4

Definitions and Attributes of Little-Known Species

Randy Molina and Bruce G. Marcot

The number of species worldwide has been estimated as 5 to 30 million (Wilson 1988). Only about 1.4 to 1.6 million of those species have been formally described, and even that number is relatively uncertain given the vagaries of systematic convention, geographic variation in species traits, and high levels of taxonomic synonymy (Stork 1997). Most of the global biodiversity, at least as reflected in species number, is unknown to science. Global patterns of estimated known and unknown number of species (fig. 4.1) suggest that the greatest unknowns among macro- and mesoscopic species occur with arthropods, fungi, and mollusks, but the gaps between known and unknown are likely even greater with microscopic species such as soil bacteria. Although much of this phantom biodiversity occurs in the species-rich tropics, there is a lack of comprehensive descriptions of many taxonomic groups in temperate areas as well.

This global pattern is repeated regionally. For example, in the inland West of the United States, of the taxa included in a major regional assessment (the Interior Columbia Basin Ecosystem Management Project of USDA Forest Service and USDI Bureau of Land Management), the greatest disparity between known and estimated numbers of species occurred with arthropods, fungi, and mollusks (fig. 4.2) over an area of 58,470,000 ha.

Before including little-known species in conservation programs, particularly from species-rich taxa such as fungi and arthropods, it is important to understand the inherent difficulty in gathering new information to determine their taxonomic and conservation status. For example, many species in these rich but little-known taxa are extremely difficult to detect

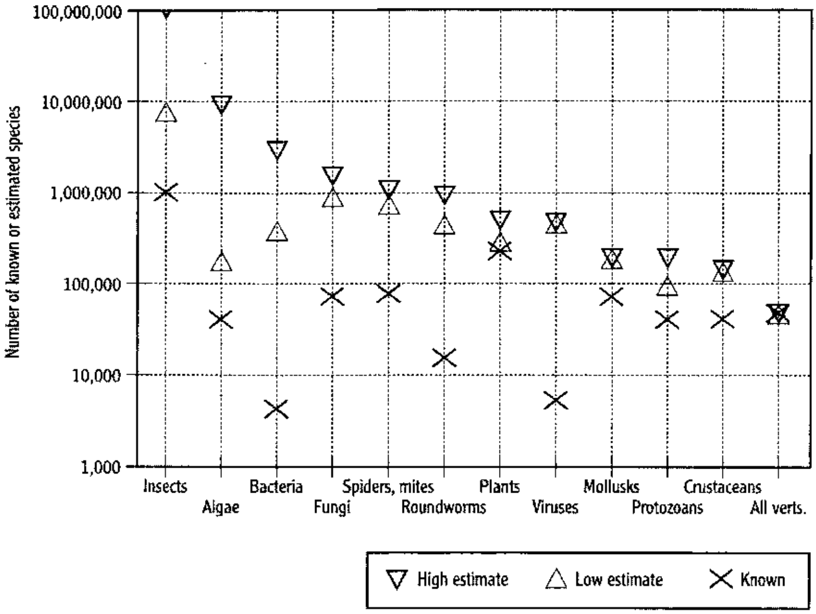

Figure 4.1. Global number of estimated and known species by taxonomic group. *Source:* Wilson 1988, Marcot et al. 1997.

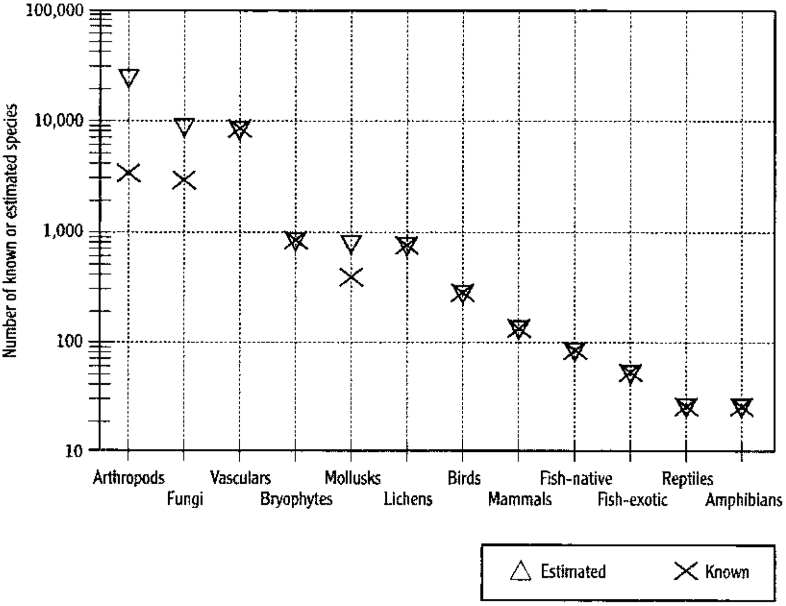

Figure 4.2. Number of estimated and known species by taxonomic group, as evaluated for the interior U.S. Columbia River basin. Values were derived from multiple taxa experts and compilations of species lists. Viruses, algae, phytoplankton, zooplankton, and most aquatic arthropods are not included. Richness of microfungi, bacteria, protozoa, and nematode species is largely unknown but may run into tens or hundreds of thousands of species. *Source:* Marcot et al. 1998.

due to their inconspicuous nature (figs. 4.3, 4.4). They are often hidden (e.g., buried in substrate) or so small that locating them is extremely difficult or impractical. Some species are simply too small to be readily detected in the field. Others have reproductive structures so minuscule (e.g., soil microarthropods) or diagnostic structures so obscure (some bryophytes) that microscopic examination and special expertise are required for identification. Some lichens cannot be reliably identified to

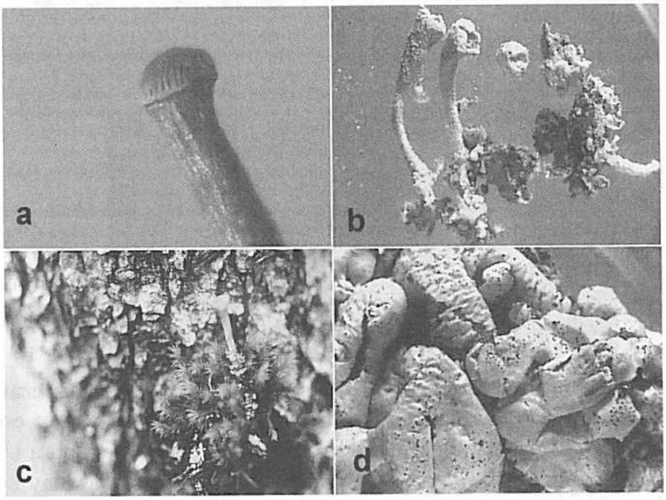

Figure 4.3. Examples of lichen and moss species in forests of the U.S. Pacific Northwest with detectability or identification difficulties, which may lend to their being little known in distribution or ecology. (a) Microscopic characteristics (60×): cord moss (*Atrichum selwynii*). The family, Polytrichaceae, is characterized by capsules, shown here, with 64 blunt peristome teeth, determined with a hand lens; the genus is among the smaller mosses in this family; the similar genus *Timmia* never has lamellae (upright ridges on the upper leaf surface), also requiring a hand lens for identification. (b) Microchemical tests and microscopic characteristics (60×): pixie cup lichen (*Cladonia fimbriata*). Identified by the medulla (loosely packed fungal hyphae below the photosynthetic zone) being K– (potassium hydroxide, negative results), P+ (p-phenylenediamine, positive results of red color), and UV– (no fluorescence under ultraviolet light); and told from *C. chlorophaea* and similar species by its powdery soredia (algal cells in fungal filaments) inside and outside the cups, and by cup shape and structure. (c) Hidden occurrence: podetium (stalk) of a *Cladonia* lichen growing within a clump of *Pohlia cruda* moss on a tree trunk. (d) Microchemical tests and mesoscopic characteristics (60×): beaded bone lichen (*Hypogymnia enteromorpha*). Distinguished from the similar *H. apinnata* by its short, budded side lobes and being P+ and KC+ (potassium hydroxide and sodium hypochlorite test, positive results). (All photos by Bruce G. Marcot.) Source: McCune and Geiser 1997; Vitt et al. 1988.

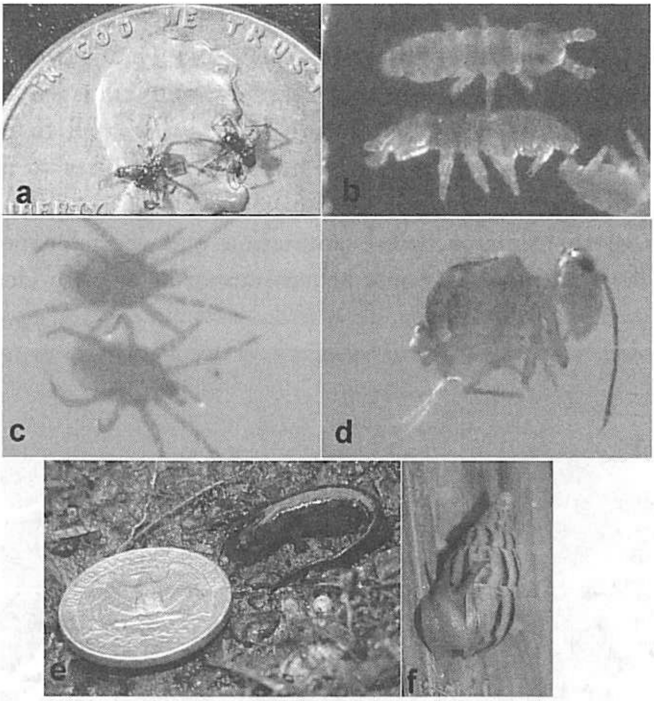

Figure 4.4. Examples of animal species with detectability or identification difficulties, which may lead to their being little known in distribution or ecology. (a) Microspiders (family Micryphantidae), full-grown adults shown on a U.S. penny (60×). Microspiders are numerous in abundance and species and play key predaceous ecological roles in soil food webs but are seldom seen, occurring in litter, duff, and soil layers. Many species may be undescribed. (b) Soil springtails or snowfleas (*Hypogastrura* sp.; family Hypogastruruidae) (200×). Occur in great numbers in the upper soil and litter layers of forests, may be important decomposers of soil fungi, lichens, bacteria, and decaying plant matter, and creators of topsoil. Some species may be undescribed and difficult to study, although their general presence can indicate healthy and productive soils. (c) Soil mite (*Pergamasus* sp.; family Parasitidae) (60×). Usually < 1 mm (0.04 in.) long, they are difficult to identify to species. Many species are likely undescribed but are numerous and key to soil health through their chewing, decomposition, and herbivory functions. (d) Soil springtail (*Ptenothrix [Dicyrtoma] maculosa*; family Dicyrtomidae) (60×). Tiny soil predators of mites and other invertebrates; difficult to identify to species by nonexperts. (e) Immature Pacific (coastal) giant salamander (*Dicamptodon tenebrosus*; family Dicamptodontidae) shown with a U.S. quarter. Adults more often found, but immatures seldom so, being tiny and cryptic or hiding at the bottom of streams; little is written of habitat ecology and environmental physiology of immatures. (f) Land snail (*Limicolaria subconica*; family Achatinidae), Congo River Basin, Africa. Hidden beneath leaves of shrubs, can easily escape detection. (All photos by Bruce G. Marcot. Photos (a) through (e) from U.S. Pacific Northwest.)

species without chemical tests. Many species are hidden in the forest floor, and extensive movement or sampling of substrates is required to find individuals. Hypogeous fungi (truffles), for example, fruit several centimeters below the forest floor and duff layer, and many mollusks or salamanders live on the undersides of leaves and woody debris or in talus. Others, such as arboreal arthropods, mammals, and lichens, live high in the canopies where extensive climbing or branch clipping might be required to sample species. Such attributes challenge our ability to locate and monitor these species.

Many little-known taxa share other life history characteristics, particularly reproductive strategies and seasonality, which also make detection difficult. Mollusks and amphibians are more active and detectable during wet, warm periods than during dry, cold periods, so effective surveys in regions such as the U.S. Pacific Northwest are limited to spring and fall. Multiple site visits and surveys may be needed to detect surface-active individuals, especially if populations are patchy, small in size, or unpredictable in substrate occurrence. Fungi offer one of the greater challenges because of their highly ephemeral nature and eruptive occurrence. Some reproduce (develop fruiting structures) in spring or fall. Timing and occurrence of fall reproduction is sensitive, however, to onset of rainfall (soil moisture) and patterns of temperature change. In many years, fungi will not reproduce, so 5 years of sampling in one location are typically required to determine their presence and diversity (O'Dell et al. 1999; Molina et al 2001). Many little-known species of fungi and other taxa also are highly patchy in distribution, which may be a response to unique microsite habitat requirements and past disturbances. The consequences of difficult detectability are discussed further under sampling considerations in chapter 5.

This chapter briefly explores causes that underlie the "little-known" conundrum and the types of information needed to make science-based decisions on conservation management of little-known species. We discuss information needs in light of the perceived risk to the species and for meeting other broad management objectives, such as sustainable timber harvest. We also reference examples from the Survey and Manage species conservation program that attempted to survey and conserve rare, little-known species of bryophytes, fungi, lichens, mollusks, amphibians, and arthropod groups as part of the Northwest Forest Plan in the Pacific Northwest (Marcot and Molina 2006; Molina et al. 2006). Chapter 5 then builds on combining concepts of rarity (chap. 3) and little-known (this chap.) to discuss the science implications of conserving species that are both rare *and* little-known.

Primary Causes of "Little-Known" Status

Little-known species fall into three categories of knowledge uncertainty: (1) taxonomic uncertainty, which occurs with overwhelming diversity and incomplete taxonomic description (and limited expertise of most observers); (2) distributional uncertainty, which occurs when few or no species inventory data are available; and (3) ecological uncertainty, which occurs with poor ecological understanding. For some species, information may be lacking in one or two of these categories, but for the great bulk of little-known species, lack of information generally stems from all three causes. The categories we provide evolve from the fact that little-known species are inconspicuous and difficult to detect, which leads to a lack of knowledge.

Taxonomic Uncertainty

It is important to understand the taxonomy of species before striving to conserve them. In addition to practical considerations of identification, taxonomic information brings with it an understanding of relatedness of species. This can be of conservation value when related species share a similar life history or ecology. Unfortunately, providing taxonomic clarity for little-known species comes with many challenges. Some taxonomic groups can number in the tens of thousands of species at the regional scale (e.g., soil microarthropods). With such overwhelming numbers of species, it is not surprising that most remain undescribed. At best, there may be a generally poor understanding of their taxonomy and systematics.

Hawksworth (1991), for example, hypothesized that, of the estimated global 1.5 million species of fungi, less than 5% have been described. Fungal classification is also in flux; for example, 10 years later, Hawksworth (2001) upheld his global estimate of 1.5 million species of fungi but clarified that the number of species now known is 74,000 to 120,000. Although his new estimate is somewhat greater than the original 5%, it remains a small fraction of the total. Even this estimate is uncertain because no comprehensive compilation of species is available. The advent of new molecular approaches that better define taxonomic relations between species has drastically altered our understanding of the major relations of fungal phyla and classes (Blackwell and Spatafora 2004; Wayne and Morin 2004).

Even with species that have been described, many can be extremely difficult to identify, and identification keys are often inadequate or nonexistent. In the Pacific Northwest with its rich array of forest macrofungi (mushrooms, truffles, cup fungi, and their allies), there is a dearth of comprehensive regional keys to species identification. General mycological guides (e.g., Arora 1986) are often the only books available with keys to start the identification process. Likewise, identifying many arthropods often relies on sending voucher specimens to those few overburdened entomologists and experts who specialize in particular genera or families; a few examples are the species-rich taxa of staphylinid beetles, micryphantid microspiders, and soil mites and nematodes. There are generally no comprehensive identification keys or "field guides" to help identification of most terrestrial invertebrate species the way there are for plants, birds and other vertebrate groups.

Well-trained taxonomists are vital to basic understanding of biodiversity (Chambers and Bayless 1983; Huber and Langor 2004), but the current decline in the cadre of taxonomic specialists who do fundamental taxonomic research compounds the challenge of describing the vast numbers of unnamed species and developing identification keys (Molina et al. 2001). In this regard, the development of sophisticated molecular-DNA tools to identify and differentiate species has been a two-edged sword. Although this new science has vastly improved our ability to detect recalcitrant taxa (e.g., of soil microorganisms), the attractiveness of this exploding research field has enticed young scientists away from traditional taxonomic fields. In the United States, the National Science Foundation (NSF) has recognized this issue and enhanced funding of its systematics program:

> The National Science Foundation (NSF), in partnership with academic institutions, botanical gardens, freshwater and marine institutes, and natural history museums, seeks to enhance and stimulate taxonomic research and help prepare future generations of experts. NSF announces a special competition, Partnerships for Enhancing Expertise in Taxonomy (PEET), to support competitively reviewed

> research projects that target groups of poorly known organisms. This effort is designed to encourage the training of new generations of taxonomists and to translate current expertise into electronic databases and other formats with broad accessibility to the scientific community (http://web.nhm.ku.edu/peet).

Efforts such as the PEET program, if sustained as part of science endeavors, will help to close the taxonomic information gap on little-known species.

Distributional Uncertainty

Basic inventory of species presence, abundance, and distribution is necessary for understanding species status and for monitoring trends. Lack of basic inventory data is at the root of the little-known status for various reasons. Taxonomic groups such as fungi, arthropods, or mollusks may simply not be included in inventory programs because they are seen as low priority compared to more "charismatic" flora and fauna. Their low-priority status reflects biases in scientific study, conservation, and social interests, and to some extent, the expertise of available biologists and taxonomists. Some taxa, such as spiders, have simply not been included in surveys and inventories, so that basic information on occurrence and distribution is lacking and thus the taxa are excluded from conservation planning (Skerl 1999). More typically, inventory programs find the idea of including such difficult and diverse taxa daunting, and they lack resources and administrative support to tackle the problem.

Issues of high diversity and distributional uncertainty are complicated by the simple dearth of knowledgeable biologists who can effectively deal with species such as fungi, mollusks, and arthropods in inventory programs. Most field botanists and wildlife biologists have been trained in vascular plant and animal species and generally have less knowledge to deal with these other taxa. A lack of familiarity with the ecological roles of little-known taxa makes it difficult to draw on available management tools to conduct specific surveys and studies contributing to species conservation. It is simpler to manage diverse macrovegetation conditions as a basis for habitat of bird or fish populations than to manage dispersed microscale habitats and substrates required by many little-known species. However, these species have been receiving increasing attention. For example, Dunn

(2005) emphasized the need to include insects in biodiversity conservation planning and assessments of recent species extinctions.

Use of population attributes to characterize viability and persistence of many groups of little-known taxa may not yet be practical given the current state of knowledge and slow pace of basic research progress on these taxa. But biologists and resource managers should not be completely discouraged from this general lack of inventory information because some progress is being made for these difficult taxa. Examples of such progress follow.

Attempts to conduct all-taxa biodiversity inventories exemplify the ability of professional societies to coordinate efforts in specific locations such as the Great Smoky Mountains National Park. As of 2006, the program had identified 625 new species and recorded 4666 species previously unknown from the park (http://www.dlia.org/atbi/index.shtml). Forest stand–level inventories and studies conducted at the H. J. Andrews Experimental Forest in the Oregon Cascades (a long-term ecological research site), have yielded comprehensive species lists and diversity, abundance, and importance data for fungi (Luoma et al. 1991; Smith et al. 2002) and arthropods (Parsons et al. 1991). Similar small-scale inventories including many little-known taxa have occurred elsewhere. Examples include surveys and inventories of amphibians in Great Smoky Mountains National Park (Dodd 2003); rare, threatened beetles in boreal forests (Martikainen and Kouki 2003); and mites in caves and deep soil (Ducarme et al. 2004). Although these examples are generally exceptions to most biodiversity inventory and survey projects, much could be learned from their successful methods to integrate into other biodiversity conservation inventory and monitoring programs. The all-taxa biotic inventory at the Great Smoky Mountains National Park, for example, conducts extensive outreach to train and educate volunteers to help with field surveys and other aspects of the program.

In another successful example, in the Pacific Northwest, the U.S. Department of Agriculture (USDA) Forest Service and U.S. Department of the Interior (USDI) Bureau of Land Management have developed survey protocols, field guides to species identification, and distribution maps, and have conducted surveys of 400 little-known species of lichens, bryophytes, fungi, mollusks, vascular plants, and amphibians, resulting in nearly 60,000 records over a 10-year program from 1994 to 2004 (Marcot and Molina 2006; Molina et al. 2006). Training of field biologists and use of parataxonomists (nonprofessionals, field-trained in species inventory and identification) as well as contracted taxonomy experts from academia were instrumental in the success of gathering useful and scientifically valid new information on abundance and distribution of these little-known species.

The current electronic information age also allows for better use of information and distribution of expertise. For example, databases from major herbaria and museums are now coming online over the Internet so historical records on species locations can be searched and analyzed. Many professional societies that focus on major groups of little-known taxa have recognized the need to include their taxa in the growing international call for biodiversity conservation. For example, a cadre of mycologists has recently published the first comprehensive treatise on inventory and monitoring methods for fungi (Mueller et al. 2004). Many authors have published on efficient methods for sampling terrestrial invertebrates, such as the use of enclosures and pitfall traps (Moffatt et al. 2004; Borgelt and New 2005; Hansen and New 2005). Such efforts bring scientific consistency to methodologies so that results can be compared among different regions. For example, the Natural Resources Monitoring Partnership (http://biology.usgs.gov/status_trends/nrmp/MonitoringPartnership.htm) has proposals to publish an inventory of monitoring projects and a library of recommended protocols covering major national and international status and trends programs.

Web-based species identification systems are becoming more available, such as for ants (AntWeb; http://www.antweb.org/index.jsp), grasshoppers (Field Guide to Common Western Grasshoppers; http://www.sdvc.uwyo.edu/grasshopper/fieldgde.htm), and butterflies and moths (Butterflies and Moths of North America; http://www.butterfliesandmoths.org/). In many cases, these tools may be the best or only way that biologists can access keys, photo series, and other expertise to identify sample specimens of little-known species.

Ecological Uncertainty

Even if something is known about the taxonomy and distribution of little-known species, there is typically a lack of information on the ecology of the species, including habitat requirements, community dynamics, response to disturbance, key interactions with other species, or ecosystem functions.

This type of information is critical to evaluating the life histories and ecological functions of little-known species in a holistic ecosystem sense, and to designing management approaches that maintain or restore species persistence and function.

The lack of general inventory data is exacerbated by the lack of information on population biology and natural history attributes needed to describe and forecast species presence, abundance, and population dynamics or trends. Knowledge of dispersal capabilities, either of individuals for mating events (animals) or of sexual or asexual propagules (plants and fungi), is usually lacking. Dispersal may be extremely slow and limited for many species (e.g., terrestrial mollusks).

Specifically with fungi, spore production, dispersal, and reproduction events leading to new fungal individuals and populations are not well understood in terrestrial ecosystems. Most population work with fungi has focused on pathogens to explore concepts of epidemiology, and molecular techniques are only now being developed to discern fungal individuals and populations at landscape scales (Dunham et al. 2003, 2006; Kretzer et al. 2003). Effects of natural and anthropogenic fragmentation of habitat, and the capability of species to disperse across unsuitable areas to maintain gene flow, remain largely unknown. Some fungal species depend on invertebrates or vertebrates for dispersal (e.g., Kotter and Farentinos 1984), further complicating analyses of fungus population distribution, abundance, and persistence.

In addition to knowledge on site occurrence, range, and distribution of little-known species, information is needed on the microhabitat and local site conditions they require. Such information is critical to understanding how these species respond to disturbance, and thus how to ameliorate threats and stressors caused by alteration of their habitat. Developing reliable habitat models of rare species is challenging, especially when species are little known and when their habitat consists of microscale features or very fine patch sizes typically not mappable across planning landscapes (e.g., using geographic information systems software). This is complicated by these species' usually sporadic and patchy distributions and dispersal limitations already noted.

Many little-known species in Pacific Northwest forests, for example, closely associate with large, coarse, woody debris and unknown microscale soil attributes or substrates such as rocks, bark of specific tree species, and moss patches. Little of this is spatially mappable from remote sensing information. Also, given dispersal limitations, patchy distribution of populations, and microscale habitat requirements, presence of habitat does not necessarily mean likely presence of predicted species. Understanding occupancy rates in seemingly optimal habitat is important for evaluating the utility of model- and habitat-based management approaches. Scaling-up from microscale habitat needs to the scale at which conservation or land-use planning occurs will remain a major challenge to predict species presence. We discuss the potential use of habitat modeling approaches in chapter 5.

Most organisms have evolved adaptations to changes in their environment over space and time. The science of disturbance ecology at the landscape scale includes understanding patterns of biotic response to immediate impacts of disturbance (natural and anthropogenic) and to long-term effects of land use and global climate change. However, the disturbance ecology of little-known species remains largely unexplored. This is perhaps one of the more critical and practical information needs as resource managers increasingly rely on re-creating natural disturbance regimes to sustain or restore healthy ecosystems.

Determining Information Needs and Setting Priorities

Addressing conservation concerns about little-known species requires gaining information on needs of the species and setting management priorities. For example, at a small site scale (a stand management unit), the most important information may simply be the presence or absence of the species of concern. This is often a criterion for sensitive and special status species programs of the Forest Service and Bureau of Land Management when planning management activities such as forest thinning projects. Identifying and inventorying microscale habitat features where the species is present may also be necessary so that habitat can be managed appropriately. At larger planning scales (e.g., watersheds to regions), information on distributions of species in reserves or concentrations of individuals may be most useful. Given often-limited resources, it is important to collect information at a scale appropriate to the specific needs of the plan area. For example, if information collection is too project-specific, the accuracy of syntheses or of running models at broad geographic scales can be lost.

Case Study: The Survey and Manage Program of the Northwest Forest Plan

The Survey and Manage program of the Northwest Forest Plan provides an example of strategic, regionwide surveys for hundreds of little-known individual species and arthropod species groups that were thought to be rare and likely associated with late-successional or old-growth forests (Molina et al. 2003, 2006). We first provide background information on the overall program and then discuss how resource managers and scientists have worked together to prioritize information needs and gather new information to reduce uncertainty on these species.

In 1994, the Bureau of Land Management and Forest Service adopted standards and guidelines for the management of habitat for late-successional old-growth (LSOG) forest-related species within the range of the northern spotted owl (*Strix occidentalis caurina*) under the Northwest Forest Plan (NWFP; USDA and USDI 1994). The main conservation elements of the NWFP are a system of reserves (with focus on maintenance and restoration of LSOG forests), an aquatic conservation strategy that protects streams and riparian areas, and various standards and guidelines pertaining to seven other land allocation categories, including "matrix" lands on which more intensive resource production and use may occur. The NWFP included mitigation to protect rare and often endemic species associated with LSOG forests. This mitigation is referred to as the Survey and Manage program. Over 400 species and four arthropod guilds, across eight major taxonomic groups, were listed for protection under this program. Initial risk analyses, which identified which species were to be addressed under the Survey and Manage program, were primarily based on expert opinion because so little quantitative information was available on abundance, distribution, population status, habitat associations, and degree of protection provided by reserve land allocations (Meslow et al. 1994; Raphael and Marcot 1994).

The Survey and Manage standards and guidelines (USDA and USDI 1994, 2001) described an adaptive management approach to conservation. Protection of sites where the organisms were known to exist was combined with regionwide surveys (as well as other information-gathering techniques such as herbarium searches and research) designed to provide new information that addressed uncertainties surrounding species viability. As new data were acquired and analyzed, the status of each species within the Survey and Manage program was revisited in formal annual species reviews, and the species management guidelines were revisited and revised if appropriate. The annual species reviews resulted in category changes among Survey and Manage status rankings and sometimes even removal from the Survey and Manage list, demonstrating the dynamic structure of the conservation program and the successful application of the adaptive management approach. Molina et al. (2003) described the process of acquiring and using new information. Details of the mitigation measure are given in the two records of decision (USDA and USDI 1994, 2001). Molina et al. (2006) provided an overview of how the Survey and Manage program evolved and the many implementation challenges encountered.

At the initiation of the Survey and Manage program, important life history information was lacking on nearly all of the Survey and Manage–listed species. For example, distribution data were not available on most species, and many species were known from only a few historic sites. Virtually no population-level data or habitat requirements were known, thus precluding use of population viability analysis or habitat modeling. In fact, natural histories of most species were so poorly understood that it was difficult to document biological threats (e.g., from limited dispersal, limited habitat availability, and habitat fragmentation) or management threats (e.g., from timber harvest and prescribed fire). Because of this lack of knowledge and high degree of uncertainty as well as the lengthy startup time to organize the program of work, the agencies allowed for at least 10 years of regionwide surveys. This allowed time to better assess persistence concerns and develop species-specific management.

Two fundamental goals of the Survey and Manage program drove the information needs assessment for the plan area: (1) to provide for the persistence of well-distributed populations, and (2) to maximize the role of the reserve lands to meet persistence requirements (e.g., provide habitat and connectivity). The first step in identifying information needs was to collect all available information from herbaria and museum records, agency field records, expert opinion, and the scientific literature, and then to synthesize this information for resource managers and biologists. This initial process indicated where significant knowledge gaps occurred. The next stage involved developing key questions and identifying the types of information needed to answer those questions. For example, what is the species distribution in reserve lands? and does the species require specific microhabitat such as large woody debris? Surveys would then be conducted in reserves, and the amount of woody debris would be measured in locations where target species are found.

Molina et al. (2003) described the types of information needs for the strategic survey effort of the Survey and Manage program (box 4.1). Information needs were organized into general categories of rarity, habi-

Box 4.1. Categories and specific information needs for survey and manage species (Molina et al. 2003).

Rarity

- Number of current and historic known sites
- Relative abundance at historic and known sites
- Size, area, diversity, and extent of inhabited sites on the landscape

Habitat

- Known or suspected habitat requirements
- Description of potential suitable habitat at both the micro- and macroscale
- Ecological amplitude

Distribution

- Historical and current distribution of known sites
- Historical and current distribution of potential suitable habitat
- Portion of suitable habitat that is occupied
- Distribution of known sites in reserve land designations

Persistence concerns

- Population trends and status of isolated populations
- Life history traits that might create additional risk
- Dispersal capacity and requirements
- Fragmentation of suitable habitat in relation to historical connectivity
- Successional trends of potential and suitable habitat
- Threats to occupied areas (both natural and anthropogenic)

Management consideration

- Quality of sites in reserve land designations
- Response to disturbance, natural and anthropogenic
- Connectivity of occupied sites needed to maintain stable populations
- Active and passive management needed to maintain or restore suitable habitat at known or potential sites (habitat quality at known sites)

tat, distribution, persistence concerns, and management considerations. Those items listed under rarity, habitat, distribution, and persistence concerns reflected many important information gaps critical to understanding the status and guiding conservation of individual species. Those items listed under management considerations reflect information needed to address key management objectives. For example, information on species response to disturbance was needed to help resource managers develop site management plans that included activities such as forest stand thinning, prescribed burning, or road building. Some management considerations have higher priority than others and thereby guide decisions on what information is most critically needed and will be gathered. Decisions typically blend information needed to address both species and management priorities.

Once operational decisions were made, surveys were strategically planned and implemented to collect the information. For example, the Survey and Manage program conducted surveys at known sites to collect crucial habitat information and regionwide, random-grid surveys to gain information on rarity and general distribution trends in reserve lands. These strategic surveys used an adaptive process wherein the survey methods and results obtained were periodically analyzed for efficiencies and effectiveness in gaining the needed information. New survey data were analyzed in an annual species review process, and changes to species management were made as appropriate. The species list and survey protocols were adjusted as needed. At the completion of this review, a new cycle of information prioritization, survey planning and implementation, and data analysis was undertaken. All planning was documented in an annual implementation guide. This adaptive management approach allowed the Survey and Manage program to make steady progress in meeting the objectives for this unprecedented conservation program for little-known species (see Molina et al. 2003 for more details on this planning process).

Even with a well-conceived process for acquiring new information on little-known species, the Survey and Manage program ran into many implementation challenges that revolved around many of the issues raised at the beginning of this chapter. These included difficulties in detecting species and determining their actual rarity; the complexity of defining species persistence and evaluating how well the plan's systems of reserves protected individual species; the task of training and maintaining a cadre of taxonomy specialists to identify species and provide expert interpretation of survey results; and the impracticality of targeting 400 little-known species over the 9.7 million ha plan area. Chapter 11 provides an overview of implementation challenges of conserving rare or little-known species with further examples from the Survey and Manage program.

Conducting Threat Assessments for Conservation Planning

As noted earlier, resource managers are often most concerned about the effects of various management practices on species of concern, and they desire information to help ameliorate threats to species. Part of increasing our knowledge about the response of little-known species to anthropogenic disturbances may entail first conducting basic threat assessments. A threat assessment determines what those threats are as well as the likelihood of a decline or loss of small populations in the face of human activities. A threat assessment would determine whether it is reasonable to craft management or monitoring actions for conserving little-known species. Further, it would determine the degree to which changes in management actions would be expected to solve problems; that is, the degree to which resource managers can have an impact on those threats (Morrison et al. 1998).

Results of such a threat assessment would classify species into categories, such as: (1) species for which current scientific knowledge and expert understanding are so poor that both threats and the potential impacts of management activities are very uncertain, and (2) species threatened by human activities for which reasonable (and testable) hypotheses can be devised concerning the role of these threats. The latter category can be further divided into species for which changes in specific land management activities can be expected to help reduce threats, and those that would not be so helped. For example, adverse effects on little-known terrestrial forest species from activities that compact soil could be mitigated by using different machinery such as rubber-tired tree loaders or by conducting these activities during other seasons such as when soil is frozen. Species that are influenced by human actions but that would not be aided by changing local resource management activities may include species generally sensitive to air pollution, such as some pendant arboreal lichens that are sensitive to sulfur oxide and nitrogen oxide in the atmosphere. By conducting threat assessments, the resource manager could describe realistic expectations for how and whether changing management activities would help the species.

In summary, given the high diversity and lack of essential distributional and ecological knowledge on many little-known species or taxonomic groups, it is important to set priorities for information needs to meet specific objectives. Otherwise, a program that includes many little-known species can become unwieldy and ineffective and may lose support. For example, in the Survey and Manage program discussed previously, prior to strategically focusing surveys in reserves to examine species persistence, most surveys were conducted in matrix lands before conducting ground-disturbing activities. Consequently, many sites of listed species were found in matrix lands, and resource managers often chose to forgo management activities such as timber harvest to avoid risking harm to the species. These decisions impacted the ability of the agencies to meet other management goals of the Northwest Forest Plan (e.g., timber harvest). Eventually these management frustrations and litigation from the timber industry led to the abandonment of the Survey and Manage program (USDA and USDI 2004).

Ecological and Social Implications of Little-Known Species

Interest in conservation of little-known species may be more than merely esoteric or academic. Many little-known species perform crucial ecosystem functions, including cycling nutrients, fixing nitrogen, aggregating soil, improving soil structure, and acting as links in the food web (see figs. 4.3, 4.4). Indeed, this is perhaps the most important factor in considering the protection and conservation of the functional diversity within these taxa for meeting broad goals of ecosystem management. For example, some rare plants rely on obligate pollinators (Spira 2001) that, in turn, may be poorly known and in decline (Cane and Tepedino 2001). Other rare plants can help stave off invasion of exotic species (Lyons and Schwartz 2001). Many little-known soil invertebrates play major roles as litter decomposers, and their functional redundancy may help maintain soil productivity (Andrén et al. 1995). Ostfeld and LoGiudice (2003) reported that loss of rare as well as common species led to increased incidence of Lyme disease in their modeled ecosystem.

Many little-known taxa enter into symbioses with other plants and animals and thus influence community and ecosystem dynamics. Many soil fungi, for example, form mutualistic symbioses with plant roots termed mycorrhizae. Mycorrhizal fungi—many species of which are poorly known in terms of specific autecology, distribution, or even taxonomy—strongly depend on host photosynthate as their primary energy source; in return, the plants receive much of their nutrient uptake (as well as other benefits) via their mycorrhizal fungi. Mycorrhizal fungi and plants exhibit varying degrees of host–fungus specificity in their natural associations (Molina et al. 1992), but, from a functional perspective, are obligate symbionts.

In another example of symbiosis, many arthropods tightly couple with other organisms (e.g., obligate pollination and dispersal relationships) in functional interdependencies (Buchmann and Nabhan 1996; Shepherd et al. 2003). Some rare species may be useful in bioassessments and may serve as indicators of ecosystem health (Cao et al. 2001; Welsh and Droege 2001). Conservation of these species necessitates an understanding of their interactions with other biota so that these relationships and key ecological functions can also be conserved. Although much might be known in general about these common symbioses and species interactions, they are poorly understood at the species level within specific ecosystems.

Much research remains to be done to determine the specific ecological functions of little-known species, but examples suggest that retaining little-known species may help maintain ecosystem services, biodiversity, and the full range of system functions. Little-known species can also play key social and cultural roles as well. In fact, many little-known species provide vital services to people. Many native peoples throughout tropical areas use invertebrates, for example, as a source of food and protein, and many native plants for medicines. Other little-known species may play key roles in various cultural rites, religions, and rituals and could be considered in habitat management (Bengston 2004). Yet many of these species are poorly studied or are scientifically unknown (Phillips et al. 1994). Recently, concern has been raised about adverse effects of environmental degradation on conservation of both well-known and little-known medicinal plants (Shanley and Luz 2003). In some cases, entire "ethnobiomedical" forest reserves have been delineated in tropical ecosystems to protect these little-known species (Balick et al. 1994).

Conclusion

This chapter reviewed causes and characteristics of little-known species, their ecological and cultural roles, and implications for management. Species can be little known for a number of reasons, each reason implying very different solutions. Some solutions could include further taxonomic research to describe the species systematically, field inventories to determine presence and distribution, or ecological studies to understand habitat associations, life history, and environmental correlates and stressors.

If the resource manager is interested in conservation of little-known species, the first step could be to take stock, produce a list, and compile whatever information is available in literature and from experts, on species names, taxonomy, distribution, abundance, and autecology. In such a list, the resource manager can begin to identify which species may be associated with particular environments of conservation concern, such as old-growth forests or native grasslands, and also which areas of knowledge are most lacking for each species. Also important may be to determine if species are rare and what might cause rarity (see chaps. 3 and 5).

Further, the resource manager could consider some little-known species as part of species groups such as habitat groups and ecological functional guilds (see chap. 6). For example, many aquatic macroinvertebrates could be combined into functional sets of shredders, predators, and decomposers, and terrestrial lichens can be grouped by growth form (crustose, foliose, fruticose) and substrate association (rock, tree bark, mineral soil, etc.). Some researchers and resource managers have used functional groups to include little-known species with others. Such approaches have commonly been used with vascular plants (Smith et al. 1993; Körner 1994), such as using functional plant groups of invasive species (Ramovs and Roberts 2005). By grouping species, management activities could focus on the habitats, substrates, and other attributes of species groups as an initial "coarse filter" step toward conservation strategies.

Still, by definition of little-known species, much will remain unknown and may require further study or testing of effects of management activities. What can the resource manager do in the face of such uncertainties? The most obvious, and possibly least tenable, solution is to cease all adverse, anthropogenic, environment-disturbing activities until further data can be gathered. This has the greatest chance for ensuring successful conservation of little-known species (presuming the species is not actually dependent upon anthropogenic disturbances), but this is seldom feasible or socially desirable. Such was the case with Survey and Manage species under the Northwest Forest Plan cited earlier; timber harvest and other forest management activities needed to proceed in light of a dearth of information on many species.

Short of conducting rigorous inventories and studies, the resource manager could conduct a more immediate threat assessment on individual species or on a species group. This could help identify key stressors or threats to conservation of the species, or at least key areas of uncertainty and scientific unknowns. The resource manager would then be faced with decision making under such uncertainty and choosing a risk attitude (whether one is risk averse, risk neutral, or risk seeking) toward potential effects on the species of interest from environment-disturbing activities. At this point, the resource manager could use well-established methods of decision analysis and risk management to document knowns and unknowns and their decision criteria and procedures (see chaps. 6 and 7).

The Survey and Manage program discussed earlier used an involved process of identifying little-known species based on syntheses of ecological knowledge, and then rated each species, through panels of biologists and resource managers, to determine their appropriate conservation category. Conservation categories reflected degree of rarity, levels of persistence concern, and required survey activities. The program also conducted a thorough information needs analysis for each species (i.e., what critical information was needed to improve managerial success for maintaining the species in the plan area). Following the process to prioritize species and management needs noted previously (see box 4.1), the program strategically designed surveys and research studies to gather essential information, at times using multiple-species approaches for efficiency. Two examples include a regionwide, plot-based, random grid survey (see Molina et al. 2003, 2006 for details) to improve understanding of rarity and distribution for over 200 species of little-known fungi, lichens, bryophytes, and mollusks, and field research on effects of prescribed fire and thinning on soil arthropod guilds and communities (Niwa and Peck 2002; Peck and Niwa 2005).

Another approach that could be used in tandem with threat assessments and risk management is to use better-known surrogates for species conservation. Such surrogates could include macrovegetation conditions at a broad scale and presence of other indicator species or their environmental conditions. However, as is explored in chapter 6, use of surrogates or indicators typically carries high uncertainty as to how effectively they conserve specific little-known species.

For invertebrates, another approach is use of morphospecies groups as units for conservation (Krell 2004). Morphospecies are groups of organisms (and species) that have similar appearances (morphologies) and that occur in the same location, vegetation condition, or substrate type; each morphospecies generally represents multiple taxonomic species. An example is the set of all large, black, terrestrial ants associated with decaying wood on the forest floor. A parataxonomist—typically a biologist with basic training in identifying characteristics of organisms—sorts specimens according to their common features. This approach can be useful when expertise or base scientific information is lacking to identify each taxon to the species level. For example, Barratt et al. (2003) successfully used student researchers to separate coleopteran beetles into morphospecies groups in New Zealand. The students were able to identify a total number of morphospecies within about 10% of the actual number as identified by a taxonomic expert. In another example, Longino and Colwell (1997) successfully used parataxonomists to identify and prepare specimens of ant morphospecies in a Costa Rican rainforest. Derraik et al. (2002) found that parataxonomists varied in their accuracy in identifying arthropod morphospecies groups, but initial training by expert taxonomists would likely improve results. Of course, the morphospecies approach cannot replace basic work in taxonomy, but it can be helpful to locate little-known and even undescribed organisms and to estimate overall species richness.

Other species and systems approaches to conservation of little-known species are discussed and critiqued in chapter 6. In the end, however, no model, indicator, surrogate, or grouping approach can fully substitute for knowledge gained on little-known species from basic field biology and autecology.

REFERENCES

Andrén, O., J. Bengtsson, and M. Clarholm. 1995. Biodiversity and species redundancy among litter decomposers. Pp. 141–51 in *The significance and regulation of soil biodiversity*, ed. H. P. Collins, G. P. Robertson, and M. J. Klug. Dordrecht: Kluwer.

Arora, D. 1986. *Mushrooms demystified*. Berkeley: Ten Speed Press.

Balick, M. J., R. Arvigo, and L. Romero. 1994. The development of an ethnobiomedical forest reserve in Belize: Its role in the preservation of biological and cultural diversity. *Conservation Biology* 8:316–17.

Barratt, B. I. P., J. G. B. Derraik, C. G. Rufaut, A. J. Goodman, and K. J. M. Dickinson.

2003. Morphospecies as a substitute for Coleoptera species identification, and the value of experience in improving accuracy. *Journal of the Royal Society of New Zealand* 33:583–90.

Bengston, D. N. 2004. Listening to neglected voices: American Indian perspectives on natural resource management. *Journal of Forestry* 102:48–52.

Blackwell, M., and J. W. Spatafora. 2004. Fungi and their allies. Pp. 7–21 in *Biodiversity of Fungi: Standard Methods for Inventory and Monitoring,* ed. G. M. Mueller, G. F. Bills, and M. Foster. New York: Academic.

Borgelt, A., and T. R. New. 2005. Pitfall trapping for ants (Hymenoptera, Formicidae) in mesic Australia: The influence of trap diameter. *Journal of Insect Conservation* 9:219–21.

Buchmann, S. L., and G. P. Nabhan. 1996. *The forgotten pollinators.* Covelo, CA: Island Press.

Cane, J. H., and V. J. Tepedino. 2001. Causes and extent of declines among native North American invertebrate pollinators: Detection, evidence, and consequences. *Conservation Ecology* 5 (1): 1. http://www.consecol.org/vol5/iss1/art1.

Cao, Y., D. P. Larsen, and R. S.-J. Thorne. 2001. Rare species in multivariate analysis for bioassessment: Some considerations. *Journal of the North American Benthological Society* 20:144–53.

Chambers, S. M., and J. W. Bayless. 1983. Systematics, conservation and the measurement of genetic diversity. Pp. 349–63 in *Genetics and conservation: a reference for managing wild animal and plant populations,* ed. C. M. Schonewald-Cox, S. M. Chambers, B. MacBryde, and L. Thomas. Menlo Park, CA: Benjamin/Cummings.

Derraik, J. G. B., G. P. Closs, K. J. M. Dickinson, P. Sirvid, B. I. P. Barratt, and B. H. Patrick. 2002. Arthropod morphospecies versus taxonomic species: A case study with Araneae, Coleoptera, and Lepidoptera. *Conservation Biology* 16:1015–23.

Dodd, C. K., Jr. 2003. *Monitoring amphibians in Great Smoky Mountains National Park.* U.S. Geological Survey Circular 1258. Tallahassee: U.S. Department of the Interior, U.S. Geological Survey. http://water.usgs.gov/pubs/circ/2003/circ1258/#pdf.

Ducarme, X., G. Wauthy, H. M. Andre, and P. Lebrun. 2004. Survey of mites in caves and deep soil and evolution of mites in these habitats. *Canadian Journal of Zoology* 82:841–50.

Dunham, S. M., A. Kretzer, and M. E. Pfrender. 2003. Characterization of the extent and distribution of Pacific golden chanterelle (*Cantharellus formosus*) individuals using codominant microsatellite loci. *Molecular Ecology* 12:1607–18.

Dunham, S. M., T. E. O'Dell, and R. Molina. 2006. Spatial analysis of within-population microsatellite variability reveals restricted gene flow in the Pacific golden chanterelle (*Cantharellus formosus*). *Mycologia* 98:250–59.

Dunn, R. R. 2005. Modern insect extinctions, the neglected majority. *Conservation Biology* 19:1030–36.

Hansen, J. E., and T. R. New. 2005. Use of barrier pitfall traps to enhance inventory surveys of epigaeic Coleoptera. *Journal of Insect Conservation* 9:131–36.

Hawksworth, D. L., ed. 1991. *The biodiversity of microorganisms and invertebrates, and its role in sustainable agriculture.* Wallingford, UK: CABI Publishing

Hawksworth, D. L. 2001. The magnitude of fungal diversity: The 1.5 million species estimate revisited. *Mycological Research* 105:1422–32.

Huber, J. T., and D. W. Langor. 2004. Systematics: Its role in supporting sustainable forest management. *Forestry Chronicle* 80:451–57.

Körner, C. 1994. Scaling from species to vegetation: The usefulness of functional groups. Pp. 117–40 in *Biodiversity and ecosystem function*, ed. E. D. Schulze and H. A. Mooney. New York: Springer-Verlag.

Kotter, M. M., and R. C. Farentinos. 1984. Tassel-eared squirrels as spore dispersal agents of hypogeous mycorrhizal fungi. *Journal of Mammalogy* 65:684–87.

Krell, F.-T. 2004. Parataxonomy vs. taxonomy in biodiversity studies: Pitfalls and applicability of "morphospecies" sorting. *Biodiversity and Conservation* 13:795–812.

Kretzer, A. M., S. Dunham, R. Molina, and J. W. Spatafora. 2003. Microsatellite markers reveal the below ground distribution of genets in two species of *Rhizopogon* forming tuberculate ectomycorrhizas on Douglas fir. *New Phytologist* 161:313–20.

Longino, J. T., and R. K. Colwell. 1997. Biodiversity assessment using structured inventory: Capturing the ant fauna of a tropical rain forest. *Ecological Applications* 7:1263–77.

Luoma, D. L., R. E. Frenkel, and J. M. Trappe. 1991. Fruiting of hypogeous fungi in Oregon Douglas-fir forests: Seasonal and habitat variation. *Mycologia* 83:335–53.

Lyons, K. G., and M. W. Schwartz. 2001. Rare species loss alters ecosystem function: Invasion resistance. *Ecology Letters* 4:358–65.

Marcot, B. G., L. K. Croft, J. F. Lehmkuhl, R. H. Naney, C. G. Niwa, W. R. Owen, and R. E. Sandquist. 1998. *Macroecology, paleoecology, and ecological integrity of terrestrial species and communities of the interior Columbia River Basin and portions of the Klamath and Great Basins*. General Technical Report PNW-GTR-410. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Marcot, B. G., M. A. Castellano, J. A. Christy, L. K. Croft, J. F. Lehmkuhl, R. H. Naney, K. Nelson, C. G. Niwa, R. E. Rosentreter, R. E. Sandquist, B. C. Wales, and E. Zieroth. 1997. Terrestrial ecology assessment. Pp. 1497-1713 in: T. M. Quigley and S. J. Arbelbide, eds. An assessment of ecosystem components in the interior Columbia Basin and portions of the Klamath and Great Basins. Volume III. USDA Forest Service General Technical Report PNW-GTR-405. USDA Forest Service, Pacific Northwest Research Station, Portland, OR. 1713 pp.

Marcot, B. G., and R. Molina. 2006. Conservation of other species associated with older forest conditions. Pp. 145–80 in *Northwest Forest Plan—the first ten years (1994–2003): A synthesis of monitoring and research results*, ed. R. W. Haynes, B. T. Bormann, D. C. Lee, and J. R. Martin. General Technical Report PNW-GTR-651. Portland, OR: U. S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Martikainen, P., and J. Kouki. 2003. Sampling the rarest: Threatened beetles in boreal forest biodiversity inventories. *Biodiversity and Conservation* 12:1815–31.

McCune, B., and L. Geiser. 1997. *Macrolichens of the Pacific Northwest*. Corvallis: Oregon State University Press.

Meslow, E. C., R. S. Holthausen, and D. A. Cleaves. 1994. Assessment of terrestrial species and ecosystems. *Journal of Forestry* 4:24–27.

Moffatt, C., S. McNeill, and A. J. Morton. 2004. Invertebrate community sampling of woodland field layers: Trials of two techniques involving enclosures. *Journal of Insect Conservation* 7:233–45.

Molina, R., H. Massicotte, and J. M. Trappe. 1992. Specificity phenomena in mycorrhizal symbioses: Community-ecological consequences and practical implications. Pp. 357–423 in *Mycorrhizal functioning: An integrative plant–fungal process*, ed. M. F. Allen. New York: Chapman and Hall.

Molina, R., D. Pilz, J. Smith, S. Dunham, T. Dreisbach, T. O'Dell, and M. Castellano. 2001. Conservation and management of forest fungi in the Pacific Northwestern United States: An integrated ecosystem approach. Pp. 19–63 in *Fungal Conservation: Issues and Solutions*, ed., D. Moore, M. M. Nauta, S. E. Evans, and M. Rotheroe. Cambridge: Cambridge University Press.

Molina, R., D. McKenzie, R. Lesher, J. Ford, J. Alegria, and R. Cutler. 2003. Strategic survey framework for the Northwest Forest Plan Survey and Manage Program. General Technical Report PNW-GTR-573. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Molina, R., B. G. Marcot, and R. Lesher. 2006. Protecting rare, old-growth forest-associated species under the Survey and Manage Program guidelines of the Northwest Forest Plan. *Conservation Biology* 20:306–18.

Morrison, M. L., B. G. Marcot, and R. W. Mannan. 1998. *Wildlife–habitat relationships: Concepts and applications*. 2nd ed. Madison: University of Wisconsin Press.

Mueller, G. M., G. Bills, and M. S. Foster. 2004. *Biodiversity of fungi: Inventory and monitoring methods*. San Diego: Elsevier Academic Press.

Niwa, C. G., and R. W. Peck. 2002. Influence of prescribed fire on carabid beetle (Carabidae) and spider (Araneae) assemblages in forest litter in southwestern Oregon. *Environmental Entomology* 31:785–96.

O'Dell, T. E., J. F. Ammirati, and E. G. Schreiner. 1999. Species richness and abundance of ectomycorrhizal basidiomycete sporocarps on a moisture gradient in the *Tsuga heterophylla* zone. *Canadian Journal of Botany* 77:1699–1711.

Ostfeld, R. S., and K. LoGiudice. 2003. Community disassembly, biodiversity loss, and the erosion of an ecosystem service. *Ecology* 84:1421–27.

Parsons, G. L., G. Cassis, A. R. Moldenke, J. D. Lattin, N. H. Anderson, J. C. Miller, P. Hammond, and T. D. Schowalter. 1991. Invertebrates of the H. J. Andrews Experimental Forest, Western Cascade Range, Oregon, V: An annotated list of insects and other arthropods. General Technical Report PNW-GTR-290. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Peck, R. W., and C. G. Niwa. 2005. Longer-term effects of selective thinning on microarthropod communities in a late-successional coniferous forest. *Environmental Entomology* 34:646–55.

Phillips, O., A. H. Gentry, C. Reynel, P. Wilkin, and C. Galvez-Durand B. 1994. Quantitative ethnobotany and Amazonian conservation. *Conservation Biology* 8:225–48.

Ramovs, B. V., and M. R. Roberts. 2005. Response of plant functional groups within plantations and naturally regenerated forests in southern New Brunswick, Canada. *Canadian Journal of Forest Research* 35:1261–76.

Raphael, M. G., and B. G. Marcot. 1994. Species and ecosystem viability: Key questions and issues. *Journal of Forestry* 92:45–47.

Shanley, P., and L. Luz. 2003. The impacts of forest degradation on medicinal plant use and implications for health care in eastern Amazonia. *BioScience* 53:573–84.

Shepherd, M., S. L. Buchmann, M. Vaughan, and S. H. Black. 2003. *Pollinator conservation handbook*. Portland, OR: Xerces Society.

Skerl, K. L. 1999. Spiders in conservation planning: A survey of U.S. natural heritage programs. *Journal of Insect Conservation* 3:341–47.

Smith, J. E., R. Molina, M. M. P. Huso, D. L. Luoma, D. Mckay, M. A. Castellano, T. Lebel, and Y. Valachovic. 2002. Species richness, abundance, and composition of hypogeous and epigeous ectomycorrhizal fungal sporocarps in young, rotationage, and old-growth stands of Douglas-fir (*Pseudotsuga menziesii*) in the Cascade Range of Oregon, U.S.A. *Canadian Journal of Botany* 80:186–204.

Smith, T. M., H. H. Shugart, F. I. Woodward, and P. J. Burton. 1993. Plant functional types. Pp. 272–92 in *Vegetation dynamics and global change*, ed. S. M. Solomon and H. H. Shugart. New York: Chapman and Hall.

Spira, T. P. 2001. Plant–pollinator interactions: A threatened mutualism with implications for the ecology and management of rare plants. *Natural Areas Journal* 21:78–88.

Stork, N. E. 1997. Measuring global biodiversity and its decline. Pp. 41–68 in *Biodiversity II: Understanding and protecting our biological resources*, ed. M. L. Reaka-Kudla, D. E. Wilson, and E. O. Wilson. Washington, DC: Joseph Henry Press.

USDA (U.S. Department of Agriculture), Forest Service; USDI (U.S. Department of the Interior), Bureau of Land Management. 1994. Record of decision for amendments to Forest Service and Bureau of Land Management planning documents within the range of the northern spotted owl. Portland, OR: U.S. Department of Agriculture, Forest Service, and U.S. Department of Interior, Bureau of Land Management.

———USDA (U.S. Department of Agriculture), Forest Service; USDI (U.S. Department of the Interior), Bureau of Land Management. 2001. Record of decision and standards and guidelines for amendments to the survey and manage, protection buffer, and other mitigations measures standards and guidelines. Portland, OR: U.S. Department of Agriculture, Forest Service, and U.S. Department of Interior, Bureau of Land Management.

———. 2004. Record of decision to remove or modify the survey and manage mitigation measures standards and guidelines. Portland, OR: U.S. Department of Agriculture, Forest Service and U.S. Department of Interior, Bureau of Land Management.

Vitt, D., J. Marsh, and R. Bovey. 1988. *Mosses, lichens and ferns of northwest North America*. Edmonton, Alberta: Lone Pine Publishing.

Wayne, R. K., and P. A. Morin. 2004. Conservation genetics in the new molecular age. *Frontiers in Ecology and the Environment* 2:89–97.

Welsh, H. H., Jr., and S. Droege. 2001. A case for using plethodontid salamanders for monitoring biodiversity and ecosystem integrity of North American forests. *Conservation Biology* 15:558–69.

Wilson, E. O. 1988. The current state of biological diversity. Pp. 3–18 in *Biodiversity*, ed. E. O. Wilson. Washington, DC: National Academy Press.