological systems at the broad scale and for specific ecosystem elements, such as individual species, at finer scales. As such, specifically, the planning rule refers to coarse-filter management as "designing ecosystem ... connectivity based on landscape patterns of forests, grasslands, rangelands, streams, and wetlands that were created under ecological processes and landscape disturbance regimes that occurred before extensive human alteration" (section 23.11b: Ecosystem Integrity), and fine-filter management as "species-specific plan components, including standards and guidelines, for each of those species" (section 23.13: Species-Specific Plan Components for At-Risk Species).

Schultz et al. (2013) recommended directly monitoring selected species of conservation concern and focal species because of inconsistencies in the 2012 planning rule between its operational requirements and its generous discretionary allowances. They suggested that monitoring should evaluate viability of such species and that management should do no harm to species for which viability cannot be provided solely on Forest Service lands; and that monitoring should specify trigger points to spark reviews of management activities affecting species conservation.

As a point of history, BLM proposed a new rule for resource management planning nationally on BLM lands (USDI BLM 2016), but in February 2017, Congressional action nullified the regulations. In the NWFP area, BLM Resource Management Plans (RMPs) are in effect from records of decision signed in August 2016.[14] The new RMPs are intended to provide protection for northern spotted owls, listed fish species, and water resources, and provide for jobs, recreation, and timber harvest. At this point, it is unclear if the RMPs will provide additional guidelines for conservation of other old-forest species and biodiversity under the NWFP in addition to guidelines provided by ISSSSP.

Key Findings

New Information on Other Species and Biodiversity of Older Forests

In this section, we review new research information on individual species and species groups under the NWFP and in old-forest environments, conducted mostly since the previous science synthesis (Haynes et al. 2006).

Fungi—

Fungi are an important part of forest ecosystems. Fungi have always been a conservation challenge in terms of species identification, taxonomic designation, inventory and monitoring of furtive and seldom-appearing species, and understanding of their key ecological roles in late-successional and old-growth forest ecosystems. Many fungi are rare or little known, but much has been learned about some aspects of species occurrence and distribution since the previous science synthesis. Some of this work is presented in peer-reviewed publications, and other work is available through an agency peer review process. Recent regional work provides information on California fungal species. Other work provides a better understanding of the status of fungal species in the NWFP area.

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[14] https://www.blm.gov/or/plans/rmpswesternoregon/.

Occurrence of fungal species is influenced, at least in part, by the type and intensity of disturbances, time since disturbance, and vegetation development, and by forest stand management and forest age class (Heithecker and Halpern 2006, Trofymow et al. 2003). Studies by Hebel et al. (2009) suggested that high-severity wildfire can reduce or prevent colonization of, and can kill, beneficial arbuscular mycorrhizal fungi. As noted in chapter 3 and in Reilly et al. (2017), current rates of high-severity fire in the NWFP area are very low even in the moist forests where fire was historically infrequent. In the dry forests, where fires were historically frequent, recent fire rotations have been well below the historical levels; however, in forests that historically had low-severity fire and little high-severity fire, the recent amounts of high-severity fire appear to be higher. It is unclear how current fire regimes might affect forest structure, age class, and disturbance intensity.

Presumably, native fungi species were able to persist across landscapes with frequent to very frequent fire (<50 years) and in landscapes with occasional, moderately frequent, mixed-severity fire (50 to 200 years). Fire suppression has affected the various forest ecosystems of the NWFP area in different ways (chapter 3), although little is known about effects of fire suppression activities on fungi. Luoma and Eberhard (2005) urged the conservation of rare truffle and mushroom species "... in a manner that recognizes their different responses to forest disturbance." They also hypothesized that fire suppression activities may have favored mushroom production over truffle production, and that presence of fire is a factor in the reproductive evolution of ectomycorrhizal fungi. Thus, they concluded that providing for ectomycorrhizal fungi would include restoring forest health from the adverse effects of decades of fire suppression.

Many fungi species are soil dwellers and mostly subterranean, and, with intermittent fruiting cycles, they are not easy to detect and collect. Determining presence can be difficult, but they can play major roles in nutrient uptake by trees and other plants and in aiding coarse-wood decomposition, contributing to soil organic matter, and maintaining overall forest health.

Luoma (2001)[15] found that retention of green trees in late-successional forests helped retain *Arcangeliella camphorata*, a rare truffle fungus, as compared to the species' loss in clearcuts. Trappe et al. (2009) provided an extensive study of the distribution, ecology, and conservation of truffle species in the Pacific Northwest. In southwest Oregon, Clarkson and Mills (1994) and Amaranthus et al. (1994) also had previously demonstrated that clearcuts ranging from 4 to 27 years since harvest nearly eliminated truffle production and that retention of mature trees and coarse woody debris promote their diversity and abundance. Marcot (2017) reviewed the role of fungi in wood decay of forest ecosystems of the Pacific Northwest.

Some fungi are dispersed in unusual ways, such as on the beaks of foraging and cavity-excavating woodpeckers (Jusino et al. 2016). Fungi such as truffles and their ectomycorrhizal sporocarps are key food resources for northern flying squirrels (*Glaucomys sabrinus*) (Lehmkuhl et al. 2004); in turn, flying squirrels are a key prey species of northern spotted owls in parts of the owl's range. Deliberate introduction of fungi in live trees is a management tactic sometimes used to induce wood decay and create partially dead trees and snags for wildlife use such as in western Washington (Bednarz et al. 2013).

In 1994, the Survey and Manage program listed some 234 rare fungi species associated with late-successional and old-growth forests (Molina 2008). Molina's (2008) review of mycology herberia eventually yielded 14,400 records of these species, with 55 percent of the species found at 20 or fewer sites and 42 percent found at 10 or fewer sites; it is unclear which of the 42 percent are rare or undersurveyed. Some 90 percent of the species had some fraction of their locations occurring within reserves, but only a third of the species had all their locations within reserves. This led Molina (2008) to conclude that fine-filter conservation of rare species outside reserves was needed to help ensure conservation of the entire late-successional and old-growth-associated fungal biota.

[15] Luoma, D.L. 2001. Monitoring of fungal diversity at the Siskiyou integrated research site with special reference to the survey and manage species *Arcangeliella camphorata* (Singer & Smith) Pegler & Young. Unpublished report. On file with: Chetco Ranger District, Siskiyou National Forest, Brookings, OR 97415.

Overall, although this work has provided much information on presence and distribution of rare fungi, in general their species-specific status and trends are still not well known.

The ISSSSP Fungi Work Group has compiled an annotated bibliography on rare fungi species on the Special Status Species list for California, Oregon, and Washington.[16] This work includes 174 references, each with annotated findings and indexed to keywords pertaining to ecological and management topics.

Mushroom collection for individual use is a popular recreational activity in forests of the Pacific Northwest (Trappe et al. 2009). Individual national forests in the NWFP area may have specific regulations on commercial mushroom harvests. For example, Siuslaw National Forest (2007) sells individual commercial collection permits, up to 1,000 permits per year, with permits being unlimited by weight or amount of mushrooms collected. Alexander et al. (2002) compared the economics of timber harvest with mushroom harvest in the Pacific Northwest and found that some mushrooms (e.g., chanterelles, morels) have lower value and some (matsutake) have about the same value as commercial timber, as measured by soil expectation value analysis. At present, though, we have encountered no studies on the impacts of mushroom collection on these species' populations in the NWFP area.

Lichens—

Much has been learned over the past decade about the occurrence and rarity of forest lichens (table 6-2) and the effects of forest management in the Pacific Northwest. Lichens play important ecological roles in late-successional and old-growth forests of the Pacific Northwest (chapter 3). Epiphytic macrolichens, because of their complete reliance on atmospheric sources of water and nutrients, are useful for monitoring air quality and climate (fig. 6-1) (Geiser and Neitlich 2007; similar work by Root et al. 2015 followed

[16] http://www.fs.fed.us/r6/sfpnw/issssp/documents3/cpt-fu-effects-guidelines-att3-annotated-bibliography-2013-10.docx.

Table 6-2—Selected recent findings on lichen species associated with late-successional and old-growth forest conditions within the Northwest Forest Plan area

Lichen taxa	Topic	Source
Bryoria subcana to *B. fuscescens*	Taxonomy of *Bryoria* section Implexae	Velmala et al. 2014
Dermatocarpon	*Dermatocarpon luridum* now found to not occur in the United States. The species in the Pacific Northwest (PNW) is *D. meiophyllizum*.	Glavich 2009, Glavich and Geiser 2004
Fuscopannaria	*Fuscopannaria saubinetii* (misidentification) does not occur in the PNW. Previous records were misidentifications of *F. pacifica*, a common species in the PNW.	Jørgensen 2000
Leptogium	*Leptogium burnetiae* var. *hirsutum* is now a synonym of *L. hirsutum*, which does not occur in the PNW. The taxon of conservation concern is *L. burnetiae*.	Esslinger 2015
Leptogium	*Leptogium rivale* is changed to *Scytinium rivale*. *L. teretiusculum* is changed to *S. teretiusculum*.	Otálora et al. 2014
Usnea	*Usnea hesperina* is changed to *U. subgracilis*. Previously, *U. hesperina* and *U. subgracilis* were both considered synonyms of *U. schadenbergiana; U. schadenbergiana* is distinct from *U. hesperina* and *U. subgracilis*.	Truong et al. 2013

Bruce G. Marcot

Figure 6-1—Some arboreal, epiphytic lichens, such as this *Alectoria* in Wind River Experimental Forest in the south Washington Cascade Range, are fully dependent on atmospheric sources of water and nutrients, and thus can serve as sensitive indicators for monitoring of air pollution and climate change.

mostly east of the NWFP area).[17] Trofymow et al. (2003) found that arboreal lichen abundance and species richness differed between mature (75 to 95 years old) and old-growth (>240 years old) conifer forest stands on Vancouver Island, and thus can serve as indicators of late-successional and old-growth forest conditions. Arsenault and Goward (2016) reported that, in inland wet conifer forests of British Columbia, some macrolichens, such as *Lobaria pulmonaria*, are good indicators of old-growth forests in some ecological conditions but not in others, highlighting the need for caution when determining species' association with, and dependence on, old-growth forest conditions. Sillett et al. (2000) showed that dispersal can limit the development of some lichens (e.g., *Lobaria oregana*) in late-successional and old-growth forests, as well as in young forest plantations.

Bokhorst et al. (2015) reported that lichen species in southern Norway have a large impact on associated invertebrate communities, varying with lichens that differ in nitrogen fixation and nutrient concentration, thallus structure, and terricolous versus arboreal or epiphytic habitat. Whether such contributions of lichen diversity to overall lichen-invertebrate communities occur within

[17] Also see: http://people.oregonstate.edu/~mccuneb/epiphytes.htm and http://people.oregonstate.edu/~mccuneb/biblio.htm.

late-successional and old-growth forests of the Pacific Northwest is apparently unstudied.

Effects of wildfire and fire suppression activities on late-successional and old-growth-associated lichens have been poorly studied. Large-scale, stand-replacing fires will likely reduce distribution and biomass of late-successional and old-growth-associated lichens over decades to centuries, as a function of the species' dispersal mechanisms and limitations (Sillett et al. 2000).

Recent studies suggest that variable-density thinning treatments in young forests of Douglas-fir (*Pseudotsuga menzeisii*) and western hemlock (*Tsuga heterophylla*) can provide habitat for a variety of lichen species (Root et al. 2010) that could complement lichen assemblages found in unthinned late-successional and old-growth forest environments. Earlier studies suggested that uniform thinning of dense forest stands provides only minor improvement of habitat of lichens and bryophytes, whereas some variable-density thinning can help promote development of tree branches lower in the canopy profile as substrates for lichens and bryophytes. Earlier studies (e.g., Neitlich and McCune 1997) also revealed that forest structure may play a greater role in determining lichen diversity and biomass than forest age per se from observations that lichen biomass can be greater in structurally diverse young forests with gaps and older remnant trees than in some old-growth forests. Neitlich and McCune (1997) suggested, for conserving epiphytic macrolichens, to protect forest gaps, wolf trees (large trees with wide-spreading crowns), and old remnant and legacy trees. Retention of propagule sources, such as old legacy trees in younger stands, and older-forest patches in cutting units, can be critical to providing for old-growth-associated epiphytes (Sillett et al. 2000) and cryptogams (Hofmeister et al. 2015).

Much work has also been done over the past decade on riparian lichens. Three groups of lichens depend on riparian areas:[18] (1) nonepiphytic, instream species (e.g., *Dermatocarpon meiophyllizum*, *Leptogium rivale*, and *Peltigera hydrothyria*); (2) epiphytic species occurring in streamside and lakeshore forest and woodland environments (e.g., *Leptogium polycarpum*, *Ramalina thrausta*, *Sticta fuliginosa*, *Usnea wirthii*, and many cyanolichen species); and (3) epiphytic species in forested wetlands, particularly in Oregon ash (*Fraxinus latifolia*) swamps (e.g., *Fuscopannaria mediterranea*, *Hypotrachyna riparia*, and many cyanolichens). A number of these riparian lichens are likely afforded habitat under the NWFP's Aquatic and Riparian Conservation Strategy. For further information on riparian lichens in the Pacific Northwest, see McCune et al. (2002) and Ruchty (2000).

As with fungi, many species of lichens and other rare and poorly known species in the Pacific Northwest are difficult to detect, inventory, monitor, and study because they require specialized expertise in the field and the laboratory. To address such problems, the Survey and Manage program spurred the development of methods for statistically determining the occurrence and frequency of rare species of lichens (Edwards et al. 2004, 2005). A guide was produced under the Survey and Manage program on natural history and management considerations of selected lichen species under the NWFP (Lesher et al. 2003).

Additionally, Miller et al. (2017) tested techniques for surveying *Lobaria oregana*, a rare canopy lichen, at the southern edge of its range in northwest California within the NWFP area. They found the species on branches of large trees in the mid-crown, and on boles of small trees near ground level, suggesting that the species benefits from cool, wet microclimates, and that maintaining such microhabitats is key to its long-term viability. They also concluded that ground surveys are useful for detecting abundant lichen species, but that tree-climbing to conduct canopy surveys also may be needed to detect low-abundance species associated with mid- or upper-canopy conditions.

Bryophytes—

Bryophytes—including hornworts, liverworts, and mosses (in general, nonvascular plants)—are a conspicuous component of many late-successional and old-growth forests of the Pacific Northwest, and many species have been part of the Survey and Manage program. Many late-successional and old-growth-associated bryophytes may be sensitive to disturbance and may require old-forest stands larger than

[18] McCune, B. Personal communication. Professor, Oregon State University, Corvallis, OR 97331.

2.5 ac (1 ha) (Halpern et al. 2012) or with more than 15 percent retention of older green trees in dispersed retention harvests (Heithecker and Halpern 2006).

Mölder et al. (2015) reported that 31 bryophyte species in north Germany can serve as ancient woodland indicators; a number of bryophyte species of the Pacific Northwest can serve similar functions (Rambo and Muir 1998, 2002). In an older study, Ryan et al. (1998) found that cryptogams in mixed-conifer forests of southern Vancouver Island were largely associated with humus, and especially coarse woody debris and rock substrates, and that old-growth forests variously excluded shade-intolerant species and selected for shade-tolerant species.

A recent taxonomic update has changed *Diplophyllum plicatum* to *Douinia plicata* (Konstantinova et al. 2013).

Pacific Northwest forests are the main source of commercially harvested moss in North America with dozens of species likely affected by the practice (Peck 2006, Peck and Christy 2006). The main mosses collected are epiphytes that require 15 to 25 years to recover, and which are most abundant in riparian and low-elevation forests and absent or much less abundant in young (<70 years) Douglas-fir plantations (Peck 2006). Commercial harvest methods of stripping entire moss mats can greatly impede recovery of the species (Peck and Frelich 2008) and may be a major, local threat to this group.[19] Peck and Moldenke (2011) reported a wide array of invertebrates (205 morphospecies) associated with subcanopy epiphytic bryophyte mats subject to commercial harvest in the Coast and Cascade Ranges of the Pacific Northwest, where more than 8.2 million lbs (3.7 million kg) of bryophytes are harvested per year. However, the impact of moss harvest on populations of these invertebrate species is undetermined.

Overall, few studies are available on the status and trends of the full suite of bryophyte species (and associated other taxa) considered under the NWFP and ISSSSP. In the NWFP area, some individual national forests in Region 6 (Washington and Oregon) have their own direction regarding commercial moss collection, although there is no overall regional direction. For example, Siuslaw National Forest and Willamette National Forest may have instituted local direction of moss collection under their special forest products or nontimber forest products regulations (e.g., Siuslaw National Forest 2007). Siuslaw National Forest's direction, for instance, permits commercial moss harvests to be limited to 16,000 lb (7258 kg) per year, from harvest areas that would be open for 12 years, with only one harvest area open at a time and rotated every 12 years, and harvest areas consisting of forest stands <110 years old (Siuslaw National Forest 2007).

Vascular plants—

Vascular plants are a conspicuous and important component of late-successional and old-growth forests in the NWFP area. The diversity of vascular plants tends to increase during structural development following logging in western hemlock-Douglas-fir, and to peak in old-growth forest conditions (Halpern and Spies 1995), but less is known in other vegetation zones of the area. Late-successional and old-growth-related vascular plants in the Pacific Northwest are generally considered to be protected under the NWFP guidelines and within LSRs, and have constituted only a small fraction of all Survey and Manage species thought to be closely associated with late-successional and old-growth forests (Marcot and Molina 2006).

Most studies of changes in plant communities over seral development have used a chronosequence (space-for-time) approach and compared composition or abundance in young logged stands with naturally regenerated stands in middle or later stages of development. These studies generally agree that understory plant species diversity increases following disturbance then decreases during canopy closure, and subsequently increases again and sometimes peaks in old-growth conditions (Halpern and Spies 1995, Jules et al. 2008). Few perennial understory plant species are either absent from, or restricted to, any specific stage of successional development, although the abundance of individual species changes over time (Halpern and Spies 1995). Some species are most abundant in old growth or are closely associated with old growth (table 6-3), but none of these species is on the current Survey and Manage species list and might be candidates

[19] For a compendium of literature on moss harvesting, see: http://bryophytes.science.oregonstate.edu/MossHarvest.htm.

Table 6-3—Vascular plant species found to be associated with late-successional and old-growth forests in the Northwest Forest Plan area[a]

Species	Halpern and Spies 1995[b]	Lindh and Muir 2004[c]	Jules et al. 2008[d]
Trees/shrubs:			
Abies amabilis	✓		
Acer circinatum	✓		
Taxus brevifolia	✓		
Tsuga heterophylla	✓		
Rhododendron macrophyllum		✓	
Vaccinium alaskaense	✓		
Vaccinium membranaceum	✓	✓	
Vaccinium parvifolium	✓		
Ribes lacustre			✓
Low/subshrubs:			
Berberis nervosa	✓		
Chimaphila menziesii			
Chimaphila umbellata	✓	✓	
Cornus canadensis	✓		
Gaultheria ovatifolia	✓		
Goodyera oblongifolia		✓	✓
Linnaea borealis	✓	✓	
Herbs, forbs, and fern allies:			
Achlys triphylla	✓	✓	✓
Adenocaulon bicolor	✓		✓
Anemone oregana			✓
Coptis laciniata	✓	✓	
Clintonia uniflora	✓		✓
Disporum hookeri	✓		
Galium spp.			✓
Lycopodium clavatum	✓		
Osmorhiza chilensis			✓
Pyrola asarifolia	✓	✓	
Senecio bolanderii			✓
Smilacena stellata			✓
Synthyris reniformis	✓		
Tiarella trifoliata	✓	✓	
Trillium ovatum			✓
Vancouveria hexandra	✓		

Table 6-3—Vascular plant species found to be associated with late-successional and old-growth forests in the Northwest Forest Plan area[a] (continued)

Species	Halpern and Spies 1995[b]	Lindh and Muir 2004[c]	Jules et al. 2008[d]
Saprophytes/root parasites:			
Corallorhiza maculata			✓
Corallorhiza mertensiana	✓		
Hemitomes congestum			
Hypopitys monotropa			
Monotropa uniflora			
Pterospora andromedea			

[a] None of these species is on the current Survey and Manage species list.
[b] Oregon Coast Range and Oregon and Washington Cascade Range.
[c] H.J. Andrews Experimental Forest, western Cascade Range, Oregon.
[d] California Klamath Province.

for such consideration. Bailey et al. (1998) suggested that understory communities are relatively resilient to past cutting as few species differed in frequency of occurrence between young- and old-growth forests in the Oregon Coast and western Cascade Ranges. These results contrast with those of Halpern and Spies (1995) but are based on a much smaller sample size (9 vs. 196 plots) and are only from the drier part of the moist forest region.

The affinity of some species of vascular plants to old-growth forest conditions has been attributed to multiple mechanisms including the presence of canopy gaps and unique microclimatic conditions, greater heterogeneity in resources, and sensitivity to disturbance (e.g., logging and fire) coupled with low rates of growth and reestablishment (Halpern and Spies 1995). Jules (1998) found that ~97 percent of *Trillium ovatum* were eliminated following clear-cutting and planting of conifers. Furthermore, fragmentation of habitat had negative demographic consequences including decreased recruitment and seed production in this species (Jules and Rathcke 1999). Slow recovery rates of dispersal-limited, perennial herbs (e.g., *Trillium* spp., *Cornus canadensis*, *Clintonia uniflora*, *Disporum hookeri* var. *hookeri*) may take centuries for populations to recover following clearcutting (Kahmen and Jules 2005). Halpern and Spies (1995) suggested that long-term rotations (150 to 300 years) may be needed to maintain understory plant species that require long recovery times following disturbance. Observations are lacking on how these dynamics differ from historical dynamics following natural disturbance (e.g., fire).

The response of understory vascular plants to management is known primarily from western hemlock-Douglas-fir forests (e.g., Halpern et al. 1999, Puettmann et al. 2013) and generally suggest that certain management activities can increase later seral species in previously managed stands (i.e., clearcuts). Precommercial thinning can increase compositional similarity of shrubs and herbs between young- and old-growth stands and increase the abundance of late-seral herbs (Lindh and Muir 2004). Conversely, thinning in 60- to 80-year-old stands can increase diversity and the abundance of early-seral species but have little effect on late-seral species (Puettmann et al. 2013). North et al. (1995) found that richness of herb and shrub species was greater in a green tree retention harvest than in an adjacent clearcut and in an intact 65-year stand (also see Halpern et al. 2005).

Retention patches of late-successional and old-growth forest scattered between late-successional forest reserves might serve as conservation centers for some understory vascular plants. Nelson and Halpern (2005) studied the short-term (1 and 2 years) response of understory plants to patterns of aggregated retention harvest and found that old-forest patches larger than 2.5 ac (1 ha) helped retain populations of late-seral plant species, although disturbance within 33 ft (10 m) of the stand edge ("depth of edge" influence) was evident by the incursion of early-seral plant species. Late-seral herbs were more frequently extirpated in harvested portions of aggregated treatments as opposed to dispersed treatments

Fire exclusion may have affected understory communities in late-successional and old-growth forests in vegetation zones where fire was frequent historically (Loya and Jules 2008), but these effects are poorly understood and more research is needed. Some evidence suggests increases in shrub cover may be associated with fire exclusion (Loya and Jules 2008). Loss of bear grass (*Xerophyllum tenax*) in anthropogenically maintained savannahs has also been attributed to fire exclusion (Peter and Shebitz 2006). Studies from mixed-conifer forests in the eastern Washington Cascades and from ponderosa pine (*Pinus ponderosa*) forests suggest that a single application of prescribed fire can reduce shrub cover, but effects on understory response were minor and limited to slight increases in vegetation cover (Dodson et al. 2008) and diversity (Busse et al. 2000). Donato et al. (2009) found that almost all species in mature and old-growth stands were present following high-severity fire in the Biscuit Fire. There is some evidence that reintroduction of wildfire to dry forests of the Sierra Nevada had little effect on diversity of vascular plant species but may increase the distribution of species that may have been negatively affected by fire exclusion (Webster and Halpern 2010).

Invertebrates—

The ISSSSP provides a series of products on selected invertebrate species.[20] Range maps are provided on a number of mollusks species[21]and conservation assessments and species fact sheets are provided for all sensitive invertebrates including bumblebees, beetles, true bugs, butterflies and moths, damselflies and dragonflies, amphipods, and other taxa. The following sections summarize other recent studies on various invertebrate taxa including soil invertebrates, mollusks, and other insects and arthropods.

***Soil invertebrates*—**Soil invertebrates constitute a wide array of taxa, including microorganisms, nematodes, mites, springtails, microspiders, centipedes, millipedes, earthworms, and others, with an equally diverse set of ecological functional roles as comminutors (chewers), detritivores and saprophages (detritus-feeders), fungivores (fungi-eaters), prey, predators, parasites, and more (Berg and Laskowski 2005). In addition, there are four functional groups of arthropods—litter- and soil-dwelling species, coarse wood chewers, understory and forest gap herbivores, and canopy herbivores—that are listed as Survey and Manage species in the Oregon and California Klamath, California Cascade, and California Coast Range physiographic provinces.

Some functional roles of soil invertebrates are yet to be discovered and may be surprising. As an example, Duhamel et al. (2013) reported that fungivorous springtails may play the ecological role of transferring secondary metabolites (catalpol) from host plants to arbuscular mycorrhizal fungi that then helps prevent the mycorrhizae from being grazed, thus protecting the host plant that uses the symbiotic fungi as a source of soil nutrient update.

Soil microorganisms include protozoa, rotifers, bacteria, and others that also play key ecological functions contributing to forest health, resilience, and productivity (Luo et al. 2016). Overall, soil invertebrates, including microorganisms, of late-successional and old-growth forests in the Pacific Northwest have been little studied but likely include species that are undescribed and some that closely associate with closed-canopy, late-successional, and old-growth forest conditions (see chapter 3 for a discussion of closed-canopy and open-canopy late-successional and old-growth forests and associated degree of shade-tolerant understory plants). Several older identification guides and species lists for the Pacific Northwest or selected sites therein are available such as on oribatid mites (Moldenke and Fichter 1988), arthropods (Parsons et al. 1991), and spiders (Moldenke et al. 1987).

[20] http://www.fs.fed.us/r6/sfpnw/issssp/species-index/fauna-invertebrates.shtml.

[21] http://www.fs.fed.us/r6/sfpnw/issssp/planning-tools/species-distribution-maps.shtml#invertebrates.

Forest invertebrate species vary in their sensitivity to disturbance and to forest canopy closure and tree density conditions. For example, Brand (2002) found that species richness, frequency, and density of epigeic (litter-dwelling) springtails in the Midwest are sensitive to fire; findings included the springtail *Tomocerus flavescens,* which is also a component of Pacific Northwest forests. Brand suggested using scattered refuges to maintain survival of fire-sensitive invertebrates in the face of fires; whether this is practical in the face of increasing rates of fire in the drier forests of the NWFP area is untested. Within the NWFP area, Moldenke and Fichter (1988) documented that oribatid mites, which are diverse and numerically dominant in ecosystems worldwide, occurred in very different species groups in open- and closed-canopy forests. The closed-canopy species were found throughout all stages of closed-canopy succession but differed markedly in relative abundance between young and old forests.

Milcu et al. (2006) found various responses of earthworms, springtails, and soil microorganisms—all decomposers—to grass and herb species diversity, functional group diversity, and growth form, but that the response of the decomposers did not correlate with plant productivity. Niwa and Peck (2002) found variable responses to time since prescribed fire burning in the occurrence and abundance of species of spiders (Araneae) and beetles (Carabidae) in southwest Oregon.

Some late-successional and old-growth-associated invertebrates, particularly dispersal-limited species, can serve as indicators of biodiversity and climate change risk (Ellis 2015, Homburg et al. 2014), and indicators of response of species groups to thinning (Yi and Moldenke 2005). Such potential indicator species include flightless terrestrial carabid beetles (e.g., Brumwell et al. 1998, Driscoll and Weir 2005, Eggers et al. 2010), which are a component of the entomofauna of LSRs in the Pacific Northwest, and flightless saproxylic weevils (Coleoptera: Curculionidae) (Buse 2012), which are also found in late-successional and old-growth reserves in the Pacific Northwest.

Yi and Moldenke (2005) studied the effects of thinning in 40- to 60-year-old Douglas-fir forest and associated changes in forest floor environmental conditions in Willamette National Forest in the Oregon Cascade Range. They reported that Formicidae ants preferred heavy thinning intensities; Araneae spiders, Carabidae ground beetles, and Polydesmida millipedes positively correlated with litter moisture, which in turn was sensitive to season and negatively correlated with thinning intensity; and Gryllacrididae camel-crickets were negatively associated with litter moisture.

Rykken et al. (2007) found that invertebrates associated with headwater streams on the Willamette National Forest of Oregon, within the NWFP area, constitute spatially constrained but extremely species-rich communities. This occurred particularly within 3 ft (1 m) of the stream edge in mature forests and in 100-ft (30-m) riparian buffers within managed landscapes, such as may be provided as part of the Aquatic and Riparian Conservation Strategy of the NWFP (see chapter 7).

Caesar et al. (2005) assessed the genetic structure of a soil-inhabiting beetle (*Acrotrichis xanthocera*: Ptiliidae) in LSRs in the Klamath-Siskiyou ecoregion of northern California within the NWFP area. They concluded that the reserve system currently maintains high genetic variation for the species and suggested that intervening habitat gaps among the reserves should be reduced to maintain connectivity among the beetle populations within the reserves, apparently under the tacit assumption that the LSR system would continue in its current form under its current fire and fuels management approach (e.g., Fire suppression and limited use of prescribed fire) (see chapter 3).

Of concern for the conservation of invertebrates in LSRs is the incursion by invasive species. Of high concern are exotic earthworms (Ewing et al. 2015), e.g., *Lumbricus terrestris*, and about two dozen related species of Lumbricidae, introduced from Europe and currently found throughout North America including the Pacific Northwest although not yet in natural conifer stands. Exotic earthworms have been shown to reduce germination of tree seeds and survival of seedlings in southern Quebec, Canada (Drouin et al. 2014). In greenhouse and laboratory experiments, Eisenhauer and Scheu (2008) and Gundale (2002) found that exotic earthworms aid establishment of invader plants. In northern hardwood forests of Michigan and New York, Gundale et al. (2005) and Eusenhauer and Sheu (2008), respectively, found that exotic earthworms reduce nitrogen retention. Hendirx and Bohlen (2002) reported that exotic earthworms, in general, can adversely affect soil processes and can introduce pathogens. In northern temperate forests of North America, Bohlen et al. (2004a, 2004b) reported that invasive exotic earthworms can adversely alter soil nutrient content (total carbon and phosphorus, and carbon-nitrogen ratios) and soil food webs. In the Northeastern United States, increased abundance of white-tailed deer (*Odocoileus virginianus*) can facilitate the spread of invasive earthworms; the deer's herbivory promotes the spread of nonnative understory vegetation that, in turn, fosters less acidic soils that are more favorable to the invasive earthworm species (Dávalos et al. 2015). Ziemba et al. (2015) reported that invasive *Amynthas* earthworms are altering detrital soil communities in North America, adversely affecting eastern red-backed salamanders (*Plethodon cinereus*) (also see Ransom 2012). Other invasive invertebrates occur throughout the Western United States (e.g., Chen and Seybold 2014) but are largely unstudied within the NWFP reserve system.

Few such studies of the specific impacts of exotic earthworms have been conducted in the NWFP region. Bailey et al. (2002) compared the influence of native and exotic earthworm species on soil and vegetation in remnant forests in the Willamette Valley of western Oregon. They discovered two genera of native earthworms and the exotic earthworms were present in all five forest study sites, and reported that although there was no direct evidence that exotic species were affecting native species, they did not detect numerous native species presumed present in the region. They further suggested experimental studies to more clearly identify impacts of exotic species on native fauna.

Mollusks—Mollusks of the Pacific Northwest—particularly slugs and snails—have been the earlier focus of inventory, monitoring, and taxonomic study under the NWFP. Field guides have been produced under the Survey and Manage program for freshwater mollusks (Frest and Johannes 1999) and terrestrial mollusks (Kelley et al. 1999). Recent findings on mollusk species taxonomy are presented in table 6-4.

In a study in northern California, Dunk et al. (2004) sampled five species of terrestrial mollusks (*Ancotrema voyanum*, *Helminthoglypta talmadgei*, *Monadenia churchi*, *M. fidelis klamathica*, and *M. f. ochromphalus*). In a comparison across randomly selected sample plots of various forest conditions, they found that *A. voyanum* was associated with late-successional and old-growth forests, *M. churchi* was a habitat generalist, and data were insufficient to determine habitat associations of the remaining three species. As a result of the information on *M. churchi* being a habitat generalist, the species was removed from the Survey and Manage species list owing to not being specifically associated with late-successional and old-growth forests.

Table 6-4—Selected recent findings on taxonomy of mollusk species associated with late-successional and old-growth forest conditions within the Northwest Forest Plan area

Mollusk taxa	Topic	Source
Fluminicola (aquatic snail)	Updated taxonomy in northern California: *F.* n. sp. 14 = *F. potemicus* *F.* n. sp. 15, 16, & 17 = *F. multifarious* *F.* n. sp. 18 = *F. anserinus* *F.* n. sp. 19 & 20 = *F. umbilicatus*	Hershler et al. 2007
Lyogyrus (aquatic snail)	*Lyogyrus* n. sp. 1 is now described as *Colligyrus greggi*. The genus was transferred and then the species fully described.	Hershler 1999, Liu et al. 2015
Deroceras	*Deroceras hesperium* is now considered *D. leave*, a common and widespread slug in North America	Roth et al. 2013
Pristiloma	*P. arcticum crateris* is now changed to *P. crateris*	Roth 2015

In a study of species in old-forest leave islands (up to 1 ac or 0.4 ha) in western Oregon, Wessell (2005) found that leave island size positively correlated with overall slug and snail density, and density of three mollusk species groups. Studies conducted beyond the Pacific Northwest also indicate that mollusk species richness is related to habitat area (Horsák et al. 2012) or hardwood forest stand age (Moning and Müller 2009). Other studies elsewhere (Moss and Hermanutz 2010) suggest the importance of monitoring for nonnative gastropods, particularly slugs, and especially along the margins of disturbed (burned) areas. Invasive slugs can negatively affect native slug diversity and plant regeneration and should be included in the monitoring of protected areas (Moss and Hermanutz 2010).

Jordan and Black (2015) provided a conservation assessment and finding of a potential threat for the mollusk *Cryptomastix devia*, otherwise known as the Puget Oregonian (Jordan and Black 2015). This terrestrial Gastropoda snail is strongly associated with large, old bigleaf maples (*Acer macrophyllum*) (fig. 6-2) growing among conifers, typically Douglas-fir, western hemlock, and western redcedar (*Thuja plicata*), or among other hardwoods such as black cottonwood (*Populus trichocarpa* ssp. *trichocarpa* and red alder (*Alnus rubra*). A primary threat identified in the conservation assessment for this species is reduction or loss of large, old bigleaf maples through suppression by Douglas-fir and other conifers, and through selective commercial thinning of hardwoods. Further, over the past 10 to 15 years,

Bruce G. Marcot

Figure 6-2—Large, old bigleaf maples are important hosts for the terrestrial gastropod snail known as the Puget Oregonian. Loss of maples in the southern Washington Cascade Range from commercial thinning of hardwoods, suppression by conifers, and disease may be threatening this snail.

there has been widespread mortality of bigleaf maples in the Upper Cowlitz and Cispus River drainages of the south Washington Cascades,[22] the area with the vast majority of known locations of this mollusk. Other threats may include vertebrate and invertebrate predators (predatory snails, and beetles), and the occurrence of invasive slugs. As with nearly all Survey and Manage species, there is no ongoing research and monitoring program for this mollusk.

***Other insects and arthropods*—**Studies of macromoths in H.J. Andrews Experimental Forest in Oregon (and in companion study sites in Mount Jirisan National Park in South Korea) revealed that most species consisted of the families Noctuidae and Geometridae, and that more than 3 years of sampling are needed to determine 90 percent of species richness (Choi and Miller 2013). Miller et al. (2003) studied 15 species of uncommon to rare moths (Noctuidae: Plusiinae) in the Cascade Range and identified three guilds of conifer, hardwood tree and shrub, and herbaceous-feeding species. They concluded that uncommon and rare species with special or restricted habitat requirements add to overall biodiversity, and that diverse environments such as meadows and early-successional vegetation contribute to the species' diversity.

A number of regional species identification guides have been recently produced on insects (Acorn and Sheldon 2001, Haggard and Haggard 2006), lepidoptera (Miller and Hammond 2003), macromoths (Miller and Hammond 2000), butterflies (Pyle 2002), bumblebees (Koch et al. 2012), dragonflies and damselflies (Kerst and Gordon 2011), and others, adding to previous identification keys such as on arboreal spiders (Moldenke et al. 1987).

Additional arthropods of late-successional and old-growth forests of the Pacific Northwest include millipedes and centipedes. Taxonomy, ecology, and habitat elements of many of these species remain poorly known. A study of riparian-associated millipedes in southwest Washington by Foster and Claeson (2011) revealed 15 species among 10 families, and that millipede species assemblages varied between spring and fall and among sites. The authors urged further study on taxonomy and habitats and emphasized the importance of the ecological role of millipedes as detritivores in the forest ecosystem.

We did not find any recent autecology studies on centipedes in late-successional and old-growth forests of the Pacific Northwest. Insights into habitat associations of centipedes from studies elsewhere only suggest that some native species may be more closely associated with interior forest habitat conditions, and exotic species more associated with edge and disturbed habitat conditions (Hickerson et al. 2005).

A fairly recent management concern is the reduction in populations of pollinators on federal lands. In the Pacific Northwest, native bee populations are declining because of parasites, pathogens, pesticides, and invasive species (Spivak et al. 2011). Recent research has aimed at providing methods for restoring and conserving habitat for honeybee (*Apis* spp., nonnative species), bumblebees (*Bombus* spp.), and other pollinators (Decourtye et al. 2010, Wratten et al. 2012). The work highlights the economic benefit and ecosystem services provided by pollinating insects (Losey and Vaughan 2006).

Amphibians and reptiles—

***Amphibians and reptiles of forest systems*—**Recent studies on the distribution, movement, and habitat relationships of forest amphibians and reptiles help assess how well the NWFP has served to provide habitat for late-successional and old-growth forest-associated amphibians and reptiles.

Old-growth forest-associated amphibians and reptiles are often described as secretive because most are fossorial and only seasonally encountered on the ground surface under down wood, rocks, leaves, and moss. Nonetheless, creative study approaches and modern landscape modeling and genetics techniques have furthered our understanding of the distribution, life history, and status of these species in the Pacific Northwest. For example, genetics were used to identify two new species: Scott Bar salamander (*Plethodon asupak*) and forest sharp-tailed snake (*Contia longicaudae*). The Scott Bar salamander is associated with cool, moist forests and talus slopes

[22] Kogut, T. Personal communication. Wildlife biologist (retired), P.O. Box 258, Packwood, WA 98361.

of an extremely restricted range in northern California; and, similar to other plethodontid salamanders (lungless salamanders of the family Plethodontidae), it is likely sensitive to changes in its habitat and in microclimate conditions (DeGross and Bury 2007, Mead et al. 2005). The forest sharp-tailed snake is associated with mesic and dense canopied forests of northern California and southwestern Oregon (Feldman and Hoyer 2010). Although little is known about this new species, the more wide-ranging species, *C. tenuis*, displays life history characteristics such as slow growth, late maturity, and low fecundity that are consistent with functional rarity and intrinsic vulnerability to population declines (Govindarajulu et al. 2011).

However, in an analysis of conservation risk of wildlife, including amphibians and reptiles, of Washington and Oregon, Lehmkuhl et al. (2001) determined that although life history traits can be used to qualitatively determine potential vulnerability, alone they are not an adequate quantitative predictor of vulnerability without additional information on species' habitat selection, habitat breadth, demography, and other factors. Clearly, additional survey and monitoring efforts and research are needed to better delineate species ranges and to improve our understanding of species' distributions, status, habitat requirements, and potential vulnerability (Gibbs 1998).

Another example of a furtive species yielding surprises upon study is the Shasta salamander (*Hydromantes shastae*) that, prior to 2012, was thought to be endemic to limestone outcroppings in the Shasta Lake watershed (Mooney 2010). Management decisions and land use project planning were based on this assumed association. Yet, Shasta salamanders subsequently have been found at sites lacking limestone outcrops and in an adjacent watershed (Lindstrand et al. 2012, Nauman and Olson 2004).

The Survey and Manage program and the ISSSSP have greatly increased scientific knowledge of forest-dwelling salamanders and their relationships with environments in the Pacific Northwest. Conservation Assessments for seven terrestrial salamanders (*Aneides flavipunctatus*, *Batrachoseps attenuatus*, *B. wrighti*, *Plethodon larselli*, *P. stormi*, *P. vandykei*, and *P. asupak*) have been completed since 2005.[23] The Density Management and Riparian Buffer Study of western Oregon (Anderson et al. 2007, Burton et al. 2016, Olson and Burton 2014) was initiated in 1994 when the NWFP implemented riparian buffers along non-fish- bearing streams (Cissel et al. 2006). This study assessed the long-term effects of thinning and differing riparian buffer widths on the distribution, abundance, and movement of terrestrial and aquatic amphibians. It showed that terrestrial salamanders are more abundant and more mobile in unthinned, densely canopied (with visible sky ranging 5 to 7 percent) (Anderson et al. 2007) riparian buffers as compared to nearby upland thinned forest (with visible sky ranging 9 to 12 percent) (Anderson et al. 2007; Kluber et al. 2008; Olson et al. 2014a, 2014b). This work highlights the importance of maintaining areas of dense canopies within at least 50 ft (15.2 m) of perennial streams in managed forests to serve as habitat for terrestrial species and as corridors for their dispersal (Olson et al. 2014b).

Recent studies have determined that the assumed dependence of terrestrial salamanders to late-successional and old-growth forests is more nuanced than previously thought (Bosakowski 1999). Some species have been found to be more abundant or occur more frequently in late-successional and old-growth forests (*B. attenuatus*, *Ensatina eschscholtzii*, Welsh and Hodgson 2013; *P. elongatus*, Welsh et al. 2008), but studies are inconsistent (e.g., *P. stormi*, Bull et al. 2006, Suzuki et al. 2008, Welsh et al. 2008). Relationships between plethodontid salamanders and cool, moist microhabitat conditions characteristic of late-successional and old-growth forests have been identified, but these conditions can be provided by other environmental features such as proximity to streams, talus slopes, and shading by vegetation, aspect, or topography (*P. stormi*, Suzuki et al. 2008; Welsh et al. 2007; *P. larselli*, Crisafulli et al. 2008). For species associated with forest floor attributes such as amount of down wood, a high volume of down wood may mediate the otherwise adverse effects of changes to the microhabitat conditions after thinning (*E. eschscholtzii*, Welsh et al. 2015; *E. eschscholtzii* and *P. vehiculum*, Kluber et al. 2008, Rundio and Olson 2007; *B. wrighti*, Clayton and Olson 2009).

[23] http://www.fs.fed.us/r6/sfpnw/issssp/species-index/fauna-amphibians.shtml.

Substrate type and availability are important correlates of some species (*P. vehiculum*, Kluber et al. 2008; *P. larselli*, Crisafulli et al. 2008; *H. shastae*, Mooney 2010; *P. vandykei*, McIntyre et al. 2006, Olson and Crisafulli 2014), and down logs may provide thermal refugia for salamanders in thinned upslope zones (Kluber et al. 2009). In areas deficient in preferred substrates that provide cool refugia, salamanders may be associated with old-growth forest and related microhabitat conditions (e.g., *P. larselli*, Crisafulli et al. 2008). Maintaining cool and humid refugia may be central in protecting populations in areas that may experience disturbances.

Recent studies have started to unravel the complex trophic relationships of amphibians in forest and woodland food webs. Best and Welsh (2014) noted that plethodontid salamanders serve as predators of invertebrates, and as prey for carnivores. In an experiment, the authors found that *E. eschscholtzii* predation on diverse invertebrate prey suppressed some invertebrate taxa and released others resulting in increased retention of leaf litter and increased carbon sequestration, although such functions varied by the timing and amount of precipitation. We expect many other species of reptiles and amphibians play ecological roles influencing the trophic and nutrient dynamics of forest ecosystems to varying degrees, although quantitative studies are few and wanting.

Amphibians of stream systems—
The Aquatic Conservation Strategy under the NWFP provides for conservation and restoration of selected stream and riparian systems of the Pacific Northwest (Reeves et al. 2006). Although most protections are for fish-bearing-streams, the importance of protecting non-fish bearing headwater streams and associated riparian environments has been increasingly recognized (Sedell and Froggatt 1984, Wilkins and Peterson 2000). First- and second-order headwater channels comprise the majority of stream miles (kilometers) within the Pacific Northwest and serve as cold water refugia in a warming climate (Isaak et al. 2016). In addition, they serve as headwater linkages between watersheds that provide important dispersal corridors for aquatic and terrestrial species, alike (Olson and Burnett 2009, Richardson and Neill 1998). Within stream networks, amphibians occur from the headwaters to the alluvial flood plains, and their community structure is closely tied to channel types and within-channel attributes (Welsh and Hodgson 2011). For this reason, combined with their sensitivity to environmental perturbations, stream amphibians have been recognized as biometrics of stream health (Welsh and Hodgson 2008). In a study predating the NWFP, in the Oregon Cascades and Coast Range, Corn and Bury (1989) found that four species of aquatic amphibians—coastal giant salamander (*Dicamptodon tenebrosus)*, Olympic salamander (*R. olympicus*), coastal tailed frog (*Ascaphus truei*), and Dunn's salamander (*P. dunni*)—had greater occurrence and abundance in streams flowing through uncut forests than in forests logged 14 to 40 years ago, and that tailed frogs and Olympic salamanders may be extirpated from headwaters in clearcuts. More recently, Olson et al. (2014a, 2014b) found that streambank amphibian species, including Dunn's salamander and western red-backed salamander, were sensitive to forest thinning within 20 to 49 ft (6 to 15 m) of small streams including headwaters.

Research has greatly advanced in the Pacific Northwest to incorporate amphibians to answer questions about the role of riparian buffers in the retention of aquatic ecosystem services. Studies have addressed how wide no-entry buffer zones should be to retain sensitive amphibian species or their critical habitat conditions and whether no-entry buffers are needed under differing upslope ecological forestry approaches. They are also asking whether or not it is appropriate to thin riparian zones to accelerate riparian restoration to achieve biodiversity goals in some cases. Using a meta-analysis to test the effectiveness of riparian buffers for conserving terrestrial fauna, Marczak et al. (2010) reported that riparian buffers, in general, maintain fewer amphibians compared to riparian forests in unharvested areas. Stream-associated amphibians such as coastal tailed frog and torrent salamanders are highly sensitive to timber harvest and the associated instream effects of increases in water temperature and sedimentation rates (Ashton et al. 2006, Bury 2008, Emel and Storfer 2015, Olson et al. 2007a, Pollet et al. 2010, Welsh and Hodgson 2011). Coastal giant salamanders appear to be more resilient to timber harvest practices than are other stream-associated amphibians of the Pacific Northwest (Leuthold et al. 2012, Pollet et al. 2010). While the general findings that certain species are more sensitive to timber harvest than others holds relatively consistent in the literature, alternative findings in some areas (e.g., Raphael et al. 2002) highlight the importance of recognizing that abiotic and biotic factors interact with management actions in complex ways to influence the distribution and density of stream amphibians (Kroll et al. 2009).

The preponderance of evidence suggests that streams with riparian buffers within harvested landscapes do help to ameliorate some of the adverse effects of timber removal on instream conditions (Olson et al. 2014a, Pollet et al. 2010, Stoddard and Hayes 2005. In a replicated field experiment, Olson et al. (2014a) concluded that the NWFP Aquatic Conservation Strategy riparian buffers of ~230 to 476 ft (~70 to 145 m) seem to protect the headwater amphibian biota, and in a multiscaled survey, Stoddard and Hayes (2005) found that presence of a 150-ft (46-m)-wide riparian buffer predicted increased occurrence of tailed frogs and two species of torrent salamanders in a managed landscape. In the Oregon Coast Range, Kluber et al. (2008) found that ground surface attributes such as amount of rock or fine substrate determined the response of riparian and upland amphibian species to forest thinning along headwater streams, and that variable-width riparian buffer retention can provide for such microhabitat conditions. Olson and Burton (2014) examined the effects of alternative riparian management approaches including three no-harvest buffer treatments (site-potential tree-height (~230 ft [~70 m]), variable width with a 49-ft (15-m) minimum buffer on each side of the stream, and streamside retention (~20 ft [~6 m]) and a thin-through treatment whereby overstory tree density in a ~476-ft (~145-m) buffer treatment was reduced from 430 to 600 trees per acre (hectare) to ~150 trees per acre. They found that densities of torrent salamanders decreased along streams with the narrowest buffer, ~20 ft (~6 m), and that densities of Dunn's salamanders and coastal giant salamanders decreased in thin-through buffers (Olson and Burton 2014). The authors recommend the use of a 49-ft (15-m) or wider buffer to retain headwater stream amphibians (Olson and Burton 2014).

Riparian buffers can also maintain habitat connectivity and headwater linkage areas for dispersing amphibians. Using landscape genetics, Emel and Storfer (2015) found that gene flow among populations of the southern torrent salamander (*R. variegatus*) becomes restricted in streams with low canopy cover and high heat loads. The authors suggest that maintaining stream corridors with continuous riparian buffers may increase connectivity in managed landscapes. Coastal tailed frogs disperse more readily through intact forests than clearcuts (Wahbe et al. 2004) and, thus, may benefit from headwater management for connectivity across ridgelines, or the creation of "headwater linkage areas" (Olson and Burnett 2009). Olson and Burnett (2009) recommend linking headwater drainages across 7^{th}-code hydrologic units to maintain landscape connectivity for headwater species. They propose extending buffers or alternative forest management practices that maintain canopy structure and shading to link neighboring watersheds over ridgelines (Olson and Burnett 2009, Olson et al. 2007).

***Amphibians of still-water systems*—**In the Pacific Northwest, still-water (lentic) environments such as lakes, ponds, and wet meadows, and their adjacent riparian and terrestrial environments, also provide for species diversity. Many such sites do not provide habitat for fish, however, if they are impermanent. Lentic breeding amphibians such as red-legged frogs (*Rana aurora*), Oregon spotted frogs (*R. pretiosa*), Columbia spotted frogs (*R. luteiventris*), Cascades frogs (*R. cascadae*), northwestern salamanders (*Ambystoma gracile*), western toads (*Anaxyrus boreas*), and Pacific chorus frogs (*Pseudacris regilla*) flourish in these environments. Yet modifications and disturbances to these species' habitats (e.g., damming to increase water storage, ditching to increase drainage, siltation owing to timber harvest in the watershed, and overgrazing), combined with diseases and the spread of invasive species such as American bullfrogs (*Lithobates catesbeianus*) and brook trout (*Salvelinus fontinalis*), have resulted in some population declines (Adams 1999, Fisher and Shaffer 1996, Pearl et al. 2007).

The Oregon spotted frog is one of the most threatened amphibians in the Pacific Northwest; much information on this species can be found from the U.S. Fish and Wildlife Service Federal Register of notice of threatened status for this species (USDI FWS 2014). Blouin et al. (2010) found that low connectivity between populations has resulted in decreased genetic diversity, and they recommended maintaining habitat connectivity and expanding the availability of appropriate wetlands.

Whereas palustrine wetlands and the amphibians that depend on them are not directly protected under the NWFP, riparian buffers likely benefit these species. In a literature survey of the use of wetland buffers by reptiles and amphibians, Semlitsch and Bodie (2003) found that core habitat of wetlands, as used by breeding populations, ranged from 522 to 951 ft (159 to 290 m) for amphibians and 417 to 948 ft (127 to 289 m) for reptiles from the edge of the aquatic site, and thus that adjacent terrestrial environments also were essential for population persistence.

Recent and ongoing issues for amphibians: fire and timber harvest**—**For most of the species discussed, effects of large disturbances such as wildfire and broad-scale timber harvest on populations, have not been adequately studied, and monitoring programs are not in place to assess the status of species and effectiveness of the NWFP in protecting these species. With recent decades of fire suppression in the Pacific Northwest, most of the forests have experienced much less fire than they did historically (see chapters 2 and 3). The effect of this change on habitats and populations of wildlife, including amphibians that require shaded, cool, moist microsites, is not known.

For the Larch Mountain salamander (*P. larselli)*, Van Dyke's salamander (*P. vandykei)*, California slender salamander (*B. attenuatus)*, and Shasta salamander (*H. shastae)*, a high proportion of known occurrences are within federal reserves associated with the NWFP where timber harvest is minimal compared to on nonreserve lands and thus these species are more protected, at least from timber harvest, under the NWFP. Species with a significant portion of their range on nonreserve land allocations (Siskiyou Mountains salamander (*P. stormi)* and Scott Bar salamander (*P. asupak)*, Clayton et al. 2005, Nauman and Olson 2008; Oregon slender salamander (*B. wrighti)*, Clayton and Olson 2009; black salamander (*A. flavipunctatus)*, Olson 2008), however, might still be negatively affected by future land management activities if they deviate from the LSR standards, and management of these lands may be crucial to protect these species. Furthermore, much of the range of many plethodontids is on nonfederal forest land (Suzuki and Olson 2008). Adaptive management areas (AMAs) and matrix lands were expected to function as experimental areas to address unresolved questions and to conduct long-term studies on timber harvesting and fire effects on forest salamanders and their response to these disturbances (Stankey et al. 2006, Suzuki and Olson 2008). However, the AMA program was never fully instituted under the NWFP, although AMAs were designated.

Recent and ongoing issues for amphibians: climate change**—**Climate change models for the Pacific Northwest region predict a warming of 0.2 to 1.1 °F (0.1 to 0.6 °C) per decade, with wetter autumns and winters, but drier summers (Mote and Salathe 2010). Significant warming is projected for the Pacific Northwest by the end of the 21st century, with simulation results projecting an increase in warming of 5.9 to 17.5 °F (3.3 to 9.7 °C) in Washington and Oregon and 2.7 to 8.1 °F (1.5 to 4.5 °C) in northern California, with generally increasing aridity but with higher uncertainty about specific precipitation levels (see chapter 2).

Changes in the climate can affect amphibians by altering habitat features such as vegetation, soil, and hydrology directly or via interactions with other threats such as timber harvest, wildfire, and disease (Blaustein et al. 2010). Plethodontid salamanders are particularly vulnerable to climate warming because they are specialized to cool microclimates, have limited dispersal capabilities, and may lack physiological tolerance to warm-induced stresses (Bernardo and Spotila 2006, Velo-Antón et al. 2013). Climate change may influence the distribution of suitable environments, which can result in fragmenting populations and shifting or retracting species ranges (Blaustein et al. 2010). More precipitation during the autumn and winter may lengthen the period of surface activity, but warmer and drier summers could result in fewer available surface and subsurface refugia that prevent desiccation. Forest management practices that retain canopy cover, and maintain or supplement surface refugia such as down wood and logs may help to ameliorate the effects of climate change (Shoo et al. 2011).

Recent and ongoing issues for amphibians: pests and pathogens—Minimal research has been conducted on the effects of nonnative animals or plants on amphibians in the Pacific Northwest, and the degree to which the NWFP influences establishment and spread of such invasives. Introduced American bullfrogs (*L. catesbeianus*) have become widely established in lentic environments in the Pacific Northwest and are considered an important predator of native pond-breeding amphibians. Most documented effects are from lowland areas (<0.2 mi [<240 m]) such as the Willamette Valley where Pearl et al. (2004) found greater effects of bullfrogs on Oregon spotted frogs compared to northern red-legged frogs. Breeding bullfrog populations have been documented from the Oregon Cascades (Garcia et al. 2009), but environmental conditions such as high UV-B levels (Garcia et al. 2015) may preclude extensive colonization.

As noted previously, the invasive Asian earthworm *Amynthas* that has invaded much of North America has been found to alter the behavior of eastern red-backed salamanders, but similar studies have not been conducted with salamander species found in the Pacific Northwest.

The threat of novel diseases entering populations of amphibians of the Pacific Northwest appears increasingly pressing. The deadly amphibian disease, chytridiomycosis, emerged in the 1970s and has become a prominent threat to amphibian biodiversity worldwide (Olson et al. 2013, Skerratt et al. 2007). Chytridiomycosis is caused by the fungus *Batrachochytrium dendrobatidis* (*Bd*) and has been identified as causing decline or extinction of over 200 amphibian species globally (Skerratt et al. 2007). It affects a broad host-range among amphibians, including salamanders, and has been reported in 516 (42 percent) of 1,240 amphibian species evaluated (Olson et al. 2013). *Bd* is widespread in the Pacific Northwest and has been found in northern red-legged frog, Columbia spotted frog, Oregon spotted frog, and Cascades frog (Pearl et al. 2007, 2009). Although the risk posed by *Bd* to these species is mostly unclear, evidence suggests that Cascades frogs at the southern extent of their range in northern California have experienced severe declines owing to chytridiomycosis (De León et al. 2016, Piovia-Scott et al. 2014, Pope et al. 2014).

More recently, in 2010, a second infectious chytrid pathogen, *B. salamandrivorans* (*Bsal*), emerged in Europe where it has decimated fire salamanders (*Salamandra salamandra*) (Martel et al. 2014). Unlike *Bd*, *Bsal* appears to affect only salamanders, not anurans (Van Rooij et al. 2015). As *Bsal* is not yet known to occur in North America, amphibian disease specialists are bracing for its arrival, which will probably occur through international pet trade routes (Grant et al. 2016, Gray et al. 2015, Martel et al. 2014). Models of amphibian habitat suitability predict that the Pacific Northwest is among the highest risk areas in North America (Richgels et al. 2016, Yap et al. 2015). The Pacific Northwest represents a hotspot for salamander biodiversity and contains numerous species from the two most *Bsal*-susceptible families, Plethodontidae and Salamandridae (Martel et al. 2014). In January of 2016, the U.S. Fish and Wildlife Service responded to the threat of *Bsal* by enacting a temporary rule restricting the importation of 201 species of salamanders for the pet trade (USFWS 2016). Although a critical step, the risk of spread of *Bsal* to North America, home to the world's richest salamander fauna, is still great and surveillance, research, and management actions are mandatory for successful mitigation of spread and response to this emerging infectious disease (Grant et al. 2016, Gray et al. 2015, Yap et al. 2015).

Recent and ongoing issues for amphibians: connectivity—The movement capabilities of most Pacific Northwest amphibians, especially plethodontid salamanders, are presumed to be limited, and fragmentation of their habitats may inhibit gene flow, and thus could isolate subpopulations. In forest watersheds with harvested upland areas, amphibians may disperse along riparian corridors that provide cooler, humid conditions (Olson et al. 2007a, 2014b). Stream buffers, riparian corridors, and down wood "chains" may provide connectivity for terrestrial species between their riparian and upland habitats, their adjacent stream and terrestrial habitats, and over ridges (Olson and Burnett 2009, 2013; Olson et al. 2014b). Providing linkage areas between adjacent watersheds and using various combinations of alternative management approaches (riparian buffers, thinning, down wood, leave islands, and uncut blocks) to retain forested areas along headwater ridgelines may facilitate upland dispersal and connectivity between subpopulations (Olson and Burnett 2009, 2013).

***New methods for amphibians*—**Recently, environmental DNA has been applied to identifying the presence of endangered freshwater biodiversity including amphibians in lakes, ponds, and streams (Thomsen et al. 2012). Environmental DNA originates from cellular material shed by organisms (via skin, excrement, etc.) into aquatic environments that can be sampled, sequenced, and assigned back to the species of origin. Such methodology is important for the early detection of invasive species as well as the detection of rare and cryptic species. Environmental DNA approaches have been applied to imperiled aquatic amphibians in the Southeastern United States (McKee et al. 2015); an invasive salamander in Australia (Smart et al. 2015); and the trematode *Ribeiroia ondatrae*, a pathogenic parasite on North American amphibians (Huver et al. 2015). They have recently been applied to amphibians of aquatic systems in the NWFP area (e.g., Welsh and Cummings).[24]

Birds—

Bird species pertinent to the development of the LSRs and late-successional and old-growth forests of the NWFP are covered elsewhere (see chapters 4 and 5). Many other bird species live in or migrate through the NWPF area, contributing to the region's biodiversity; here we address new science since the 10-year synthesis.

Recent studies have addressed various aspects of avian ecology in late-successional and old-growth forests, for example on pileated woodpecker (*Dryocopus pileatus*) (Aubry and Raley 2002a, Raley and Aubry 2006) and its role as a keystone species providing such ecosystem engineering functions as cavity excavation (Aubry and Raley 2002b). Other studies have provided information on forest habitat selection by white-headed woodpeckers (*Picoides albolarvatus*) (Lorenz et al. 2015), black-backed woodpeckers (*P. arcticus*) (Bonnot et al. 2009), and others. These studies suggest the role of disturbance (fire and forest pathogens) in providing habitat for these species.

For example, white-headed woodpeckers were found to establish home ranges within forest patches that had undergone recent disturbance including small patches of prescribed burning and incidence of disease. Other studies have suggested that habitat associations of white-headed woodpeckers may differ by location and condition. Latif et al. (2015) found that the species in dry conifer forests on the east side of the Cascade Range in Oregon was closely associated with canopy openings adjacent to closed-canopy forests. In unburned, dry conifer forests of central Oregon, Hollenbeck et al. (2011) found that nest sites of white-headed woodpeckers were associated with low elevation, high density of large trees, low slope, and interspersion–juxtaposition of low- and high-canopy cover ponderosa pine patches. In postfire ponderosa pine forests of south-central Oregon, Wightman et al. (2010) found that low nest survival of white-headed woodpeckers was due to predation and was not correlated with habitat and abiotic features, and that survival in recently burned forests is likely enhanced with mosaic burn patterns with retention of larger, decayed snags.

Fontaine et al. (2009) studied response of bird communities to single fires (2 to 3 and 17 to 18 years following fire), repeated high-severity fire (2 to 3 years after fires repeated at 15-year intervals), and stand-replacement fire (>100 years following fire) in mature and old-growth mixed-evergreen forests of the Klamath-Siskiyou region of southwest Oregon. They reported that bird species richness (number of bird species) did not differ significantly among the various postfire conditions; that bird density was lowest 2 years after fire and highest 17 to 18 years after fire; and that repeat-fire conditions favored shrub-nesting and ground-foraging species, and unburned mature forests favored conifer-nesting and foliage-gleaning species. In that ecoregion, the researchers reported that bird communities were structured mostly by conditions of broadleaf hardwoods and shrubs, by extended periods of early-seral broadleaf dominance and short-interval high-severity fires.

Natural disturbance patterns, including fire, windthrow, and other forces, can leave remnant and legacy elements of older forests such as old-forest patches, large-diameter green trees and snags, and large-diameter down wood, as key habitat elements for a variety of species. Subsequent regrowth of the vegetation through secondary succession then creates early-seral structures

[24] Unpublished data.

more complex than those resulting from final timber harvests such as clearcuts. The complexity of naturally regenerating vegetation following natural disturbances can often contain habitat for a wide variety of birds and other wildlife associated with early-successional environments (Marcot 1983, 1985; Swanson et al. 2011).

Vogeler et al. (2013) adopted the use of light detection and ranging to evaluate forest structure conditions for brown creepers (*Certhia americana*), an old-forest associate. In the Eastern United States, Poulin and Villard (2011) determined that brown creeper nest survival was greater in forest interiors at least 328 ft (100 m) from the forest edge, and that young forest conditions—plantations from previous management—in the managed matrix can adversely influence productivity of the species.

In a study of the influence of forest land ownership on focal species, McComb et al. (2007) projected habitat decreases for warbling vireo (*Vireo gilvus*) and increases for pileated woodpecker, as early-successional vegetation is projected to decline in area and older forests to increase. They also noted that land ownership patterns affected dispersion of habitat for both species, and that, for wide-ranging species, public lands provided habitat less available or not present on adjacent private lands.

On southeastern Vancouver Island, British Columbia, Canada, just outside the NWFP area, Hartwig et al. (2003) noted that pileated woodpeckers selected for largest diameter trees and for patches of older forests for nest cavities in coastal forests of Douglas-fir and western hemlock. They recommend retaining large live and dead grand fir, Douglas-fir, and red alder for pileated woodpecker nest sites, and to provide mature climax stands with greater proportions of bigleaf maple and grand fir.

On the Washington Pacific coast, Aubry and Raley (2002a) found that pileated woodpeckers selected Pacific silver fir (*Abies amabilis*) for nesting and western redcedar for roosting, and selected against western hemlock for both activities; that trees used for just nesting ranged from 26 to 61 inches (65 to 154 cm) diameter at breast height (d.b.h.), and trees used for just roosting ranged from 61 to 122 inches (155 to 309 cm) d.b.h.; that trees used for both nesting and roosting were at least 90 ft (27.5 m) tall; and that trees less than 49 inches (125 cm) d.b.h. or less than 57 ft (17.5 m) tall were generally selected against. The authors suggested that habitat management for the species may need to also consider roost trees by providing snags and decadent live trees with heart-rot decay fungi. Raley and Aubry (2006) further reported that pileated woodpeckers in coastal forests foraged almost exclusively in closed-canopy stands, that they selected for relatively tall, large-diameter snags in early to moderate decay stages, and that they did not appear to use down logs for foraging because down logs did not support their primary prey of carpenter ants.

Great gray owls are considered late-successional and old-growth forest associated within the NWFP area and are still a Survey and Manage species. A conservation assessment was developed for the species in 2012, and the most recent survey protocol is from 2004, as posted on the ISSSSP site.

Carnivores—

This section summarizes new science associated with the taxa of mammalian carnivores that were either ranked as "not likely to remain well distributed" by the FEMAT or that had state or federal listing status. One species and one subspecies met both criteria (the fisher and the coastal population of the Pacific marten), and two species met the latter criterion only (the lynx [*Felis lynx*] and wolverine).

Taxonomic and listing updates of carnivores—Recent phylogenetic studies have changed the relationships of several of the species considered here. Within the Mustelidae, the fisher—formerly recognized as *Martes pennanti*—has been shown to be more closely related to the wolverine and tayra (*Eira barbara*) than to martens (*Martes* sp.) (Koepfli et al. 2008, Sato et al. 2012). Consequently, the fisher is now recognized as being the sole extant member of its own genus—*Pekania*—and is now recognized as *P. pennanti*. In April 2016, the U.S. Fish and Wildlife Service determined that the West Coast Distinct Population Segment of fisher does not warrant federal listing status. No other federal listing pertains to the species in the NWFP area.

Dawson and Cook (2012) evaluated phylogenetic and morphological evidence across the distribution of the American marten (*M. americana*) in North America and agreed with previous work (Carr and Hicks 1997) that there are two species of martens in North America. The American marten occurs east of the crest of the Rocky Mountains and across northern Alaska, and the Pacific marten (*M. caurina*) occurs west of the Rocky Mountains and includes the NWFP region. Dawson and Cook (2012) found significant genetic substructuring consistent with existing subspecific designations in the Pacific marten, and Slauson et al. (2009) agreed with these designations except in coastal California and coastal Oregon. Populations of the Pacific marten in coastal Oregon and coastal California appear to be a single evolutionary unit and have been proposed to be referred to collectively as the Humboldt marten (*M. c. humboldtensis*), a taxon formerly described as occurring only along the coast in northern California (Grinnell and Dixon 1926, Slauson et al. 2009). As of this writing, the U.S. Fish and Wildlife Service has determined that there is insufficient data to warrant federal listing of the Humboldt marten, but this decision is being appealed. The Humboldt marten is a state candidate species in California and is under a 1-year review for listing there.

The contiguous U.S. Distinct Population Segment of Canada lynx is currently listed as threatened in Washington, Oregon, and beyond[25] (USFWS 2000). On August 13, 2014, the Fish and Wildlife Service withdrew a proposal to list the North American wolverine in the contiguous United States as a threatened species under the Endangered Species Act; but then on April 4, 2016, the U.S. District Court for the District of Montana ordered U.S. Fish and Wildlife Service to reconsider whether to list the wolverine as a threatened species, and it currently sits as proposed threatened status.[26] A proposed rule for listing of wolverine will be finalized in the future (Further, recent information on life history of each species is available through Web sites noted above).

[25] http://ecos.fws.gov/ecp0/profile/speciesProfile?sId=3652.

[26] http://ecos.fws.gov/ecp0/profile/speciesProfile?sId=5123.

***Current distribution of carnivores*—**In the NWFP area, the fisher continues to be restricted to a single native population in northwestern California and southwestern Oregon (Lofroth et al. 2010), a single small introduced population in the southern Oregon Cascades from source populations in Canada and Minnesota (Aubry and Lewis 2003), and recently reintroduced populations on the Olympic peninsula (Lewis 2014) and in the Washington Cascades (Lewis 2013).

The Pacific marten appears to remain fairly well distributed in the high-elevation forests of the inland mountain ranges but occupies less than 5 percent of its historical range in the coastal forests of California and less than 10 percent of its historical range in Oregon (Slauson et al., in press), and it is known from a single recent verifiable record from the Olympic peninsula.[27]

In the NWFP area, lynx are known only from high-elevation (>4,600 ft [1400 m]) spruce (*Picea* spp.) and lodgepole pine (*Pinus contorta*) forest habitats of Washington in the northern Cascades, and from disjunct mountain ranges in the counties bordering Canada.

Verifiable wolverine occurrences in the NWFP area continue to be limited to high-elevation alpine and subalpine habitats in the central and northern Cascades of Washington (Aubry et al. 2007). However, recent detections in northeastern Oregon[28] and of a single male in the northern Sierra Nevada (Moriarty et al. 2009) suggest that wolverines have the potential to occur in the Cascades of Oregon but have yet to be detected there.

***Habitat and feeding ecology of carnivores*—**We summarize here the new insights on habitat relationships of each species, and how these relate to each species' key life history needs for feeding, resting, and reproducing. Where possible, we link these new insights to management actions that may benefit each species. Our emphasis is primarily on martens and fishers, which occur across a larger proportion of the NWFP area than do lynx and wolverine.

[27] K. Aubry, personal communication, Emeritus scientist, Pacific Northwest Research Station, 3625 93rd Ave., Olympia, WA 98512.

[28] A. Magoun, personal communication, Wildland Research and Management, 3680 Non Road, Fairbanks, AK 99709.

***Fisher*—**In the NWFP area, fisher home ranges vary from 2.9 to 24.5 mi^2 (7.4 to 63.5 km^2) for males and 0.7 to 49.5 mi^2 (1.7 to 128.3 km^2) for females (Lewis 2014, Lofroth et al. 2010), with home ranges decreasing in size from north to south. Overall, home ranges tend to be composed of mosaics of forest stand types and seral stages, but still include high proportions of mid- to late-seral forest (Raley et al. 2012). Notable exceptions exist in the coastal forests in northwestern California, where fishers occur both in areas with mosaics of young regenerating forest and residual mature forest (Matthews et al. 2013), as well as in areas with high proportions of young regenerating forest (Thompson et al. 2008). Higher use of young regenerating forest in these areas is related to the abundance of dusky-footed woodrats (*Neotoma fuscipes*), which are an important prey species (Lofroth et al. 2010) and which reach peak densities in young even-aged stands 5 to 20 years postharvest (Hamm and Diller 2009). Fishers typically avoid entering open areas devoid of or with significantly reduced overhead cover and escape cover, and exhibit avoidance by positioning home ranges to minimize overlap with large open areas (Raley et al. 2012) or by moving within home ranges to avoid such large open areas.

Fishers are dependent on large-diameter live and dead trees and downed logs with features such as cavities, platforms, and chambers as daily resting sites and seasonal den sites for females raising young (Raley et al. 2012). Female fishers are obligate cavity users for reproduction, with cavities in trees and snags providing secure environments for kits by regulating temperature extremes and providing protection from predators (Raley et al. 2012). These structures take hundreds of years to develop (Raley et al. 2012), emphasizing the critical importance of retaining these features for conservation of the species.

Rest structures for fishers primarily include large deformed or deteriorating live trees and secondarily include snags and logs (Raley et al. 2012, Weir et al. 2012). The species of trees and logs used for resting appear less important than the presence of a suitable microstructure, such as a cavity or platform. A meta-analysis by Aubry et al. (2013) of resting site selection by fishers across the NWFP area and adjacent areas found that rest site characteristics selected by fishers were consistent across the Pacific States and British Columbia, and occurred on steeper slopes, in cooler microenvironments, with denser overhead cover, greater volumes of logs, and a greater prevalence of large-diameter trees and snags than were generally available. This meta-analysis provides managers with empirical support for managing for these conditions where maintenance or restoration of resting habitat conditions is an objective, even in locations where fishers have not been studied. Cavities used by female fishers for birthing and preweaning periods of kits were most often created by heart rot in older trees, and most often in the largest diameter trees available (Raley et al. 2012). During the postweaning period, female fishers continue to use tree cavities but also make use of downed logs.

Truex and Zielinski (2013) studied the influence of fuel treatments in forests of the Sierra Nevada, California, and found that mechanical treatments and fire treatments together, but not separately, reduced resting sites for fishers. Also, late-season burns adversely affected resting sites, but early-season burns did not. The authors suggested evaluating the effects of fuel treatment activities at various scales—fisher resting sites, home range, and landscape—to best balance fuel reduction with restoration and maintenance of fisher habitat.

***Marten*—**In the NWFP area, martens occur in two distinct forest regions: (1) high-elevation forests of the inland mountain ranges, such as the Cascades of California, Oregon, and Washington and the Marble-Salmon-Trinity Mountains of California, that receive significant snowfall and (2) low- to mid-elevation coastal forests in Oregon and California that receive little snowfall. In mesic west-slope forest types in inland mountain ranges, martens select riparian areas and avoid landscapes with large patches of young forest; in contrast, in xeric east-side forests in inland mountain ranges, martens select sites with higher tree canopy cover and avoid fragmented forests (Shirk et al. 2014).

Pacific martens have recently been located in forests of the central and south coast regions of coastal Oregon (Moriarty et al. 2016a). In coastal California and Oregon, they occur in three environmental conditions: productive soil types where Douglas-fir, hemlock, and redwood forest associations occur; and two restricted environments on low-productivity soils, including near-coast serpentine forest environments restricted to south coast Oregon and north coast California, and shore pine (*Pinus contorta* var. *contorta*) forest associations found in stabilized dunes in central coastal Oregon (Slauson et al. 2007, in press). Although the tree composition and vegetation structure vary among these three environmental conditions, they have one feature in common: a dense (more than 60 percent cover) shrub understory dominated by ericaceous species such as salal (*Gaultheria shallon*) or evergreen huckleberry (*Vaccinium ovatum*) (Slauson et al. 2007). In coastal forests at the home-range scale, martens select for large patches (more than 250 ac or 100 ha) of old-growth and late-mature forest or serpentine areas (Slauson et al. 2007).

Complex vertical and horizontal forest structure is an important characteristic of marten habitat, providing features used to meet daily resting and seasonal denning needs as well as providing food and cover for prey species. Just outside the NWFP area in north-central California, Moriarty et al. (2016b) found that martens strongly selected complex-structured forest stands over simple stands and openings. Stand structure influenced martens' movement patterns, being quicker and more erratic and linear in simple stands and openings, likely related to predator behavior; and more sinuous and slower in complex stands, likely related to foraging under cover from predators.

In coastal California, the summer and fall diet of martens is dominated by sciurid and cricetid rodents (chipmunks [*Tamias* sp.], Douglas squirrels [*Tamaisciurus douglasii*], and red-backed voles [*Myodes californicus*]) and medium-sized birds. During winter, martens shift to larger bodied prey species such as medium-sized birds and northern flying squirrels (*Glaucomys sabrinus*) (Slauson et al., in press). Many of these key prey species of the Humboldt marten reach their highest densities in forest stands with mature and late-successional structural features (e.g., Carey 1991, Carey and Johnson 1995, Hayes and Cross 1987, Rosenberg et al. 1994, Waters and Zabel 1995) where their key food resources—conifer seed crops, truffles (the fruiting bodies of ectomycorrhizal fungi), and late-successional and old-growth-associated pendant lichens—typically reach their greatest abundances (Luoma et al. 2003, Smith et al. 2002). Dense ericaceous shrub layers are also positively associated with key prey species including chipmunks (Hayes et al. 1995), northern flying squirrels (Carey 1995), and small mammals in general (Carey and Johnson 1995). Coarse woody debris also has been shown to positively influence foraging efficiency for martens by making prey more vulnerable to capture; where it has been reduced from timber harvest, marten foraging efficiency declines (Andruskiw et al. 2008).

Like fishers, martens also depend on large decadent woody structures including live and dead trees and downed logs with features such as cavities, platforms, and chambers for daily use as resting sites and as seasonal den sites for females raising young (Raphael and Jones 1997, Slauson and Zielinski 2009, Thompson et al. 2012). In summer and fall, martens in coastal forests rest predominantly in large-diameter snags, downed logs, and live trees, and less commonly in slash piles, boulder piles, and shrub clumps (Slauson and Zielinski 2009). Use of the sizes of trees, snags, and downed logs is similar between coastal and inland mesic forests, but tree diameters are larger than reported for inland xeric forest (Raphael and Jones 1997). Female martens are also obligate cavity users for reproduction, with cavities in trees and snags providing secure environments for kits by regulating temperature extremes and providing protection from predators (Raphael and Jones 1997, Slauson and Zielinski 2009, Thompson et al. 2012). Reproductive den structure types are more restricted than are rest sites (Ruggiero et al. 1998), and all natal dens have occurred in aerial cavities in large-diameter hardwoods, and maternal dens have included cavities and platforms in both large-diameter hardwoods and broken top live and dead conifers (Slauson and Zielinski 2009; Slauson, in press). In contrast to inland forest types, the dens found to date in coastal forests have been predominantly in hardwoods.

Lynx—In northern Washington, Koehler et al. (2008) found that lynx exhibited the strongest selection for Engelmann spruce (*Picea engelmannii*) and subalpine fir (*Abies lasiocarpa*) forest on moderate slopes, and to a lesser degree, forests with moderate canopy cover, at elevations of 5,000 to 6,000 ft (1525 to 1829 m), and either avoided, or used proportional to their availability, the following cover types:

lower elevation Douglas-fir, ponderosa pine forests, forest openings, and recently burned areas with sparse canopy and understory cover. Lynx in Washington spend more time hunting in patches of Engelmann spruce and subalpine fir where their predominant prey, snowshoe hare (*Lepus americanus*), occur at their highest densities (Maletzke et al. 2008). Lynx den sites typically occur in sheltered spaces most often created by downed logs, root wads of fallen trees and less often by boulder fields, slash piles, and live trees (Moen et al. 2008, Squires et al. 2008). In Montana, lynx den sites typically occurred in mature and mid-seral conifer stands with abundant woody debris, located in drainages or drainage-like basins (Squires et al. 2008).

Wolverine**—**The combination of historical records (Aubry et al. 2007) and contemporary studies of wolverines (Copeland et al. 2007, 2010) reveals that, during the denning and nondenning periods of the year, the species is closely associated with persistent spring (April to May) snow cover, and that this represents an obligate association with this bioclimatic feature. Wolverine habitat selection is strongly influenced by the distribution of seasonal prey resources, which tend to be dominated by large ungulates (e.g., moose, deer, elk, and caribou) (Copeland 1996, Lofroth et al. 2007) and large rodents (e.g., beaver, hoary marmots, and porcupine) (Lofroth et al. 2007).

Female wolverines have been shown to be more sensitive than males to predation risk and human disturbance. Females make greater use of rugged terrain to avoid predators and avoid areas with winter ski recreation and higher road densities within their home ranges (Krebs et al. 2007). Wolverine den sites tend to occur in areas with persistent spring snow cover and with large boulders and downed trees where females find secure sites for giving birth to and raising kits (Dawson et al. 2010, Magoun and Copeland 1998).

Landscape habitat suitability and connectivity for carnivores**—**Studies and habitat modeling of carnivores conducted at the landscape scale primarily address issues related to population processes, such as dispersal, gene flow, habitat connectivity, and population persistence. Regional landscape habitat models have been developed for the fisher in various portions of the NWFP area (Carroll et al. 1999, Davis et al. 2007, Halsey et al. 2015, Lewis 2013, Zielinski et al. 2010). Collectively, the most important predictors of suitable fisher habitat measured at various scales include areas with higher annual precipitation, moderate to dense tree canopy cover, higher basal area and diameter classes of hardwoods and conifers, and topographically complex areas at mid to low elevations.

The southern portion of the NWFP area supports the largest extant fisher population in the Pacific Northwest. Modeled suitable habitat for fishers in the southern portion is projected to be well distributed and well connected, and the habitat models provide managers with a tool for planning activities and for monitoring habitat changes.

In the coastal forests of California and Oregon, Slauson et al. (n.d.)[29] modeled landscape habitat suitability for the Humboldt marten where the most important predictors, at various scales, were old-growth forest structure, amount of serpentine environment, and areas of higher precipitation, all positively correlated with marten detection locations versus nondetection locations. This model predicted that less than 15 percent of the historical habitat of this subspecies in the NWFP area is currently suitable. In the southeastern portion of the NWFP area, Kirk and Zielinski (2009) modeled landscape habitat suitability for martens in inland forest areas and found that marten occurrence was best predicted by a large amount of the biggest size classes of mesic forest types, by landscape configuration (more habitat patches), and by more habitat in public land management.

Moriarty et al. (2015) used new methods for evaluating functional connectivity of Pacific martens across fragmented forest landscapes: use of food incentive experiments, and nonincentive locations of martens collected with global positioning system telemetry. They found that Pacific martens selected complex stands and crossed open areas in the winter when enticed by bait, and without bait they avoided openings and simple-structured forest

[29] Slauson, K.M.; Zielinski, W.J.; Laplante, D.; Kirk, T. [N.d.]. Landscape habitat suitability model for the Humboldt marten (*Martes caurina humboldtensis*). Manuscript in preparation. On file with: Keith Slauson, U.S. Forest Service, Pacific Southwest Research Station, 1700 Bayview Drive, Arcata, CA 95521. kslauson@fs.fed.us.

stands. Pacific martens also selected complex stands during summer and winter alike. Baiting can induce movements and introduce bias in habitat selection analysis intended to represent bait-free conditions. Dispersal and connectivity of Pacific martens thus seemed to be afforded partially by snow cover across open areas, and more fully by networks of complexly structured forest stands during summer.

Koehler et al. (2008) developed a model of lynx habitat suitability from snow tracking and estimated that 1,467 mi^2 (3800 km^2) of habitat suitable for lynx is present in the NWFP region, far less than prior estimates based on the correlation of historical records to vegetation types (McKelvey et al. 2000). Most lynx habitat identified by Koehler et al. (2008) occurs in western Okanogan County, Washington, and it was estimated that this amount of habitat could support a population of 87 lynx. Murray et al. (2008) assessed the state of lynx research and conservation in the species' southern range, including the NWFP area, and concluded based on their review of the existing science that successful lynx conservation will require protection and management of large tracts of lynx and snowshoe hare habitat, and ensuring connectivity between lynx populations at the core and periphery of the species' range.

The global distribution of wolverines is closely associated with areas of persistent spring snow cover (Copeland et al. 2010). In the NWFP area, the most significant areas with persistent spring snow cover are high elevations of the north-central Washington Cascades, where most records of wolverines occur. Although smaller areas with these conditions occur in the Oregon and California Cascades, limited connectivity to areas known to be occupied by wolverines may impede the ability for wolverines to reoccupy these areas. Other than models of areas with persistent spring snow cover across the NWFP area (Copeland et al. 2010), no additional habitat suitability models have been developed for wolverine. Similar to the lynx, ensuring connectivity between the largest areas of suitable habitat for the wolverine in the NWFP area with areas occupied by wolverines in British Columbia will be one of the most critical requirements to help ensure wolverine conservation in the NWFP area.

Landscape-scale habitat connectivity is a significant requirement for the carnivores considered here. For lynx and wolverine, connectivity to population source areas outside the NWFP is essential for population persistence (Aubry et al. 2007, Murray et al. 2008, Schwartz et al. 2009). For the fisher in the Washington Cascades (Lewis and Hayes 2004), and for lynx (Koehler et al. 2008), a current lack of connectivity likely is a main factor inhibiting the recolonization of suitable habitat in the northern portions of the NWPF area. For species that occupy high-elevation areas, particularly in the Cascades (i.e., lynx, wolverine, marten), climate change will likely reduce the amount and connectivity of habitat (Lawler and Safford 2012, McKelvey et al. 2011). In the coastal forests of northwestern California, the lack of connectivity of habitat for the Pacific marten is likely inhibiting the recolonization of suitable habitat patches within their dispersal capability (Slauson, in press).

In general, current and future problems of habitat connectivity for carnivores include wide distances among patches of suitable habitat, low quality of intervening habitat, and adverse effects of natural and anthropogenic movement filters and barriers such as rivers and roads on dispersal behavior and survival (Crooks et al. 2011). Owing to the high cost of creating habitat corridors and enhancing connectivity such as by constructing wildlife crossings on highways, or the long time necessary for regenerating late-successional forests where they have been lost, connectivity enhancements that can benefit multiple species (e.g., Singleton et al. 2002) could be most efficient at achieving objectives for carnivore conservation.

New threats to carnivores: predation—Studies in the NWFP area, as well as studies from adjacent areas in the Pacific States (Bull et al. 2001), have identified the bobcat (*Lynx rufus*) as a major predator of fishers (Wengert et al. 2014) and martens (Slauson et al., in press). Whereas predation is a natural mortality factor, its magnitude may have increased from historical times owing to the increase in early- to mid-seral forests in the NWFP area, which provide conditions suitable for predators such as bobcats and coyotes (*Canis latrans*) that have general habitat needs. In the NFPW area, studies of bobcat habitat use and diet in coastal forests indicate that they select for young regenerating stands (Slausonet al., in press; Wengert 2013) where they find key prey species such as lagomorphs, woodrats, and mountain beavers (*Aplodontia rufa*) (Knick et al. 1984; Slauson et al., in press). Halsey et al. (2015) modeled bobcat habitat to account for predation risk in evaluating reintroduction locations for fishers in the southern Washington Cascades, and found that reintroduction sites at middle to higher elevations rather than at lower elevation would likely reduce risk of predation by bobcats.

***New threats to carnivores: rodenticides*—**The widespread use of rodenticides and other toxic chemicals found at illegal marijuana-growing operations has emerged as a major new threat. In California, most [dead] fishers tested for toxicant exposure tested positive for one or more anticoagulant rodenticides, which were ingested when the fishers consumed contaminated rodent prey. Several fishers recently have been confirmed to have died from acute rodenticide poisoning on the Hoopa Valley Indian Reservation located in the southern portion of the NWFP area (Gabriel et al. 2012, 2015). Exposure rates of Humboldt martens to rodenticides is less well understood, but in California, rodenticide exposure has been confirmed in one of six (17 percent) [dead] martens tested (Slauson et al., in press). This threat may be limited to the southern portion of the NWFP area where cultivation of marijuana is illegal on federal land but common, and where most suspected use of rodenticides is at such illegal growing sites on public, tribal, and private land alike.

***New threats to carnivores: wildfire and fuels treatments*—**In 2007, the Fisher Conservation Strategy Biology Team held an expert panel workshop to conduct a threats analysis on fishers within the West Coast Distinct Population Segment and British Columbia portions of the species' range in the Pacific Northwest. The team evaluated 20 types of potential threats and ranked four equally as the greatest threats: uncharacteristically severe wildfire, forest canopy and overstory reduction, reduction of forest structural elements, and forest habitat fragmentation (Marcot et al. 2012a).

Wildfire is a natural process that can alter environments in various ways, including leaving behind remnants of older forest stands and large wood components that can serve as legacy structures as the vegetation subsequently regenerates. However, major loss or degradation of forests, especially from extensive high-intensity wildfire, can significantly affect habitat for the carnivores considered here. Effects of wildfire will be the most severe where fire suppression has resulted in the unnatural buildup of fuels. Severe wildfire occurrence is primarily in the southern portion of the NWFP region and at lowest elevations, putting the fisher at greater risk to loss of habitat than the other carnivores considered here. These are also the areas where fuels treatments such as mechanical thinning, which can potentially negatively affect fisher habitat, are most commonly prescribed. High-severity wildfire can have positive effects on some prey species, particularly herbivorous species such as Leporids (*Lepus americanus* and *Sylvilagus bachmani*) and dusky-footed woodrats (*Neotoma fuscipes*), by creating early-seral conditions that favor these populations. The degree to which high-severity wildfire can benefit the carnivores considered here depends on their reliance on these species as important components of their diets and the degree to which fires result in landscape patterns (e.g., mixed severity in the range of the fisher) compatible with supporting the rest of their life history needs.

The effects of fire suppression on carnivore forest habitat in the Pacific Northwest have received little study. Fire suppression activities often result in denser forests with more canopy layers and more dead wood from shade-tolerant trees. Whether these outcomes increase habitat quality or amount for forest carnivores is unstudied.

Initial research on the effects of fuels treatments on fishers outside the NWFP area suggests that treatments have significant indirect benefits by protecting fisher habitat from wildfire (Scheller et al. 2011) and that some types of fuels treatments may be compatible with fisher occupancy as long as they do not exceed a particular rate and extent (Sweitzer et al. 2016a, Zielinski et al. 2013) and they do not affect the density of large structures (logs, snags, live trees) used by fishers for foraging, resting, and denning.

Loss of habitat from wildfire was ranked as one of the top threats to the Humboldt marten in coastal California (Slauson et al., in press). In the last two decades, several fires have burned in marten-occupied areas with unknown effects on the population. Fuels treatments are typically used to minimize the severity of wildfire in these situations, but to avoid reducing marten habitat, they could be carefully planned and monitored. Fuels treatments that reduce surface and ladder fuels produce stand structures that martens either avoid or travel through quickly (Moriarty et al. 2016), similar to how marten respond to open linear features such as ski runs (Slauson et al 2017) and seismic lines (Tigner et al. 2015). Therefore to minimize impacts to martens from fuels treatments, they could be carefully designed to minimize their overlap with habitats supporting important aspects of marten life history such as denning and have a spatial arrangement that most likely represents a tradeoff between affecting fire behavior and minimizing negative effects on connectivity and foraging for martens (Moriarty et al. 2015, 2016b). Since 1985, fires have burned more than 386 mi^2 (1000 km^2) of forest habitat in Okanogan County, the only region in Washington where lynx has been verified recently; this loss of forest habitat from fire, coupled with the naturally fragmented distribution of suitable habitat, represent a present, significant threat for lynx conservation where they persist in the NWFP area (Koehler et al. 2008).

The effect of wildfire and fuels treatments on wolverines has not been directly studied.

***New monitoring methods for carnivores*—**New developments in methods for monitoring carnivores include methods of detection, improvement of statistical survey designs, and advances in statistical analyses of carnivore survey data. Once the objectives of monitoring are identified, a suite of survey designs can be considered (Long and Zielinski 2008, O'Connell et al. 2011). Statistical advances in occupancy modeling (MacKenzie et al. 2006, Royle et al. 2008, Slauson et al. 2012) and spatially explicit capture-recapture analysis (Royle et al. 2014) provide two new statistical frameworks to conduct carnivore monitoring. Because of the importance of designing surveys capable of reliably detecting a species, detecting magnitudes of change as specified in the monitoring objective, and optimizing the costs of such designs, Ellis et al. (2014) developed a power-analysis tool to evaluate the effects of alternative design elements for monitoring wolverines that has also been evaluated for fishers (Tucker 2013). Monitoring population status via sampling DNA from noninvasively collected hair samples is an increasingly realistic goal for carnivores (Kendall and McKelvey 2008, Pauli et al. 2011, Schwartz and Monfort 2008). Recent advances also have been made in the use of camera-trap sampling of carnivores (Mcfadden-Hiller and Hiller 2015), including fishers (Sweitzer et al. 2016b), and mountain lions (*Puma concolor*) (Caruso et al. 2015), and carnivores elsewhere (e.g., Herrera et al. 2016, LaPoint et al. 2013) including arboreal situations (Cotsell and Vernes 2016).

Red tree vole and *Arborimus* allies—
Since the 2006 synthesis (Haynes et al. 2006), much work has taken place on the morphology, genetics, and taxonomy of red tree voles and related species (Bellinger et al. 2005; Miller et al. 2006, 2010). Three species of *Arborimus* forest voles are now recognized to occur within the NWFP area. The white-footed vole (*A. albipes*) occurs in the Coast Range, Willamette Valley, and a portion of the western Cascades, from northwestern California north through Oregon to the Columbia River border with Washington. The red tree vole (*A. longicaudus*) occupies a subset of the range of the white-footed vole but does not extend as far into California, is absent in extreme northwest Oregon, and extends into the Cascades east of Portland, still constrained by the Columbia River to the north. The Sonoma tree vole (or California red tree mouse; *A. pomo*) is found only in coastal northern California, extending northward to where the red tree vole's range ends. Red tree voles and Sonoma tree voles are arboreal, making nests and using movement runways in canopies of late-successional and old-growth forests; white-footed voles, however, are only partially arboreal.

Red tree voles and Sonoma tree voles are particularly ecologically interesting for their arboreal life history and their reliance on needles and twigs of conifers as food sources. Chinnici et al. (2012) documented association of Sonoma tree voles with unharvested and partially harvested old-growth Douglas-fir forest in California. Genetics analyses by Blois and Arbogast (2006) revealed that, although Sonoma tree voles consist of one panmictic (interbreeding) population, some genetic evidence suggests that southern Sonoma tree voles may occur as a distinct management unit within the species.

Swingle and Forsman (2009) found that red tree voles occasionally moved short distances across small forest openings or across small logging roads less than 82 ft (25 m) wide. However, they saw no evidence of tree voles moving across large nonforest areas and thereby speculated that such areas are barriers to dispersal, and that long-term persistence of red tree voles depends on size and connectivity of forest cover and structure of the forest canopy.

Dunk and Hawley (2009) recognized threats to red tree vole populations, including fire and recent historical conversion of forests to nonforest uses. They developed habitat association models, and their most statistically significant model identified the best habitat correlates as site percentage of slope, basal area of trees 18 to 35 inches (45 to 90 cm) d.b.h., maximum tree height, and variation in diameters of conifers. They applied the model to the distribution of the species and determined that reserves have significantly higher quality habitat than do nonreserved lands.

Studies by Wilson and Forsman (2013) noted that silvicultural thinning of young forest stands to promote late-seral forest conditions can provide habitat for a number of vertebrate species, but thinning can delay the development of a mid-story layer of trees, which is an important habitat component for red tree voles (and also of northern flying squirrels, *Glaucomys sabrinus*). The authors suggested that long-term forest and habitat management goals should include developing more structurally and biologically complex forests across the landscape at scales appropriate to the species' ecologies.

Other recent research on red tree voles includes determining their distribution and abundance based on occurrence in pellets regurgitated by a principal predator, northern spotted owls (Forsman et al. 2004). Working in Oregon, the authors found that the incidence of red tree voles in the owl pellets occurred most commonly in the central and south coastal regions, were relatively sparse in the northern Coast Range and Cascades areas of the state, and were absent from pellets on the east slope of the Cascade Mountains and most of the dry forest area in south central Oregon. Incidence also declined by elevation in the Cascades, being most common in owl pellets below 3,200 ft (975 m) and rare above 4,000 ft (1220 m) elevation. The authors also speculated that red tree vole populations have declined in landscapes dominated by young forests and with increased occurrence of logging, fire, and human development. Their finding of low incidence of red tree voles in spotted owl pellets along the north coast area of Oregon was also supported by direct surveys there in Tillamook and Clatsop State Forests by Price et al. (2015) who found 33 tree vole nests at only 4 out of 86 randomly selected sites. They speculated that the dearth of nests there is because of logging or burning in the early 1900s and subsequent intensive forest management, and suggested that remnant old-forest stands on BLM and state lands serve as source populations.

Rosenberg et al. (2016) presented models of red tree vole habitat, comparing and combining their best performing model with previously published models. They concluded that the ensemble combination of models provided the most accurate predictions of red tree vole occurrence and habitat suitability, and that it could be used to reduce survey costs and to guide management decisions and habitat conservation strategies for the species.

Swingle et al. (2010) discovered that a key predator of red tree voles in western Oregon is weasels (*Mustela* spp.). Activity behavior and dispersal timing of red tree voles were studied by Forsman et al. (2009) using video cameras at nest sites, and additional studies of red tree vole home ranges and activity patterns were conducted by Swingle and Forsman (2009). At present, a major review has been completed on the distribution, habitat, and diet of red tree voles and Sonoma tree voles (Forsman et al. 2016), and an annotated bibliography has been compiled on all three *Arborimus* species discussed here (Swingle and Forsman 2016).

The ISSSSP's 2016 Red Tree Vole High Priority Site Management Recommendations[30] provides guidance to field personnel for identifying land use allocations consistent with red tree vole conservation, high-priority sites outside of those allocations, and connectivity areas for linking sites, as well as nonpriority sites and key information gaps.

On the International Union for Conservation of Nature and Natural Resources Red List, although relatively rare, white-footed voles are listed as of "least concern," whereas red tree voles and Sonoma tree voles are both listed as "near

[30] http://www.blm.gov/or/plans/surveyandmanage/files/RTV-HPS-MR-201604-final.pdf.

threatened" because of their restriction to mature forests—old-growth forests for the red tree vole—and from threats of logging and fragmentation of their forest habitats. In 2009, the U.S. Fish and Wildlife Service evaluated whether red tree voles in the North Coast Range of Oregon—sometimes referred to as "dusky tree voles" that seem to differ in diet and other aspects from other red tree voles—deserve designation as a distinct population segment under the Endangered Species Act. The Fish and Wildlife Service convened a panel of species experts and managers to evaluate the evidence (Marcot and Livingston 2009), and ultimately announced that the north Oregon Coast Range population warrants listing as a distinct population segment but is precluded from development of a proposed listing rule because of higher priority actions (USFWS 2011). Morphological study of the dusky tree vole (putatively *A. longicaudus silvicola*) did not find evidence to support the proposed, separate subspecies designation (Miller et al. 2010). The current listing status of red tree vole is Continuing Candidate; the Fish and Wildlife Service's species assessment[31] also provides a summary of recent biological and ecological information on the species.

Bats—

At least 14 species of bats are found within the NWFP area. Some of these species are late-successional and old-growth associated, and their forest habitats are likely provided by NWFP reserve guidelines, although studies are incomplete.

Kroll et al. (2012) reviewed the state of knowledge on birds and bats dependent on cavities and snags (dead standing trees) in the Pacific Northwest. They concluded that relatively little is known about how the viability of populations of these species is affected by distributions of snags and by the proximity and amount of mature and late-successional forests across the landscape. Rodhouse et al. (2012) provided models of the distributions of little brown bats (*Myotis lucifugus*) in the Northwestern United States, finding a link of the species with forest cover and productivity.

Lacki et al. (2012) studied use of snags for roosting by long-legged myotis (*M. volans*) in the Pacific Northwest, and found that fir snags (*Abies* spp.) had the lowest persistence rates (highest falling rates) over the course of their 5-year study (2001–2006), and that roost snags that persist standing the longest are larger in diameter, shorter in height, and with fewer branches. The authors recommend reserving sufficient, large-diameter leave-trees to provide for future use by roosting bats, given the persistence and fall rates of the snags they observed. Luszcz et al. (2016) studied three bat foraging guilds in southwest British Columbia, Canada, and reported that foraging activity of long-eared myotis increased with increasing forest age, and in general, *Myotis* spp. feeding along edges and in forest gaps was greater in black cottonwood stands and in the interior of old Douglas-fir stands than in other types of forests.

On a far broader scale, Duchamp et al. (2007) suggested managing for bats at a landscape scale to accommodate their nocturnal foraging movements, alternative forest roost sites for some species, and reduce adverse effects of forest habitat fragmentation. The authors cite evidence that some bat species seem sensitive to local habitat fragmentation but also require mixes of conditions across broad geographic areas to meet all resource needs.

Few studies are available on response of bats to fire. Buchalski et al. (2013) studied the response of bats to wildfire severity in a mixed-conifer forest in the Sierra Nevada of California and reported use in unburned, moderate-severity burn, and high-severity burn locations, with large-bodied bats showing no preference. They concluded there was no evidence that burn severity affected site selection and that bats in their region are resilient to landscape-scale fire that served to open up the stands and increase the availability of prey and roost structures.

One issue of growing concern is the recent discovery (March 2016) of white-nose syndrome in a little brown bat (Lorch et al. 2016) 30 mi (48 km) east of Seattle, Washington.[32] White-nose syndrome is caused by the fungus *Pseudogymnoascus* (prev. *Geomyces*) *destructans* (Verant et al. 2014) and is a major cause of mortality in a variety of bat species in the Eastern United States, having killed over 6 million bats since 2006. So far, white-nose syndrome

[31] http://ecos.fws.gov/docs/candidate/assessments/2015/r1/A0J3_V02.pdf.

[32] http://wdfw.wa.gov/conservation/health/wns/.

seems to exist mainly in species of bats that roost or hibernate in cave or cave-like environments; at least four species of bats in the Pacific Northwest are known to use such locations: little brown bat, big brown bat (*Eptesicus fuscus*), Townsend's big-eared bat (*Corynorhinus* [*Plecotus*] *townsendii*), and the poorly known long-eared myotis (*M. evotis*). Whether white-nose syndrome will spread geographically or among species in the Pacific Northwest, or to bat species using other roost situations such as large trees with sloughing bark and dense canopy foliage, is unknown.

The 2001 amended standards and guidelines for NWFP implementation provided specific direction on bat conservation and management, including safety considerations for conducting bat surveys, survey protocols for bat surveys in buildings, environmental education on bat ecology and presence, and plans for building bat boxes. Other issues regarding bat conservation in the NWFP area include gating of caves and mines to prevent disturbance of bat colonies, bat mortality from wind energy installations (Rodhouse et al. 2015, Weller and Baldwin 2012), and concerns for human health and safety from bat colonies occupying buildings.

The ISSSSP has developed a set of management and safety guidelines, and survey and monitoring protocols, for bat conservation in the Pacific Northwest.[33] Forest Service Region 6 has also conducted bat surveys using a Bat Grid Monitoring design and protocol.[34] The Bat Grid Monitoring study was conducted from 2003 to 2010 to provide a baseline of knowledge on bat distribution for future change detection, and produced predictive distribution maps of 11 bat species in the Pacific Northwest.

Recent Research and Development on New Tools and Data

Along with scientific studies specifically conducted on species, their habitats, and biodiversity of the NWFP area since the 2006 synthesis (Haynes et al. 2006), several advancements have been made in the development of new scientific tools, datasets, study methods, and assessments.

Much work has focused on developing geographic models and map projections, particularly related to projected effects of climate change. The Nature Conservancy has assessed and mapped the degree of resilience of ecosystems through a broad area of western North America including portions of the Pacific Northwest and NWFP area (east Cascades, west Cascades, north Cascades, Klamath Mountains, California north coast, Pacific Northwest coast, Willamette Valley, and Puget Trough).[35] They have also developed a mapping tool for assessing connectivity of "resilient terrestrial landscapes" in the Pacific Northwest (McRae et al. 2016). The U.S. Geological Survey has evaluated vulnerability of species and ecosystems to future climate in the Pacific Northwest.[36] A number of other institutions, academic studies, and agencies also have addressed climate change impacts in the NWFP area. Other sources of information on biodiversity and species in the NWFP area include the Washington Biodiversity Council[37] and the Oregon Biodiversity Information Center.[38]

Species and natural-area mapping studies and evaluations, specifically in the Klamath province, have been provided also by Sarr et al. (2015) and Olson et al. (2012). Sarr et al. compared three ecoregional classification systems and found that the top one (Omernik) served to map the distribution of tree species best, but the distribution of mammal species poorest. Olson et al. (2012) projected effects of climate change and determined that some old-growth forest conditions ("microrefugia") were not captured in the existing reserve designs. These microrefugia conditions would lend to the reserve system being more resilient under climate change; they include old-growth and intact forests on north-facing slopes and in canyon bottoms, lower and middle elevations, wetter coastal mountains, and along elevational gradients. However, the degree to which these findings for the Klamath province can be applied beyond is unevaluated, and we anticipate that other patterns might

[33] http://www.fs.fed.us/r6/sfpnw/issssp/species-index/fauna-mammals-bats.shtml.

[34] http://www.fs.fed.us/r6/sfpnw/issssp/species-index/fauna-mammals-bats-grid-monitoring.shtml.

[35] https://www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/oregon/science/Pages/Resilient-Landscapes.aspx.

[36] http://gec.cr.usgs.gov/projects/effects/vulnerability/index.html.

[37] http://www.rco.wa.gov/biodiversity/about_the_council.shtml.

[38] http://inr.oregonstate.edu/book/export/html/549.

occur in more moist forest environments farther north in the NWFP area (see chapter 2)

A number of tools for analyzing species' habitat connectivity are available (e.g., Brost and Beier 2012). Zielinski et al. (2006) used MARXAN to analyze habitat of spotted owls and fisher in northern California under the NWFP, and concluded that spotted owls require a greater percentage of planning units with habitat than do fisher, and that the current location of the late-successional reserves may not be best to maintain habitat connections for the two species. The individual movement modeling shell HexSim (Schumaker 2013) has been used in the NWFP area to assess habitat patch size and dispersion patterns for northern spotted owls (Marcot et al. 2013, Schumaker et al. 2014). Trumbo et al. (2013) used the modeling tool Circuitscape (McRae and Shah 2009) to evaluate landscape genetics relationships of Cope's giant salamander (*Dicamptodon copei*). Using an example of American pika (*Ochotona princeps*), Schwalm et al. (2015) championed the use of species distribution models for evaluating effects of climate change and habitat conditions on landscape genetics. They found that wide local variation in pika response, ranging from complete extirpation in some areas to stable occupancy patterns in others, as well as habitat composition and connectivity, were important to include in the pika model. Many other simulation and modeling tools are available.

Another recent advancement in mapping species distributions is the development of maps of probability of suitable habitat coupled with maps of uncertainty, such as the one produced by Rodhouse et al. (2012, 2015) and hosted by the ISSSSP, for bat species of the Pacific Northwest (see footnote 34), thereby providing managers with information on locations of habitat as well as confidence in the projections shown spatially. Other approaches to evaluating the effects of forest management on rare species can address the need for balanced sampling designs, such as using the application EstimateS (Colwell 2013) to statistically compare samples among various land condition categories (treatments).[39]

The modeling framework of MaxEnt (maximum entropy) has recently become popular, as used to map potential habitat in the Pacific Northwest for northern spotted owls (e.g., Carroll et al. 2010, Loehle et al.; also see chapter 4), white-headed woodpeckers (Latif et al. 2015), historical range of California condors (*Gymnogyps californianus*, D'Elia et al. 2015), fisher (Zielinski et al. 2012), and other species. Cautions in the use of the MaxEnt approach, however, have been offered by a number of researchers, such as Yackulic et al. (2013).

Olson et al. (2007b) summarized the strategic surveys conducted under the NWFP guidelines. Strategic surveys (Molina et al. 2003) are designed to fill key information gaps on species distributions and ecologies, the basic criteria for Survey and Manage, to help answer three questions: (1) Does the species occur in or occur close to the NWFP area? (2) Is the species associated with late-successional and old-growth forest? (3) Does the reserve system and other standards and guidelines of the NWFP provide for a reasonable assurance of species persistence? Olson et al. (2007b) reported that all strategic surveys were conducted under the Survey and Manage program from 1994 to 2004 and from 2006 to 2007 (other types of surveys are ongoing on a district-by-district basis). Survey results in the form of projects, publications, and reports on 10 taxa (fungi, lichens, bryophytes, vascular plants, arthropods, mollusks, amphibians, red tree voles, great gray owl, and bats) are now available in a regional repository of the ISSSSP[40] that is currently managed for a list of sensitive species, some of which are Survey and Manage species.

Recent and Ongoing Issues Adding Challenges and Opportunities

We have raised a number of issues related to other species under the NWFP, in the above text. Here we summarize these and additional challenges and opportunities, regarding conservation of other species, that have emerged since the 2006 synthesis (Haynes et al. 2006).

[39] As suggested by D. Luoma. Personal communication. Assistant professor, Department of Forest Ecosystems & Society, Oregon State University, 239A Richardson Hall, Corvallis, OR 97331.

[40] http://www.fs.fed.us/r6/sfpnw/issssp/.

Disturbance ecology and system dynamics—

***Wildfire and fire suppression*—**In this chapter, we have reviewed the mostly adverse direct effects of severe wildfire on fungi, soil arthropods, forest salamanders, forest carnivores, and tree voles. Chapter 3 reviews historical fire regimes of moist and dry forests, effects of recent historical fire suppression on increasing fuel loads and current fire risk, fire suppression effects on reducing early-successional environments, use of fire for restoration, and how the role of fire in late-successional reserves varies across the NWFP area.

Healey et al. (2008) reported that, since the initiation of the NWFP in 1994, loss of large-diameter forests to fire has exceeded loss from harvest across large areas of the region including federal and nonfederal lands (also see Davis et al. 2015). They also found that increased fire incidence is correlated with climate change and that retention of dry-site forests will hinge on coordinated, landscape-scale fire management (also see Halofsky et al. 2014, Podur and Wotton 2010, Sheehan et al. 2015). Healey et al. (2008: 1117) cited several sources for types of strategic fuel management approaches that "may have the potential to reduce the [future] impact of fire on the landscape…"

Although severe wildfire in the NWFP area is an increasing threat to conservation of existing older forest species and ecosystems, it is likely that some dense late-successional and old-growth forests of the Western United States resulted or persisted from decades of fire suppression (Sollman et al. 2016), and others likely were maintained because of topographic positions protected from fire. Fire suppression may have contributed to the development and continuation of some old-forest conditions on the east side of the Cascade Range, such as on the Deschutes National Forest (also see chapter 3). Fuels reduction activities also have changed habitat for many NWFP species in the managed forest matrix, particularly in the dry forest types in the southern part of the NWFP region, by removing fuel loads that in turn reduces presence and amounts of fine litter fuels, and in some cases, large down wood used as den sites by fishers (Sweitzer et al. 2016a). Historically, frequent fires in dry forest types of the Pacific Northwest resulted in a diversity of vegetation ages and structures among multiple seral stages, and natural legacies of old-forest elements such as large trees and large down wood often remained postfire. But, acting as a double-edged sword, fires of various intensities and frequencies can either create standing and dead wood structures useful to wildlife, or burn them up, unless they are protected or unless fires are of generally low intensity.

As fire regimes in the region shift location and increase in intensity (see chapter 3), there may arise difficult management and social choices between fire suppression and natural fire restoration. Wildfire in the Pacific Northwest is inevitable, and massive "megafires" have the potential of posing threats to old-forest species, such as reported on spotted owls in California by Jones et al. (2016).

Prescribed fire, on the other hand, can be a valuable management tool for maintaining open old-growth forests, forest openings, and early-successional vegetation. Fuels management can help reduce risk of spread of large, high-severity fire. Management options include the use of fuelbreaks, managing for low fuel loading on the forest floor, thinning heavily stocked "doghair" and stagnant stands, pruning to eliminate fire ladders, and other methods. However, there is disagreement over the need to use such treatments, even in fire-prone systems (see chapter 3). Whereas fuel treatments and restoration management can affect fire behavior, these actions expose bare soil that, in turn, could promote invasion of exotic plant species that could spread into adjacent lands, and where nonnative plant cover is twice as high on fuel breaks as in adjacent wildlands (Merriam et al. 2006; also see chapter 3).

Modeling by Ager et al. (2007) suggested that treating 20 percent of the landscape as fuel breaks and for fuel reduction can result in a 44 percent increase in the probability of conserving late-successional and old-growth spotted owl habitat (see chapter 4). Moriarty et al. (2016) suggested that fuel treatments that simplify stand structure can adversely affect movement and habitat connectivity for martens. The authors noted that martens avoided openings at landscape- and home-range scales, but thinned stands were avoided mostly at only the home range scale because such stands were uncommon in their study area of Lassen National Forest, in northeastern California, just outside the NWFP area. The authors also suggested that fuel treatments that would create landscape- or home range-scale openings be done at elevations lower than where martens typically occur. However, the effectiveness of such fuel-treatment approaches in providing for marten habitat likely varies with other considerations, in particular, habitat considerations for other species. Such treatments also may be more effective on south slopes and ridgetops, and less effective on north aspects and in drainage bottoms.

Further, fuels treatments as mentioned above could have adverse effects on the many species, within late-successional and old-growth forest stands and other forest age and structure classes, that occupy litter and duff (the organic matter soil horizon) and down wood of various decay, size, and cover classes and tree species, as well as standing partially dead trees and snags. The flip side of this, however, is that species associated with open stands of late-successional and old-growth forest or from burn conditions might benefit from lower severity wildfire. As mentioned below, balancing reduction of fire risk with providing such microhabitat elements for species and biodiversity conservation can be the subject of a decision analysis and decision science process (see chapter 12).

***Early-seral vegetation environments*—**Early-successional vegetation conditions provide habitats for young-seral species and thus contribute to overall biodiversity of the region (Swanson et al. 2011, 2014). For example, in the Klamath-Siskiyou province, early-successional vegetation, including grass- and shrub-dominated areas and areas of young trees and shrubs, helps support abundant populations of dusky-footed woodrats, which are a primary prey of northern spotted owls in that area. Lists of special status and sensitive species of Forest Service and BLM in Washington and Oregon include a few species associated with early-successional vegetation conditions, such as green-tailed towhee (*Pipilo chlorurus*).

However, natural early-successional vegetation conditions have been reduced throughout the Western United States, including the Pacific Northwest, from plantation forestry operations of tree planting, control of competing vegetation (typically broad-leaf or hardwood species), fire suppression, and some thinning (Bormann et al. 2015). The result is reduction in habitat for some species closely associated with complex, natural early-successional conditions and with landscape mosaics of early-successional and old-growth forests. For example, Betts et al. (2010) reported declines in bird species associated with early-seral broadleaf-dominated vegetation following stand-replacing disturbance, including timber harvest and fire, in the Pacific Northwest. However, variable-density thinning and heavy thins can promote subsequent growth of hardwood shrubs and trees and provide habitat for some species of lichens, invertebrates, and other organisms (Schowalter et al. 2003, Wilson and Puettmann 2007), but more study is needed on specific conditions and effects on late-successional and old-growth species (Wilson and Forsman 2013). In general, though, early-successional vegetation created naturally from fire, windstorm, or other natural disturbances usually differs substantially in structure and composition of plant and animal species from that created by timber harvest subsequently subject to tree planting and control of competing vegetation.

Early-successional vegetation conditions created artificially also can become sources of plants, invertebrates, and other species that can compromise adjacent forest-interior conditions in late-successional and old-growth forest patches. We have noted that recent historical increases in artificially created early-successional vegetation have likely provided increased habitat for predators of mustelids, such as bobcats and coyotes.

Depending on amounts and dispersion patterns, early-successional vegetation can serve to fragment otherwise extensive and connected late-successional and old-growth forest cover and impede movement, population connectivity, and population size of canopy-associated late-successional and old-growth species such as red tree voles, martens, fishers, northern flying squirrels, and brown creepers. Sollmann et al. (2016) found that forest thinning reduced local densities of northern flying squirrels which moved into adjacent unthinned stands; that there was no difference in effect from even thinning and variable thinning; and that their results underscore the need to consider effects of stand management in a broader landscape context, particularly regarding movement and dispersal (functional response) of the squirrels.

***Full range of conditions*—**The full suite of native species and biodiversity of the Pacific Northwest occurs only with a mix of the full range of environmental conditions, including all forest successional stages that support the full array of terrestrial vertebrates (e.g., Raphael 1988, Raphael and Marcot 1986) and geophysical conditions such as montane wet meadows that support associated invertebrates. The NWFP was designed to provide aquatic and late-successional and riparian forest environments; the most appropriate balance with other conditions (e.g., mixed of early- and late-successional stages) is beyond the scope of the NWFP's original mandate and its guidelines under the 1982 planning rule, and is a matter of public policy informed by the best science. The 2012 planning rule increases emphasis on ecosystem approaches to conserving species and ecological integrity, based in part on the coarse-filter approach of providing structures and functions of ecosystems. Thomas et al. (2006) called for the NWFP to be recast as an integrative conservation strategy with federal forests managed as dynamic ecosystems.

Climate change: indicators, tipping points, and thresholds—

Complicating management objectives to provide the full array of environmental conditions are the dynamic and potentially sudden influences of climate change on vegetation, fire, species distributions, and development of so-called novel ecosystems, that is, specific groups of species in assemblages and communities that have not previously occurred in those combinations (Collier 2015, Pace et al. 2015). The current locations of late-successional forest reserves under the NWFP may not be fully resilient to expected effects of climate change. We know little about how management of vegetation, fuels, and fire will be affected by changing climate and thus the future of late-successional and old-growth forests and associated species and biodiversity (Pfeifer-Meister et al. 2013, Wimberly and Liu 2014), although some indications are that, under the NWFP, large reserves in moist forests have been relatively stable compared to smaller reserves, and that moist forests may be at less risk of disturbance from climate change than are dry forests (see chapter 3).

Changes in climate, particularly increased temperatures and aridity, can adversely affect amphibians by altering regimes of local hydrology (see chapter 7 for more discussion of climate change effects on aquatic ecosystems), fire, and disease occurrence and transmission. More directly, it may cause physiological stress on species adapted to cool and moist microclimates. If climate change reduces availability and connectivity of higher elevation older forests, populations of associated carnivores such as lynx, wolverine, and marten might suffer, as summarized above ("Carnivores" section). In a study of 34 species of small mammals in montane environments in the Sierra Nevada Mountains and Lassen Volcanic National Park in California, Rowe et al. (2015) reported that 25 species shifted their ranges since the early 20th century in response to climate change, with high-elevation species contracting their lower range limits downslope and low-elevation species showing variable responses.

Some lichens and bryophytes found in late-successional and old-growth forests could serve as useful indicators of changes in, and thresholds of, forest conditions and climate and air quality (Ellis 2015, Hofmeister et al. 2015, Mölder et al. 2015). Some late-successional and old-growth-associated invertebrates also can serve as indicators of biodiversity and climate change risk (Yi and Moldenke 2005). Halpern et al. (2012) suggested that disturbance has passed a threshold level for bryophyte conservation in Pacific Northwest forests, and that 15 percent retention of late-successional conifer forests—which the authors cited as the minimum standard on federal forest lands in the Pacific Northwest[41]—is inadequate to maintain the abundance or diversity of late-successional and old-growth species.

Turner et al. (2015) developed models to simulate potential impacts of climate change and disturbances on vegetation in the Willamette River basin of Oregon. Their projections under climate-warming scenarios suggest that potential forest types will transition from evergreen needleleaf to a mix of broadleaf and needleleaf forms, with as much as a nine-fold increase in area burned by the end of the 21st century. Implications for lowland plants and animals suggest a shift to more warm-temperate and fire-tolerant species mixes. Research by Creutzburg et al. (2017) suggests a more modest change, as climate change will increase forest productivity and carbon storage capacity that will not be offset by wildfire under the legacy of management and fire suppression activities.

Carroll et al. (2010) modeled the NWFP reserve network under climate change stressors. They concluded that using spotted owls as an umbrella species for reserve design, as under the NWFP, included habitat for other dispersal-limited ("localized") species but will not include much of their core habitats, as defined in the Zonation model they used, under projections of climate change. Thus, the current array of fixed late-successional and old-growth reserves designed for the owls may not suffice for other species that may change locations as their habitats shift under climate change. The authors suggested that a fixed-reserve system should be designed for resilience under anticipated climate change by including additional areas, particularly by adding reserves in higher elevation sites (Carroll 2010). However, not all species will respond to climate change by migrating their distributions to higher elevations. Crimmins et al. (2011) reported anomalous downhill shifts of some plant species in California, following regional changes in climatic water balance rather than responding to changes in temperature. Tingley et al. (2012) projected effects of climate change on altitudinal distributions of birds in the Sierra Nevada of California, and found that species will likely respond differently and individually at their range margins to increasing temperature and increasingly variable precipitation. Similarly, variable responses by plants, birds, and other taxa in the NWFP area are likely. The lesson is that the response to changing climate and associated weather conditions will vary, sometimes greatly, among species, and such variability will likely occur in all taxa and species groups.

Bagne et al. (2014) evaluated the efficacy of managing for special status species under climate change and its secondary effects on providing for overall biodiversity in the Southeastern United States. They concluded that 74 percent of terrestrial vertebrates potentially vulnerable to climate change were not included in current lists of special status species, and omissions were greatest for birds and reptiles. Current lists of special status species—potentially including those of the ISSSSP in the Pacific Northwest under the NWFP—could be evaluated for potentially adding species that might be vulnerable to climate threats, particularly with regard to those environmental conditions that would exceed physiological thresholds, if such species were lacking. Such analyses have not been conducted across all taxa, although this chapter and others in this compendium (e.g., chapter 2) provide insights on some species that might be vulnerable to future climate change effects, such as marten, pika, and others.

Aside from climate change effects are questions of balancing conservation between biodiversity and individual species. For example, Arthur et al. (2004) modeled tradeoffs in western Oregon between maximizing overall species richness and providing for individual endangered species. They found that the tradeoff was nonlinear, whereby increasing endangered species protection from

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[41] The reference here to 15 percent retention might more clearly pertain to the 1994 Standards and Guidelines (USDA and USDI 1994, page C-41) that state "Landscape areas where little late-successional forest persists should be managed to retain late-successional patches. This standard and guideline will be applied in the fifth field watersheds (20 to 200 mi^2 [52 to 518 km^2]) in which federal forest lands are currently comprised of 15 percent or less late-successional forest."

90 to 99 percent caused a decline in all-species protection 2 to 14 percent. Their risk tradeoff approach could be applied elsewhere throughout the Pacific Northwest and NWFP area to evaluate variations in proportion of landscapes in late-successional and old-growth reserves and managed matrix lands (Arthur et al. 2002). However, their model did not quantify species persistence or viability, and it did not evaluate endemic, rare, or specialized species considerations that could be added to their analysis.

Matrix lands and habitat connections—
Many studies suggest that habitat connectivity, fragmentation, and isolation are among the most dire stressors on populations, and that, under environmental changes, movement barriers for many species are likely to shift over space and time (Caplat et al. 2016). Much has been written in the conservation biology literature on wildlife habitat corridors and connectivity among habitat patches and reserve areas (e.g., Beier and Brost 2010; Beier et al. 2008, 2011). The literature has addressed the influence of conditions in matrix lands on arthropods (Shields et al. 2008), butterflies (Ross et al. 2005), birds (Neuschulz et al. 2013), and mammals (Kurek et al. 2014). Beier et al. (2008) suggested designing habitat linkages between wildlands to provide for multiple species rather than single focal species. Brady et al. (2009) used measures of disturbance, structure, and floristics in habitat core areas, habitat patch edges, and matrix landscapes to assess small mammal populations in northeast Australia. They found that small mammal conservation entails controlling disturbances and providing for habitat preservation and restoration within matrix lands. Wessell's (2005) study of abundance and diversity of vascular plants, arthropods, amphibians, and mollusks in western Oregon suggested the value of managing forest matrix lands for habitat heterogeneity.

Several studies in the Pacific Northwest have suggested a need to view the LSR system under the NWFP as a habitat network (Molina et al. 2006), and to provide further connectivity of forest reserves to account for anticipated climate-change shifts in habitat quality for sundry species (Beier and Brost 2010; Carroll et al. 2010; Rudnick et al. 2012; see also Spies et al. 2010). Proulx and Santos-Reis (2012) determined the value of conserving late-successional and old-growth forests and structures in the Pacific Northwest as habitat for Humboldt and Pacific martens. Habitat connectivity for organisms such as northern flying squirrels and red tree voles that depend on contiguous tree canopies can be severed with heavy thinning of forests designed to accelerate diameter growth of trees (Wilson and Forsman 2013).

In general, these studies suggest also that the degree to which protection of species' habitats in the matrix may contribute to population conservation is species-specific, and depends in part on the size and configuration of habitat in core areas, patches, and habitat linkages, and in the amount of habitat occurring in land already conserved (e.g., NWFP LSRs).

Coarse and fine filters in conservation—
Since the last science synthesis, much has been written on sundry approaches to management of species, biodiversity, and ecosystems. These approaches include coarse- and fine-filter management; use of surrogate species such as indicators, umbrellas, keystones, and flagships; management of ecosystem services; management for the range of natural or historical variation; and much more. Much of this literature poses approaches with scant empirical testing and validation of their efficacy, however. In this section, we review recent literature on such topics as pertains to the Pacific Northwest.

A popular method for conservation assessment and management uses both coarse filters and fine filters (Hunter 1991, Noss 1987). This approach first addresses coarse-level, spatially broad environmental conditions to meet general habitat associations assumedly of a large number of species, and next adds specific environmental components and locations to meet the needs of additional species not sufficiently provided by the coarse-filter level. Such an approach was used to craft the late-successional forest and the riparian and aquatic reserve system under the NWFP. Further, the Survey and Manage standards and guidelines and its annual species reviews were specifically designed to determine which late-successional and old-growth-dependent species would not be sufficiently provided by the coarse-level reserves and may need additional fine-filter management. Determinations were made based on a rigorous, structured approach to evaluating new information (Marcot et al. 2006).

In the Pacific Northwest, Lehmkuhl et al. (2007) applied a coarse-filter approach to define the historical range of variability of the composition and pattern of forest conditions under historical fire regimes, and then a fine-filter approach to establish fuel reduction treatments at the landscape scale to provide conditions for the food web involving northern spotted owls and their prey of northern flying squirrels and bushy-tailed woodrats (*Neotoma cinerea*). Overton et al. (2006) used a coarse-filter regression approach with Gap Analysis Program information to evaluate use by band-tailed pigeons (*Patagioenas fasciata*) of abandoned mineral sites in western Oregon. In a more complex variant to the approach, Higgins et al. (2005) devised a four-tier spatial approach to identify areas critical to conservation of freshwater biodiversity in the Columbia River basin of the Pacific Northwest.

Thompson et al. (2009) used a coarse-filter approach to define the historical range of variability of forests in the Oregon Coast Range as a target for biodiversity conservation, coupled with what they termed the social range of variability to account for resource and land use patterns. They found that land development, shifts in anthropogenic fire regimes, and climate change will likely impede the use of historical range of variability as a management objective, and that more complex planning is needed in a continuous process of negotiation.

A coarse-filter approach to ecosystem management can also assume that emulating natural processes and disturbance dynamics, such as natural fire regimes, will provide for forest biota at natural population levels (Armstrong et al. 2003). Other variants of the coarse-filter approach include identifying and protecting biodiversity "hot spots" under the assumption that most or all biota will be provided. Some applications of the "hot spot" approach focus not on overall species richness but on identifying concentrations of locally or regionally endemic species, which tend to be range restricted and perhaps extinction prone. "Endemism hot spots" could signal climate refugia, and protecting them could be a useful tool for avoiding extinction under climate change (e.g., Harrison and Noss 2017).

The strength of the coarse- and fine-filter approach is that it can account for a wide array of species generally associated with an ecosystem condition such as late-successional or old-growth forests. The weakness of this approach is that it may require site surveys, habitat and ecological studies, and intensive assessments of individual species to determine which require fine-filter attention. Fine-filter management is typically viewed as management and conservation of species-specific habitats. This means that understanding species taxonomy is key to determining biological entities of potential conservation concern. In this chapter, we cite several instances of recent taxonomic findings describing newly identified species. Recent work on mitochondrial DNA (mtDNA) of flying squirrels now suggests that a geographically limited Pacific coastal form of northern flying squirrel ranges from southern British Columbia to southern California (Arbogast et al. 2017); the authors suggest the new species be designated Humboldt's flying squirrel, using the previously suggested epithet *Glaucomys oregonensis*. Nearly all of the occurrence of flying squirrels in the NWFP area now pertains to this newly described species, although there seems to be overlap with the northern flying squirrel (*G. sabrinus*) in western Washington. Thus, two species of flying squirrels may occupy the NWFP area, and their individual conservation status has yet to be determined.

Hunter (2005) suggested use of an additional "mesofilter" level to complement the coarse-filter strategy for conservation of entire ecosystems in reserves and the fine-filter strategy for conservation of selected individual species. The mesofilter ("middle" filter) level would focus on conserving critical ecosystem components, specifically microhabitat attributes such as logs, snags, and pools used by invertebrates, fungi, nonvascular plants, and other species groups that are often overlooked in conservation planning. Hunter suggested that the mesofilter approach is particularly useful with seminatural conditions, for sustaining biodiversity and commodity production. In a sense, management for snags, down wood, riparian conditions, and other ecosystem components, as already part of agency activities in the NWFP area, constitutes a mesofilter approach.

Assumptions of the coarse- and fine-filter approach, however, are seldom empirically tested in a controlled and rigorous manner, and their blind application may lead to inappropriate expectations for species conservation (Cushman et al. 2008, Hunter 2005). In one test in Oregon, Fagan and Kareiva (1997) found that hot spots of biodiversity (species richness) did not coincide with locations of rare and endangered butterflies. In another test in Oregon, Cushman et al. (2008) found that only 4 percent of the variation in bird species abundance was explained by using a general characterization of habitat as a proxy to bird species abundance and vegetation cover type as a proxy to habitat. Further, Molina (2008) found that 90 percent of fungal species has some fraction of their known sites occurring within LSRs in the NWFP area, but some 66 percent of all sites of Survey and Manage fungal species occurred outside the reserves, so that the coarse-filter level alone to identifying late-successional and old-growth forest reserves would not provide for many rare fungi. There may be some conservation salvation for these sites outside late-successional and old-growth forest reserves, insofar as the reserve strategy has changed, at least de facto, with little to no harvest of federal-land late-successional and old-growth forests outside the original NWFP LSRs (see chapter 12).

Related to the coarse- and fine-filter approach to conservation is the application of species- and system-level approaches to biodiversity conservation. Species-level approaches include use of population viability analyses; surrogate species approaches with the use of umbrella species, focal species, guild surrogates, habitat assemblage surrogates, management indicator species, biodiversity indicator species, apex predators, and flagship species; multiple-species approaches with use of entire guilds and entire habitat assemblages; and geographically based approaches with identifying locations of target species at risk and species hot spots or concentration of biodiversity (Marcot and Flather 2007). System-level approaches include the use of range of natural variability, key habitat conditions, keystone species, ecosystem engineers, and approaches to emulate or provide for regimes of fire, herbivory, key ecological functions of species assemblages, and food webs (Marcot and Sieg 2007). Much has been written about most of these species- and system-level approaches (e.g., Branton and Richardson 2014, Breckheimer et al. 2014, Hunter et al. 2016), including due caution in using them without clarity of definitions (Barua 2011) and empirical verification of their assumptions (e.g., Bifolchi and Lodé 2005).

Each of these species- and system-level approaches carries strengths and weaknesses depending on management objectives. No one approach is fully effective in providing for species diversity, genetic diversity, and ecosystem diversity conservation objectives, which is why the 2012 planning rule specifies use of both coarse- and fine-filter management. Raphael et al. (2007) and Raphael and Marcot (2007) suggested that a combination of approaches may be efficacious for meeting multiple conservation objectives. They suggested a series of steps to identify the suite of species- and system-level approaches for conservation of rare or little-known species and their habitats, and they emphasized the critical importance of setting clear goals, identifying measurable short- and long-term objectives, and including learning objectives to increase knowledge.

Uncertainties and Research Needs

Indicators and Surrogates

The debate over use of surrogate species in its many forms—indicators, sentinels, flagships, umbrellas, keystones, and others—bears closer scrutiny. The literature seems divided over cautioning against its use for more holistic ecosystem management, and using it with caution for more focused needs with clearly stated objectives. The Forest Service guidance on implementing the 2012 planning rule calls for the use of a surrogate-species approach to evaluating conditions contributing to viability of groups of species of conservation concern. In this approach, the viability of the surrogates is assumed to represent viability of the broader subset of species of conservation concern species with similar ecological requirements and similar responses to environmental conditions and changes. Surrogates are chosen also on the basis of their having more stringent ecological requirements than others of the group. Most important, surrogates are meant to represent ecological conditions that contribute to viability of the broader species group and are not meant to directly represent their population dynamics per se; this qualification may add some uncertainty over the response of the fuller species groups (Wiens et al. 2008) but is truer to the concerns expressed in the literature over use of indicators of population viability.

In many ways, the evolving planning and management framework under the NWFP has largely met earlier calls for conservation of forest biodiversity and other species. This includes viewing forests as dynamic ecosystems, explicitly providing for ecosystem processes, addressing little-known species, and attending to conditions in the managed forest matrix (Franklin 1993). Recent scientific publications have continued to suggest using management indicator species and umbrella species only with caution and empirical evaluation (Branton and Richardson 2010, 2014; Wiens et al. 2008), or not at all, because the terms are typically poorly defined and the concepts often untested. Simberloff (1998) argued that moving toward an ecological functional basis for species and biodiversity management, rather than using simpler proxies of indicator species, is more likely to succeed, particularly with application of ecological forestry approaches. Also, much recent scientific literature has moved beyond the contentious era of arguing whether species or systems should be the focus for conservation; the approaches are, as Lindenmayer et al. (2007) and Sergio et al. (2003) noted, complementary, including with the debate over conserving species versus ecosystem services (Hunter et al. 2014, Kline et al. 2016; also see chapter 8). Ultimately, successfully combining species and system approaches depends on clearly articulating management objectives and determining the efficacy of management through monitoring and research.

Climate Change

Climate change is at the heart of many conservation concerns in the Pacific Northwest, but much empirical study remains to better understand its effects on species, their habitats, and their ecological functions, and to avoid the easy but potentially erroneous assumption that it is the proximate cause of most or all observed perils, such as with the decline of amphibians (Davidson et al. 2001, 2002). Climate change might act indirectly, such as by reducing snowfall (Corn 2003, Forister et al. 2010) and increasing evaporation, leading to loss of wetlands (Corn 2005); by increasing fire frequency and extent; and by improving environmental conditions for diseases or pathogens that in turn could affect other organisms, again such as with the decline of amphibians (Carey and Alexander 2003).

Further, there may be higher order effects whereby climate change in turn alters biotic interactions among species, such as Preston et al. (2008) reported on an endangered butterfly and a threatened bird species in southern California, which led the authors to suggest that considering species interactions is important when designing reserve systems for conservation of sensitive species. How this can influence any redesign of reserves under the NWFP would require study.

Microbiota and ecosystem functioning—
There is a dearth of knowledge and understanding of Wilson's (1987) "little things that run the world," referring to the invertebrates, particularly soil microorganisms and mesoarthropods, along with the suite of poorly known fungi and allies, that collectively play crucial roles in organic matter breakdown, nutrient cycling, and maintenance of forest health (Berg and Laskowski 2005, Ulyshen 2016, Tolkkinen et al. 2015). There is also much to be learned about how biodiversity affects ecosystem functioning (Hooper et al. 2005, Marcot 2007). Here is where an interplay and complementarity of species-focused and ecological-process research and management can usefully provide for forest ecosystem conservation and restoration to meet early visions of achieving sustainable forestry for conservation of late-successional and old-growth forests and their biodiversity (Beebe 1991, Crow 1990).

The future of other species is not written, but is progressively being tilted by fluctuating dynamics of fire regimes, shifts of forest composition and structure from changing climates, increasing stressors of invasive species, and changes in societal values with increasing needs for progressively scarce forest resources and their ecosystem services. Successfully addressing these and related issues for restoration and conservation of other species of late-successional and old-growth forests necessitates continuing on the path to whole-ecosystem research and adaptive management in a socioecological scope (Ban et al. 2013, Schmiedel et al. 2016; also see chapters 8 and 11).

Conclusions and Management Considerations

Summary of Key Management Considerations

Here we apply our key findings to the set of guiding questions posed after the introduction of this chapter. We also address this additional question: If all late-successional and old-growth forests are now protected under the NWFP (and under designated critical habitat for the northern spotted owl), is there a need for additional fine-filter approaches, beyond those for the northern spotted owl and marbled murrelet, for species assumed to be associated with said forests? We will conclude the affirmative, that sufficient uncertainty exists, particularly with future changes in old-forest environments and species-specific habitats, particularly for species that are rare or poorly known or that are expected to be increasingly adversely affected by disturbances and changing climate. As to which species may need to be so studied and provided is at present unclear, although advances in identifying species of conservation concern under the 2012 planning rule will be a major step forward.

Current scientific understanding of late-successional and old-growth-associated species rarity—
Although no specific analysis has been conducted to quantify the degree of rarity of late-successional and old-growth-associated species in the latest Survey and Manage species list, the general trends since the 2006 synthesis (Haynes et al. 2006) are:

1. Scientific understanding has greatly expanded on the occurrence, distribution, ecology, and potential threats of many of these species, as noted by the rich array of inventory reports and conservation planning documents conducted by the ISSSSP.
2. Numerous Survey and Manage species had been removed from that list, during the last rounds conducted on the annual species reviews, largely because predisturbance site surveys suggested that the species are more common or frequent than previously thought and because they no longer met the concern for the basic criteria for persistence of Survey and Manage species.
3. The best scientific information to date on many of the remaining Survey and Manage species, as summarized by the ISSSSP, suggests continued rarity or potential vulnerability to habitat disturbance. It is true that some old-forest associated species are naturally rare and perhaps more vulnerable than are more abundant species, but neither the NWFP guidelines nor the 2012 planning rule state that naturally rare species are to be discounted. Although it may not be possible or feasible to increase the distribution or abundance of naturally rare species, their preservation or conservation is very much in the spirit of the NWFP. The specific lists of species currently considered under the ISSSSP are found on the web site cited above.

Planned provision of habitat for rare and uncommon species under the NWFP—
The NWFP was initially envisioned as providing habitats for late-successional and old-growth-associated species through a combination of LSRs, AMAs, aquatic and riparian reserves and buffers, and selected conservation of late-successional and old-growth forest stands in the managed forest matrix. At present, however, there is little to no harvest of late-successional and old-growth forest stands on BLM and Forest Service lands within the NWFP area, including within and outside reserves (see chapter 3). In this way, the current implementation of the NWFP is not the same as initially envisioned.

Further, there has been no official effectiveness monitoring program under the NWFP, so there is limited information for determining the degree to which all old-forest associated species are being provided, and determining their habitat and population trends. Without a formal effectiveness monitoring or research program for other species and biodiversity under the NWFP, much has to be inferred from vegetation and late-successional and old-growth conditions and trends, although some research is available on selected species and taxa, as reviewed in this chapter.

Rare and uncommon species populations under NWFP management—
The degree to which remaining late-successional and old-growth forest is adequately providing for persistent and sustainable populations of rare and uncommon species is known for only those few species for which demographic and monitoring studies have been conducted, such as with northern spotted owls and marbled murrelets. Lichen

sampling, if reinstituted in the Forest Service's FIA program, could provide answers to this question on late-successional and old-growth-associated species. Otherwise, as under the 2012 planning rule, assumptions need to be made on the efficacy of coarse-filter approaches to providing general ecosystem conditions and their adequacy to in turn provide habitat and resource conditions for individual species. To gain greater knowledge and understanding of the adequacy of these assumptions may entail further species-specific research and monitoring, perhaps including species previously deemed secure but now perhaps with uncertain futures from climate change and other disturbances unforeseen in the initial NWFP guidelines.

Efficacy of habitat conservation management recommendations—

There has been no effectiveness monitoring program for the bulk of Survey and Manage species. Various studies suggest some degree of success for specific species groups, such as headwater amphibians. For most species, however, no monitoring data are available.

Sufficient information to change species management status—

This would best be determined through an evaluation of recent scientific data, survey information, and other sources, through a structured species review process (e.g., the previously instituted annual species reviews under the Survey and Manage program). The ISSSSP has compiled and organized much survey and scientific information on the Survey and Manage species but has not been charged with conducting such species reviews per se. It is likely that significant information has been gathered on some species for making this determination, but at least some of the determination will not be made until or unless an adaptive learning and management procedure, along the lines of the annual species reviews (last conducted in 2003), is implemented again.

Species persistence under NWFP reduced late-successional and old-growth harvest—

No analysis has been conducted on threats to late-successional and old-growth-associated species, comparing threat levels perceived under the NWFP as initially envisioned with the NWFP as currently implemented. The NWFP as initially envisioned included late-successional and old-growth reserves, aquatic and riparian reserves and buffers, AMAs, and site-specific conservation of late-successional and old-growth forest stands. The NWFP as currently implemented includes little to no harvest of late-successional and old-growth forests on Forest Service and BLM lands within the NWFP area (see chapter 3); and provides for some management in LSRs in dry forests. Such a comparison between initial and current management conditions could recognize the greater roles and potential changes from shifts in local climate and especially in fire suppression, fuels management, and alternative ecological forestry approaches providing for the development of natural, complex early-seral and young-age forest vegetation conditions.

Under this suite of considerations, it is likely that some species originally ranked as having low potential for persistence might be viewed as having higher potential, particularly if their late-successional and old-growth forest habitats and specific habitat elements are better provided throughout the matrix as anticipated over time. Other species tied to specific locations that are vulnerable to fire and disturbances might not fare as well, but no evaluation is currently available. It is likely that location data accumulated from predisturbance and strategic surveys might suggest adequate numbers by which to reduce concern for the persistence of some late-successional and old-growth-associated species, but predisturbance surveys alone do not provide information on whether the species survived the disturbance, only that they were present before the disturbance.

Late-successional and old-growth species added to species-of-concern lists—

Several "species lists" cover the NWFP area, including the lists of Survey and Manage species; Forest Service and BLM special status and sensitive species; U.S. Fish and Wildlife Service's candidate, threatened, and endangered species under the Endangered Species Act; and various lists of species of conservation or vulnerability concern from International Union for Conservation of Nature Red Data Lists, state lists, Washington Natural Heritage Program, Oregon Biodiversity Information Center, and others. The Forest Service also is currently compiling a regional list of potential species of conservation concern that will also intersect with the NWFP area, its late-successional and old-growth forest-associated species, and many of the other lists noted here. There has been no evaluation of the composite set of species among all these lists, comparing to the list of late-successional and old-growth species originally ranked as high persistence or not identified as conservation concern under the NWFP.

This report has summarized new threats or new scientific information revealed over the past decade, suggesting potentially growing conservation concern for late-successional and old-growth forest-associated bats, should white-nosed syndrome spread in the Pacific Northwest; highly locally endemic mollusks and other invertebrates, under threat of invasive invertebrate species or reduction in key habitat elements (e.g., large, old bigleaf maples for the Puget Oregonian snail); new species recently split taxonomically and that occupy a smaller portion of the former species' range and that might associate with late-successional and old-growth forest environments that could be at risk from increasing wildfire (e.g., the new species of sharp-tail snake recently identified from northwest California and southwest Oregon); and other examples. For some species, a more extensive evaluation is in progress; for others, it awaits.

In the past annual species reviews, no species was added to the initial Survey and Manage species list.[42]

[42] New information to support adding a species to the Survey and Manage list (USDA and USDI 2001:15-16) must address the following three basic criteria including the specific factors used as a basis for determining concern for persistence, in addition to criteria for late-successional and old-growth association:

- The species must occur within the NWFP area, or occur close to the NWFP area and have potentially suitable habitat within the NWFP area.
- The species must be closely associated with late-successional or old-growth forest.
- The reserve system and other standards and guidelines of the NWFP do not appear to provide for a reasonable assurance of species persistence.

The specific factors must apply to at least an identified portion of the species range, on federal lands, within the NWFP area. One or more of the following factors may indicate that persistence is a concern. These factors must be considered in the context of other standards and guidelines (other than those related to Survey and Manage) in the NWFP:

- Low to moderate number of likely extant known sites/records in all or part of species range.
- Low to moderate number of individuals.
- Low to moderate number of individuals at most sites or in most populations.
- Very limited to somewhat-limited range.
- Very limited to somewhat-limited habitat.
- The distribution of the species within habitat is spotty or unpredictable in at least part of its range.

Effects of fire on rare and uncommon late-successional and old-growth species—

Species and ecosystems of the NWFP experience diverse forest types and disturbance regimes (Bunnell 1995). Regarding effects of fire on rare and uncommon species associated with older forests, research results are limited and mixed. For example, for some species such as white-headed woodpecker, small patches of prescribed burning can be used to create or elevate the quality of their habitat. For other species, prescribed fire (particularly associated with sanitation and safety harvests) and associated fuels reduction activities can diminish key late-successional and old-growth habitat components such as large hollow trees, large snags, and large down logs, in turn reducing habitat for a wide variety of denning and cavity-using wildlife species, including fishers, Humboldt marten, and other mammalian carnivores (fig. 6-3).

Effects of high-severity, stand-replacing wildfire are perceived as largely adverse to species that use dense, multilayered older forests, although much of the literature has not clarified levels of wildfire intensity, extent, and location when speculating or concluding on wildfire effects. Research suggests that (high-severity) fire can reduce beneficial mycorrhizal and other desirable fungi, but for the most part, the effects of wildfire on individual, rare and uncommon late-successional and old-growth species are largely unstudied. Insofar as atypically severe wildfire can reduce canopy closure and fragment dense, contiguous-canopy stands, it adversely affects habitat for red tree voles.

Little has been studied on the direct effects of suppression of wildfire on wildlife in the Pacific Northwest.

Efficacy of site buffers compared with landscape-scale habitat management for species persistence, dispersal, and habitat connectivity—

No studies have specifically compared site buffers with landscape-scale management of late-successional and old-growth forests, as influencing persistence, dispersal, and habitat connectivity of late-successional and old-growth-associated species. Similarly, little research has been done in the effectiveness of landscape-scale management in assuming a reasonable assurance of persistence

Bruce G. Marcot

Figure 6-3—Naturally hollow Douglas-fir log in a lowland old-growth conifer forest, west Cascade Mountains of northern Oregon. Such logs are prime denning sites for fishers, Humboldt marten, and other mammalian carnivores. Some prescribed fire, timber salvage operations, and fuels reduction activities can reduce such habitat elements.

of late-successional and old-growth-associated species. However, some studies have noted that small patches of late-successional and old-growth forests, and legacy elements of late-successional and old-growth forest such as large green trees, large snags, and large down wood, can provide limited habitat for old-forest-associated species in the forest matrix. Such patches can also be used as points of restoration of older forest. Studies of old-forest remnants and fragments suggest that, by themselves, they provide only a fraction of the original forest biodiversity. Although they may be valuable to conserve for that purpose, if they are the only remaining elements of late-successional and old-growth forests in an area, they cannot be counted on to provide for persistence, dispersal, and habitat connectivity of late-successional and old-growth-associated species.

In general, riparian stream buffers, including unthinned riparian vegetation and adjacent upland forests, have been shown to have immense conservation values, particularly for amphibians. Buffers of sufficient width along streams and wetlands can serve as movement corridors and landscape linkages for aquatic frogs, salamanders, reptiles, and birds (Perry et al. 2011, Vergara 2011). Streams with riparian buffers can provide for some birds (Nimmo et al. 2016) and arthropods. Studies suggest that buffer widths differ to accommodate different species or species groups, as noted in summaries above.

The ISSSSP under the NWFP—
The ISSSSP has provided a wealth of information to agency researchers and managers on late-successional and old-growth-associated species, such as conservation assessments, summaries of surveys, threats evaluations, range maps, survey protocols, and ecological studies. It should be remembered that the ISSSSP pertains only to Washington and Oregon; in California, the Forest Service and BLM each have their own species programs and lists.

The current special status and sensitive species list—
Some Survey and Manage species also have sensitive or strategic species status, but the ISSSSP list does not include Survey and Manage species, which are maintained as separate lists based on different criteria. The current special status and sensitive species list includes those Survey and Manage species that qualify based on the ISSSSP criteria. The current ISSSSP list is broader in application covering all of Oregon and Washington with updates as recent as July 2015. The ISSSSP list includes a broad array of fungi, lichens, bryophytes, vascular plants, vertebrates, and invertebrates. Late-successional and old-growth species, or any species for that matter, with risks to persistence would likely have been included in the list update. No changes have been made to the Survey and Manage species list since 2003 owing to capacity and funding limitations to conduct an annual species review (the adaptive management process that removes or adds species or changes Survey and Manage category based on new information).

Additional fine-filter approaches for species assumed to be associated with late-successional and old-growth forest—
Not all late-successional and old-growth forests are being protected, but surveys for Survey and Manage species are being conducted in stands over 80 years of age. Much remains to be learned about demography, persistence, viability, dispersal, and habitat connectivity of most late-successional and old-growth-associated species. The coarse-filter approach assumes that providing for general habitat conditions at a broad scale, such as through LSRs and aquatic and riparian reserves, will provide for many specific elements, but research informs on situations to be wary of taking that assumption at face value without additional information and tests. Additional knowledge is needed especially on many late-successional and old-growth-associated species still known as rare or uncommon, or that are little-known—such as most soil and canopy invertebrates, fungi, and many amphibians—and on highly locally endemic species such as some aquatic mollusks, before fine-filter (species-specific) conservation measures can be confidently replaced by coarse-filter guidelines.

Issues of Species Conservation

As a program to replace or complement the Survey and Manage program under the NWFP, the ISSSSP—spanning the Forest Service Region 6 and BLM Oregon and Washington—has produced much material since the 2006 NWFP science synthesis on a wide variety of little-known or rare late-successional and old-growth-associated species. Their products pertain directly to contributing information on conservation and management of Survey and Manage species under the NWFP and sensitive species across Oregon and Washington. The products include basic ecological information, field inventories and monitoring results, protocols for surveys, and conservation guidelines. Ongoing local monitoring efforts at district levels will continue to inform on the status of little-known and rare late-successional and old-growth-associated species, including if and when individual species should be of additional conservation concern or are doing well.

The Survey and Manage program produced guidelines and approaches on natural history and management considerations for hidden, rare, or little-known species, including soil invertebrates and some lichens. Still, research is needed on their habitat associations, ecology, and degree of tolerance to disturbances of many rare and little-known, late-successional and old-growth-associated species of fungi, lichens, bryophtes, and vascular plant species.

Beyond the biological sciences, successfully conserving, restoring, and managing for other species under the NWFP will take additional attention to social needs and interests (see chapters 8, 9, and 11). Fostering or retaining public support for conservation and restoration of rare and little-known species may require addressing social beliefs and values, and clarifying impacts and rationale of management policies, context, and actions (Stankey and Shindler 2006; see chapters 9, 10, and 11). Such was the case in the formulation of the initial NWFP guidelines, and such may be required again if the Plan is to be expanded to include other species, their habitats, or objectives beyond late-successional and old-growth forest, aquatic, and riparian environments.

Accounting for dynamic systems and uncertainties— Recent science findings suggest that successfully managing for the future of other species under the NWFP needs to explicitly account for disturbance dynamics (Odion and Sarr 2007) in forest ecosystems of the Pacific Northwest, principally fire and anthropogenic changes to species' habitats in the managed forest matrix. Collectively, our findings suggest that such changes to forest age classes, structures, and dispersion patterns may have had greater impact on species metapopulation viability and on late-successional and old-growth forest resilience than initially thought by FEMAT, in large part because of increasing occurrence of high-severity fire in recent years.

Recent science findings also have highlighted the need to consider how continuing climate change will affect such disturbance dynamics and landscape-level connectivity of habitats for late-successional and old-growth-associated species. Researchers have suggested developing adaptation planning for climate change effects, in large part for (1) flexing and migrating boundaries of LSRs (as originally intended by FEMAT (1993), (2) conserving habitat in higher elevations, and (3) providing for site-specific conservation of late-successional and old-growth forest conditions within the forest matrix to serve as connections between the reserves. The federal matrix lands are not treated as they were when the NWFP was implemented; rather, late-successional and old-growth forests in the matrix lands are generally not being harvested at the rate they had been previously (see chapter 3), which may contribute to conservation of old-forest habitat for some species, although the specific degree of contribution is unstudied. Also, the Aquatic Conservation Strategy, with its riparian buffers and headwater conservation approach, seems to be providing for nonfish aquatic species, particularly stream-associated amphibians and arthropods.

There will always be uncertainty on species' ecologies and conservation effectiveness. Several researchers have suggested use of decision science and risk analysis approaches to evaluating and managing for NWFP late-successional and old-growth-associated species under uncertainty (e.g., Kerns and Ager 2007). Such approaches might prove increasingly useful as we further enter into an era of climate change-induced disturbances, by presenting evaluations of potential changes and expected effects of alternative management actions as probabilities of outcomes in a risk analysis and risk management framework. Bormann (2004) suggested a new approach to managing forests under uncertainty, which they termed "options forestry" that would entail diversifying management operations for the purpose of learning under an adaptive management framework. Franklin and Johnson (2012) suggested a restoration strategy ("ecological forestry;" see also Franklin et al. 2007, Hanson et al. 2012) for federal public forests in Washington and Oregon that would produce ecological and economic benefits by reserving older forest stands, thinning plantations to encourage complex vegetation structures, and conducting variable-retention harvests in younger forests to provide diverse early-seral environments.

Continuing the conservation of other species and biodiversity under the NWFP may benefit from use of decision science approaches including decision support models (Staus et al. 2010) and structured decisionmaking frameworks (Marcot et al. 2012b) that clearly articulate objectives; involve managers, decisionmakers, stakeholders, and analysts in all planning stages; and provide for monitoring and adaptive management to revisit, reaffirm, or revise management objectives and guidelines (Thompson et al. 2013), particularly under dynamics of changing social values, climates, and disturbance regimes (e.g., Jactel et al. 2012). The topic is explored more fully in chapter 12.

Coarse-filter, fine-filter, and landscape-scale management—

We have discussed recent findings on the use and testing of the coarse- and fine-filter approach to management, which is still the prevailing framework under the NWFP, the Survey and Manage standards and guidelines, and the ISSSSP. The approach has been conflated with the use of a variety of species- and system-level approaches, including use of umbrella species, flagship species, management indicator species, focal species, surrogate species, guild indicators, indicator groups, and others (e.g., Lawler et al. 2003). The coarse- and fine-filter approach is a simple two-tier method of (1) providing general conditions, such as late-successional and old-growth forests in LSRs, and aquatic and riparian environments in the NWFP's Aquatic Conservation Strategy, and (2) then testing the efficacy for conservation of all species and biodiversity attributes of interest, and devising and implementing additional management activities and requirements as needed to provide for the full suite of species' habitats and biodiversity elements. What recent science has found is that the results—the combination of environmental conditions—will undoubtedly shift under climate change and disturbance dynamics, and thus might need to be at least intermittently reevaluated and readjusted.

Further, the coarse- and fine-filter approach focuses on environmental conditions and species' habitats except with the northern spotted owl and marbled murrelet, which include monitoring of population-level demographic status and trends. Whether the approach assures, to a degree acceptable to management, the long-term viability of all populations for the remaining 80 years of the NWFP is not known.

Recent studies and evaluations of how well the NWFP provides for other species and biodiversity also suggest that the role and efficacy of late-successional (and aquatic and riparian) reserves needs to be put into the broader context of the managed forest matrix and other systems of the Pacific Northwest found mainly on federal public lands, specifically subalpine forests, rock and ice substrates, headwaters, complex early-successional vegetation, and unharvested postfire conditions. However, maintaining late-successional and old-growth forest ecosystems and their biota may not be fully achievable only with old-forest reserves, and only on federal forest lands, given effects of forest fragmentation and fire suppression and dynamics (e.g., Perault and Lomolino 2000, Sheehan et al. 2015). For these and other reasons, McAlpine et al. (2007) concluded that conservation of regional biodiversity under broad forest plans including the NWFP are better achieved with sustainable forest management practices implemented on—or at least coordinated across—all ownerships and by all stakeholders, not just for focused forest reserves. Social and economic considerations for any such forest management are discussed in chapters 8 and 12.

Other considerations—

Several other considerations may be pertinent and useful for managing for biodiversity and other species other than the northern spotted owl, marbled murrelet, and salmonids under the NWFP. One idea from recent science findings is the value of providing older-forest substrates and elements outside of LSRs that can contribute to species' habitats and habitat connections in the managed forest matrix (e.g., Dunk and Hawley 2009). An example pertains to dead wood. Approximately two-thirds of Survey and Manage species under the NWFP are associated in some way with, and benefit from mitigation for, partially dead trees, snags, and down wood (coarse woody debris). The Forest Service Decayed Wood Advisor (DecAID)[43] provides substantial information on wildlife use of snags, partially dead trees, and down wood, along with guidance on management of such elements at stand and landscape scales (Mellen et al. 2002).

Further, there may be an opportunity to bolster research, conservation, and restoration guidelines for providing such conditions within the managed forest matrix and across land ownerships. The objective would be to help connect LSRs, particularly now that late-successional and old-growth forests in the federal land matrix are currently being harvested at much less the rate they once were. In the past, thinning of plantations and young stands served to reduce dead wood, especially large down wood. Dead wood provides for a surprisingly vast array of life and its essential

[43] http://www.fs.fed.us/r6/nr/wildlife/decaid/; currently undergoing a major version update.

ecological processes (Brazee et al. 2014, Seibold et al. 2015). Providing more naturally regenerating, structurally and floristically complex early-successional stands, with the aim of encouraging development of dead wood and large down wood, may be part of restoration actions.

Protection of old-forest "legacies" such as large old green trees and snags and large-diameter down logs in the managed forest matrix has long been touted as a means of conserving biodiversity in Pacific Northwest old-growth forests following disturbances (Johnstone et al. 2016, North and Franklin 1990). Remnant, shade-tolerant old-growth trees (*Thuja* spp.) have been found to provide biological legacies and seed sources in postfire conditions in Pacific Northwest conifer forests (Keeton and Franklin 2005). However, retention of old-forest legacies may not fully substitute for retention of old-growth forest stands per se. For example, Price and Hochachka (2001) reported that epiphytic and alectoroid lichens were less abundant in mature (70- to 120-year-old) stands with structural retention of old-forest legacies, than in old-growth (at least 300-year-old) stands. The point here is that old-forest legacies retained in early-successional forests can complement but not fully supplant old-growth forests in providing habitat for old-forest species.

There may be considerations for tradeoffs among the kinds of species that can be provided under different silvicultural activities such as different intensities of forest thinning. For example, in the Pacific Northwest, Pollock and Beechie (2014) found that different sets of wildlife species associated with large-diameter live trees benefited more from heavy thinning in riparian areas than species associated with large-diameter deadwood benefited from light or no thinning. The authors suggested that because far more vertebrate species use large deadwood than large-diameter live trees, riparian areas may best be left to develop naturally in the absence of thinning for the benefit of terrestrial and aquatic species. Consideration for such tradeoffs of management objectives is discussed more fully in chapter 12.

Another consideration pertains to maintaining the full suite of ecological functions provided by late-successional and old-growth-associated species. This helps provide for "fully-functional" ecosystems, including full food webs and ecosystem processes of all successional stages (Marcot 2002, Marcot and Sieg 2007, Marcot and Vander Heyden 2001).

Finally, there may be efficiencies and advantages to continue coordination of NWFP implementation and any amendments or updates, with other programs including climate science centers, disturbance research programs, and other protected area network programs.

Main Findings

Much has been learned since the 2006 synthesis (Haynes et al. 2006) about a wide variety of species and their occurrence, distribution, and rarity, and some on their ecology, reaffirming the role of LSRs and conservation of aquatic systems and riparian buffers in providing habitat for such species. Greater clarity also has been developed on the role of retaining old-forest components and substrates in the managed forest matrix to serve as connections among the reserves. Providing such connections is possible through the slowing of harvests of late-successional and old-growth forests in the federal matrix lands, the current critical habitat designation for northern spotted owls to protect all remaining owl habitat, and retention of old-forest structures in the forest matrix. Based on research on early-successional vegetation and associated biotic communities, how young stands in the forest matrix are managed will have a significant bearing on the future of older forest ecosystems throughout the NWFP area.

Recent work has also called for a far more dynamic approach to account for shifting movement barriers, fire disturbance to reserves and late-successional and old-growth forest stands, and other anthropogenic and climate-mediated changes in reserves and matrix lands alike. Habitats and population connections of other species of late-successional and old-growth forests are likely more vulnerable to the static placement of existing LSRs than previously envisioned. According to the research summarized in this chapter, a dynamic approach addressing the long-term scheduling of forest management activities and additions of reserves to further connect existing reserves and supplement them in higher elevations could better account for the influence of changing fire regimes, climate, and use of natural resources.

The Survey and Manage program, and more recently the ISSSSP, have provided much information on various rare and uncommon species associated with late-successional and old-growth environments. Their conservation evaluations provide evidence that the NWFP is generally providing habitat for late-successional and old-growth-associated species either under the late-successional, aquatic, and riparian buffer reserve system (coarse-filter management), or additionally through species-specific inventories, monitoring, and site protection (fine-filter management). Additional federal listing of late-successional and old-growth species as threatened or endangered, beyond northern spotted owl, marbled murrelet, and salmonids, has generally not proved necessary. Still, there may remain concerns for some species groups such as some late-successional and old-growth-associated bryophytes (Halpern et al. 2012) and other species groups because of the legacy of past forest harvesting patterns coupled with climate-change stressors (e.g., see section above on "Bryophytes"), but species-specific information is generally scant. For most of the other, rarer species addressed in this chapter, little to no information is available on population size and trend, especially their demographics across the managed forest matrix outside of reserves, although information is available on the general distribution or occurrence of some such species.

The Survey and Manage program, with its annual species reviews, provided the basis for reducing or removing concern for conservation of many uncommon to rare late-successional and old-growth-associated species that were originally ranked as having low potential for persistence. The lowering of conservation concern was due not so much to lower levels of harvest of older forests, but more to efforts locating such species during "pre-disturbance surveys" before local harvests and other management activities proceeded.

Since the 2006 synthesis (Haynes et al. 2006), no species have been added to the Survey and Manage species list; any additions would occur through a renewed annual species review process, and none was added during the reviews in 2001, 2002, and 2003. Those reviews resulted only in removing species from the list on the basis of new findings (viz., no concern for persistence, or the species not being late-successional and old-growth associated) or changing their conservation and monitoring categories based on new information.

Other than the research summarized in this chapter, little effectiveness monitoring has been conducted on site buffers to confirm that they are indeed providing for species persistence at those sites. Limited research on riparian stream buffers suggest high value for protected associated species' habitats.

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Metric Equivalents

When you know:	Multiply by:	To find:
Inches	2.54	Centimeters
Feet (ft)	.305	Meters
Miles (mi)	1.609	Kilometers
Acres (ac)	.405	Hectares
Square miles (mi^2)	2.59	Square feet
Pounds (lbs)	.454	Kilograms
Degrees Fahrenheit (°F)	.56(°F – 32)	Degrees Celsius

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Molalla River, Oregon.
Photo by Jeff Clark, USDI Bureau of Land Management, Oregon-Washington State Office.