Research Problem Analysis For Greater Sage-Grouse In Oregon

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Executive Summary

Habitats and populations of sage-grouse have declined substantially across major portions of the species' range in response to a variety of detrimental land uses (Drut 1994, Connelly and Braun 1997, Schroeder et al. 1999, Wisdom et al. 2000*b*). These declines have prompted increasing concern about the viability of sage-grouse populations. Questions have arisen about how best to manage and recover habitats and populations, but solutions are unclear and complicated by the diversity of potential factors that may affect the species and its habitats. Productivity and populations of sage-grouse in Oregon have shown declines similar to those elsewhere (Crawford and Lutz 1985, Willis et al. 1993). In response to these declines, the Emergency Board of the Oregon State Legislature allocated funds to the Oregon Department of Fish and Wildlife (ODFW) for sage-grouse surveys and research. The research portion of this funding was dedicated to the development of a problem analysis to identify knowledge gaps and research needs for sage-grouse in Oregon. Presumably, identifying such gaps and needs will accelerate the delivery of knowledge critical to restoration of habitats and populations. The primary goal of the problem analysis was to "determine the amount of information known and needed on sage-grouse and sagebrush obligate species found across the western United States."

For the problem analysis, we compiled and summarized the published, scientific literature for sage-grouse across the range of the species and additional, unpublished scientific reports on sage-grouse in Oregon. We reviewed the literature to assess the extent to which various life history characteristics, population attributes, land use issues, and management topics have been addressed in research. We then compared this information with the knowledge needed to address issues of population viability for the species (see Appendix 1 regarding concepts and definitions of viability and related topics), and with that needed to assess cause-effect relationships between land uses and population status. We used results from this comparison to identify and prioritize research needs that, if addressed, would presumably generate the best information to effectively improve habitat and population status of the species.

Results from the literature analysis revealed that:

- Most studies of sage-grouse have been relatively short, with a median length of 2 years.
- Few studies have involved manipulative research, from which cause-effect relations could be determined.
- Information about effects of invasive vegetation on sage-grouse habitats was scarce.
- Studies during the lekking and brood-rearing season were far more common than winter studies.
- Other notable knowledge gaps are dispersal, genetics, habitat restoration, effects of livestock grazing, and population viability.

Key research needs identified from our review included the following:

1. ***Identification of the spatial structure of populations.***
2. ***Estimation of population size and population growth rate.***
3. ***Analysis of cause-effect relationships between pervasive land uses and population responses of sage-grouse.***
4. ***Assessing the extent to which quantity and quality of seasonal habitats, such as brood-rearing habitat versus winter habitat, may limit population growth.***
5. ***Developing landscape methods for restoring degraded sagebrush habitats, including quantifying, mapping, and prioritizing large areas in need of habitat restoration.***
6. ***Understanding the role of hunting as an additive versus a compensatory factor on juvenile and adult mortality, and the subsequent effects on population growth rate.***
7. ***Assessing the effects of predation on changes in vital rates and population growth rate.***
8. ***Assessing the efficacy of using sage-grouse as an umbrella species for other sagebrush-associated vertebrates.***

Introduction

Defining the problem

As a species closely allied with the vast sagebrush (*Artemisia* spp.) ecosystem in the western United States, the sage-grouse has long symbolized the fauna of arid rangelands. (In this paper, sage-grouse refers to both greater sage-grouse [*Centrocercus urophasianus*] and Gunnison sage-grouse [*C. minimus*].) Despite its popularity as a spectacular bird to observe on its breeding grounds and its longstanding importance as an upland game bird, the sage-grouse is currently considered a species of concern across most of its range.

Sage-grouse populations have declined throughout western North America. Population size was estimated at >142,000 in 1998 (Braun 1998), and states with long-term data on population trends show an average decline of 33% since 1985 (Connelly and Braun 1997). A myriad of factors have been identified as potentially causing these declines, including conversion of sagebrush for agriculture, brush control on rangelands to create livestock forage, predation, excessive livestock grazing, wildfire and prescribed fire, changes in climate patterns, and development of power lines, fences, and roads (Willis et al. 1993, Connelly and Braun 1997, Schroeder et al. 1999, BLM et al. 2000, Connelly et al. 2000*c*). No single factor, however, has emerged as the primary cause for the observed population declines, and definitive research is lacking to identify the most relevant factors.

In Oregon, concern over sage-grouse dates back nearly a century (Quimby 1903), when populations were reported to be at all-time lows. Populations have fluctuated in the state during the last century (Batterson and Morse 1948, summarized by Willis et al. 1993) with the greatest losses noted during the 1920s and 1930s (Crawford and Lutz 1985, Marshall et al. 1996). Crawford and Lutz (1985) reported a 50% decline in the range of sage-grouse in Oregon since 1940. Sage-grouse productivity (chicks/hen and chicks/adult) and abundance (grouse/10 miles) in Oregon, as indexed from summer surveys, apparently also declined since the 1950s (Crawford and Lutz 1985, Willis et al. 1993). Counts of adults in Oregon (indexed by males/lek), however, showed no significant trend during the years for which such data were available (early 1940s until 1992; Willis et al. 1993). On a statewide basis, the species was considered to be "relatively abundant" in 1992, with 28,000 to 66,000 adults (Willis et al. 1993). A lack of systematic surveys of leks and broods, other than in core areas such as Harney County, has hampered efforts to obtain reliable, long-term population and productivity trends for sage-grouse in Oregon. New protocols, however, have been developed by ODFW to guide future survey efforts and data analysis (ODFW 2002).

Among the reasons proposed for declines of sage-grouse in Oregon are predation, habitat loss from conversion to agriculture and urban areas, shrub control for livestock forage, extensive wildfires, and habitat degradation from such causes as livestock grazing or the invasion of exotic plant species such as cheatgrass (*Bromus tectorum*) and medusahead (*Taeniatherum caput-medusae*) (Batterson and Morse 1948, Call and Maser 1985, Willis et al. 1993, Marshall et al. 1996, Miller and Eddleman 2000). In response to the fluctuating populations of the last century, hunting seasons for sage-grouse have been irregular in Oregon, with years during which no hunts were allowed (e.g., 1932-1948, 1976-1981, 1985-1988). The current season, with tags issued by permit only, is limited to 5 days, with a daily bag and season limit of 2 birds per hunter. This season has been in place since 1995 (Braun 2002), and 1,265 permits were available in 2001. Harvest rates of sage-grouse in Oregon are among the most conservative of all states in which the bird is hunted; harvest is targeted at 5% of the total population (ODFW 2002). Data from the hunt provide critical information needed for species assessment and management.

Concurrent with declines in grouse populations are declines in habitat quality and quantity. Habitat loss in the sagebrush ecosystem has been dramatic (Schneegas 1967, Knick 1999, Miller and Eddleman 2000). Schneegas (1967) estimated >2 million hectares of sagebrush range were treated using a variety of methods (e.g., through burning, spraying, or chaining) from the 1930s to the 1960s. Within the interior Columbia Basin, habitats for sage-grouse have declined approximately 30% since historical times (circa 1850-1890) (Wisdom et al. 2000*b*). These declines, however, have been less severe in Oregon than in other areas of the Columbia Basin (see ""ICBEMP sage-grouse assessments" later in this report). Of all vegetation cover types in the Basin, big sagebrush (*A. tridentata*) has suffered from the greatest losses (Hann et al. 1997). In southeastern Oregon alone, about 9,000 km^2 of sagebrush on Bureau of Land Management (BLM) lands was converted, primarily to crested wheatgrass (*Agropyron cristatum*) plantings, as of 1991 (Willis et al. 1993). Declines in sage-grouse habitat are projected to continue in the future, due primarily to habitat degradation from such causes as the continued invasion of exotic vegetation (e.g., cheatgrass), which has resulted in altered fire regimes (Hemstrom et al. 2002).

Both population and habitat losses have prompted groups such as the Institute for Wildlife Protection to seek state and federal protection for sage-grouse. In December 2000 the U.S. Fish and Wildlife Service (USFWS) designated the recently recognized Gunnison sage-grouse as a candidate species under the Endangered Species Act (ESA) (U.S. Government 2000). (Candidate species are those for whom listing as threatened or endangered is warranted but precluded due to other listing actions of higher priority.) The Washington population of western sage-grouse (*C. urophasianus phaios*) also was petitioned for listing under the ESA and was designated as a candidate by the USFWS in May 2001 (U.S. Government 2001*a*). A petition to list the Mono Lake population in California was submitted in December 2001 to the USFWS (Webb 2001). Three petitions filed in 2002 requested listing for not only the western (*C. u. phaios*) and eastern (*C. u. urophasianus*) subspecies, but also greater sage-grouse across its range (P. Deibert, USFWS, personal communication).

In Oregon, the western greater sage-grouse is considered a "sensitive-vulnerable" species by ODFW, meaning that it is not in imminent danger of being listed as threatened or endangered, and that through protection and monitoring, such listing can be avoided (Oregon Natural Heritage Program 2001). The U.S. Forest Service and BLM also list sage-grouse as "sensitive" in Oregon. The western subspecies is considered a "species of concern" by the USFWS, and is on "List 1" of the Oregon Natural Heritage Program, meaning that it is considered threatened with extinction (Oregon Natural Heritage Program 2001). These petitions and findings, coupled with range-wide threats to habitat and populations of sage-grouse, have accelerated the formation of a plethora of interagency sage-grouse committees and the development of statewide conservation plans for the species. A Sage-grouse/Sagebrush-steppe Conservation Assessment and Plan is currently being developed under the auspices of ODFW and the Oregon/Washington State Office of the BLM (BLM et al. 2000).

As the agency responsible for population management, ODFW has a key role in maintaining and enhancing populations of sage-grouse in the state. Likewise, most of the habitat occupied by sage-grouse in Oregon and nationwide is on public lands managed by the BLM (Hanf et al. 1994). Thus, management and research by these 2 agencies in such forms as hunting season adjustments, habitat management and restoration, and inventory and monitoring of habitat and populations will largely determine the fate of the species in the state.

Development of the research problem analysis

In November 2000 the Emergency Board of the Oregon State Legislature allocated $270,000 to ODFW for sage-grouse population surveys and research. Of that total, $250,000 was designated for survey work for the 2001 breeding season (Rickerson 2001). The remainder of the money was allocated for research. Representatives from ODFW, BLM, and Oregon State University (Departments of Rangeland Sciences and Fisheries and Wildlife) met and decided to fund the development of a research problem analysis, as reported here. This analysis was intended to summarize current knowledge about sage-grouse in Oregon and across its range, identify knowledge gaps, and provide direction for future research and management of the species in Oregon. Results from the surveys and problem analysis also were intended to help forestall listing of sage-grouse under the ESA; listing the species could have unprecedented effects on land management activities in sage-grouse habitat, including livestock grazing, mining, and recreation.

The problem analysis summarizes current literature about sage-grouse and their habitats, as well as information on other sagebrush obligate species. (Paige and Ritter [1999] define sagebrush obligates are those species that are "restricted to sagebrush habitats during the breeding season or year-round.") As part of the work, copies of all literature obtained for review have been delivered to ODFW with completion of our. The overall goal of the problem analysis was to "determine the amount of information known and needed on sage-grouse and sagebrush obligate species found across the western United States. This information will give managers a template to prioritize future management actions, research, and habitat restoration needs." Objectives of the problem analysis were four-fold:

1) identify major knowledge gaps in the life history needs of sage-grouse, including habitat conditions, animal/habitat relationships, management influences on habitat quality and quantity, and habitat restoration needs and limitations;
2) identify major sage-grouse/sagebrush-steppe limiting issues, such as grazing, fire, and invasive vegetation;
3) identify research needs and limitations; and
4) identify wildlife species other than sage-grouse that would benefit from, or result in increased knowledge from, this problem analysis.

How "knowledge gaps" are defined influences the analysis and discussion to follow. Knowledge is more than simply information; however, we have no standardized criteria by which to judge the relative merit of information as reported in the literature. In our literature analysis, we used proxies for quality by noting whether information had been published in journals versus in less rigorously reviewed outlets. Publication of a study in a journal, however, does not guarantee that a thorough, scientific investigation has been conducted. Nor does it assure that the results were correctly interpreted, or that any conclusions reached are applicable beyond the individual study areas and the particular years of the study. Carefully replicated studies under a variety of conditions are needed to ensure that we can be confident of the knowledge.

This problem analysis is intended to guide development of future research on population and habitat management for sage-grouse in the state. Information gathered through the problem analysis also will aid in designing future research on habitat restoration in the sagebrush biome for sage-grouse and other sagebrush obligate species. Last, the problem analysis is intended to serve as a guide in completing the Sage-grouse/Sagebrush-steppe Conservation Assessment and Plan in Oregon.

Methods

Literature search

The primary purpose of our literature search was to establish a bibliography of the published, scientific literature for analysis of current knowledge about sage-grouse. References pertaining to sage-grouse were obtained from a variety of sources and entered into an electronic database (ProCite 5.0 software). The foundation for the database was created by searching several major bibliographic databases (Cambridge Scientific Abstracts, FirstSearch, and Wildlife Worldwide) in July 2001 for all citations with the terms "sage-grouse" or "*Centrocercus urophasianus*" in the title or as key words. Following the completion of this initial search, we compared the resulting database with the references section of recent, key publications on sage-grouse (e.g., Willis et al. 1993, Schroeder et al. 1999, Connelly et al. 2000*c*) and added citations as appropriate. The following types of citations were entered in the ProCite database: journal articles; articles in published proceedings of meetings, symposia, or workshops; theses or dissertations; articles in a numbered series published by a government agency or university; and books or chapters in books.

Some additional types of material (e.g., federal aid job completion reports, abstracts, and articles in popular magazines) were entered, especially if they pertained to Oregon. Thus, for these categories ("gray" literature and articles in popular magazines), the database is incomplete and contains more articles pertaining to sage-grouse in Oregon than in other states. We did not intend to capture the complete body of unpublished literature on sage-grouse; instead, we wanted to collect a representative sample of that literature to evaluate whether current knowledge based on published literature would change with the inclusion of unpublished reports. Consequently, we evaluated the unpublished literature by attempting to collect and review all such reports available from past research conducted on the species in Oregon.

Several bibliographies on sage-grouse have been compiled or published, including those by Ryder (1964), Gill (1966*a*), Boyce and Tate (1979), Hall (1998), and Salvo (2001). We used these to check for obvious omissions from our database, but did not include most popular articles or gray literature found in these bibliographies, nor did we include articles that focused on other grouse species. In addition to searching for literature on sage-grouse, we also conducted a limited search of literature on a subset of terrestrial species associated with sagebrush habitats in Oregon. Whether management for sage-grouse will effectively address the needs of these other species has been questioned, but historical habitats for sage-grouse closely overlap those of several common, sagebrush-associated species (Wisdom et al. 2000*b*, Rich and Altman 2001).

Literature analysis

To conduct a formal, quantitative analysis of the published, scientific literature, we randomly selected a sample of 100 articles from the complete ProCite database. We excluded articles from the following categories: any literature published before 1935; articles published only as abstracts; unpublished agency reports, including those from Oregon; and articles from popular magazines. For the types of publications that were included--journal articles, books or book chapters, theses and dissertations, government agency publications, and articles in proceedings--we assumed that our random sample reflected the database as a whole. We did not formally analyze all published literature due to time constraints; our sample of 100 articles represented about 18% of the published, scientific references in our database. We did, however, review all the published literature for which we were able to obtain copies, in order to write other sections of our report (e.g., "Primary factors affecting sage-grouse").

We reviewed the 100 selected articles and characterized them in a database (Paradox 8.0 software), recording such details as publication outlet (e.g., whether a book or journal article), type of work (e.g., correlative study versus natural history description), location, and 1 or more of >70 key words (list of criteria and database fields--Appendix 2). We assigned key words, such as fire or predation, to those articles in which that topic was a focus of the research reported upon, not to all articles that broached the topic in a general way, e.g., in the discussion or introduction. For review or synthesis articles (i.e., those not reporting on original data in an empirical study), we decided whether the topic was covered in sufficient detail to warrant its inclusion as a key word.

We evaluated study quality by noting whether an article reported results of a 1) manipulative experiment; 2) field study with collection of quantitative data; or 3) descriptive, natural history study. For review or synthesis articles, we did not record study quality. We also assigned each article to the appropriate vegetation cover type(s) mentioned in the study area description (e.g., Wyoming big sagebrush, *A. t. wyomingensis*; Table 1) and distinguished between articles in which the type was simply mentioned as occurring in the study area versus articles in which results were reported for the type (e.g., percent of brood locations in Wyoming big sagebrush).

Season of use and life stage were described using the following terms: lekking, nesting, brood rearing, spring, summer, fall, winter, and year-round (Appendix 2). “Summer” was defined as after the lekking season, but before brood breakup, and refers in our summaries only to males or non-nesting or unsuccessful nesting females observed during this period.

Traditional land management practices that may affect sage-grouse populations or habitats were noted. These activities, as summarized here, were conducted irrespective of their effects on sage-grouse; however, they may directly or indirectly affect sage-grouse habitats or populations. They include livestock grazing, crop management, road and power line construction, mineral and oil development, recreation, seeding for livestock forage, fertilization, urbanization, water development, and shrub removal (Appendix 2).

Last, we characterized the literature by recording whether articles mentioned any 1 of 4 quantitative characteristics related to population management and assessment: growth rate (the term “growth rate” is used in the classic sense of population ecology, and can be negative, stationary, or positive), mortality/survival rate, reproduction (e.g., nesting success), and population trends, most commonly assessed via lek counts (Appendix 2). Other key words used in the database included such terms as predation, weather, and genetics. After reviewing the 100 articles, we computed simple summary statistics, such as percentages by type of publication (journal article versus thesis or dissertation). We also calculated summary statistics for the literature specifically pertaining to Oregon. Results in the knowledge gap sections of our report pertain to the 100 randomly selected articles and not to the complete database, nor to the Oregon literature alone.

Results and Discussion

Literature Search

The final database for sage-grouse contained 742 citations, with 89 of these specifically referencing sage-grouse or sage-grouse habitats in Oregon. (The database is posted on the SAGEMAP website at http://sagemap.wr.usgs.gov/sage_grouse_documents.htm). Most citations were from studies conducted in Colorado (19%). Other states with a relatively large proportion of citations were Montana, Idaho, and Wyoming. With regard to publication outlet, 297 (40%) of the citations were published in journals, whereas 82 (11%) were published as theses or dissertations. Seventy-three (10%) articles were found in proceedings, and only 11 (<2%) were books or chapters in books. Most publications were relatively recent, with 515 entries (70%) dated 1970 or later; moreover, 249 (34%) were published since 1990, demonstrating the increased research emphasis on sage-grouse in recent years. Review of the compiled literature formed the basis for the following summary of factors affecting sage-grouse.

Primary factors affecting sage-grouse

A plethora of factors has been suggested as affecting sage-grouse populations and habitats throughout the species' range. The composition of the list has evolved over time, reflecting the decreased importance of some issues, such as large-scale conversion of sagebrush to cultivated croplands, and the emergence of others, such as energy development or altered fire regimes in relation to invasions of exotic plants. Summaries of current issues are found in several sources, including the Gunnison sage-grouse conservation plan (Anonymous 1997), Braun's review of sage-grouse declines (1998), the Birds of North America account (Schroeder et al. 1999), and the revised sage-grouse guidelines (Connelly et al. 2000*c*; see Table 2). Paramount among the issues in these syntheses are habitat loss and degradation, which Schroeder et al. (1999:16) designate as the "primary explanations for the rangewide reduction in distribution and populations of sage-grouse." Factors identified as affecting sage-grouse in Oregon (Willis et al. 1993, BLM et al. 2000) are similar to those reported in the citations above, with the addition of juniper (*Juniperus* sp.) displacement of sage-grouse habitat and negative effects from grazing by wild horses (Table 2).

Habitat loss. Outright loss of habitat through conversion to agriculture or other uses, such as urban development, is often cited as the primary cause of habitat and population problems affecting sage-grouse (Willis et al. 1993, Schroeder et al. 1999). By 1974, about 10-12% of the 40 million ha of sagebrush rangelands in North America had been treated to provide more forage for livestock (Vale 1974). Overall, >80% of sagebrush rangelands have been altered in some way by human activities (West 1999). In Washington, it was estimated that >60% of the native sagebrush steppe had been converted for human use by 1994 (Dobler 1994). Nearly 170,000 ha of BLM-managed rangelands in Oregon were treated with brush control in 1 decade, from 1960 to 1970 (BLM et al. 2000). Sagebrush control efforts diminished in the 1970s, both in Oregon and across the range of sage-grouse, primarily due to reduced federal funding combined with increasing concerns over the environment (Donoho and Roberson 1985). Although habitat conversion has not been as pervasive in southeastern Oregon as it has in the northern portions of the state or in Washington (Willis et al. 1993), such losses comprise about 12% of the present range of sage-grouse in the state (Willis et al. 1993). For a species so intimately allied with an ecosystem, such losses are unavoidably detrimental.

Whereas vast areas of former sagebrush have been converted to non-native grasses such as crested wheatgrass, some lands have also been planted in agricultural crops such as alfalfa, potatoes, or wheat. Although sage-grouse will use alfalfa fields and other agricultural lands when such lands are adjacent to large patches of native sagebrush, especially during brood rearing (Wallestad 1971, Gates 1981, Connelly et al. 1988), the application of chemicals to agricultural lands poses a hazard to sage-grouse populations (Blus et al. 1989).

Habitat loss - herbicides. Herbicides such as 2,4-D were the most common method of converting large expanses of sagebrush until the 1980s (Connelly et al. 2000*c*). These lands were often subsequently planted in crested wheatgrass or other non-native perennial grasses as livestock forage. Application of herbicides affects all seasonal ranges of sage-grouse (Connelly et al. 2000*c*) and has been widely studied compared to other land management practices (e.g., Gill 1965, Martin 1965, Carr 1967, Pyrah 1970, Braun and Beck 1976). Although most of these studies report negative effects of herbicide application within sage-grouse habitats, others report positive effects, such as increased production of forbs used by sage-grouse (e.g., Autenrieth 1969).

Habitat loss - mechanical methods. Mechanical removal of shrubs, while as effective as herbicides or fire in eliminating sagebrush, tends to be applied to smaller patches of habitat (Connelly et al. 2000*c*). Swenson et al. (1987) found that the plowing of 16% of their study area in Montana to remove sagebrush led to large declines in lek counts, while nearby control areas suffered no comparable losses. The authors concluded that plowing was a more serious threat to sage-grouse than was herbicide application, primarily because plowed lands tend to be planted in crops, whereas recovery of sagebrush in sprayed habitats is possible.

Habitat loss - fire. Prescribed fire also has been used to remove rangeland shrubs such as sagebrush, especially since the use of herbicides declined (Beardell and Sylvester 1976, Britton et al. 1981, Connelly et al. 2000*c*). Although some studies have demonstrated neutral or even positive effects on sage-grouse habitats from fire (e.g., Martin 1990, Fischer 1994, Pyle and Crawford 1996, Crawford and Davis 2002), others have documented population declines and long-term habitat degradation (Connelly et al. 2000*b*, Nelle et al. 2000). While some short-term benefits may accrue from prescribed burning, such as increased productivity of desirable grasses and forbs, nesting cover may be reduced and thus less suitable for at least the first year post-burn (Wrobleski 1999). Insect abundance has also been found to decline following prescribed burning in sage-grouse habitat in Idaho (Fischer 1994). At Sheldon National Wildlife Refuge in Nevada, however, arthropod abundance did not decline following wildfire (Crawford and Davis 2002).

Various sagebrush communities respond differently to fire, and these differences must be carefully considered when restoring burned habitats or when using fire to enhance habitat for sage-grouse or other shrubsteppe wildlife (Fischer et al. 1996, Pyle and Crawford 1996, Connelly et al. 2000*b*). Although fire has been a natural disturbance in all sagebrush ecosystems, fire return intervals vary among subspecies of sagebrush (Miller et al. 1998). Intervals for basin big sagebrush (*A. t. tridentata*) communities are intermediate between those for mountain big sagebrush (*A. t. vaseyana*; 5-15 years) and Wyoming big sagebrush (10-70 years) (Sapsis 1990). The spread of cheatgrass into the more arid Wyoming big sagebrush communities and the resultant altered fire regimes in these sites have had major impacts. Not only are fire intervals shorter, with returns of 5-10 years not uncommon, but also complete removal of Wyoming big sagebrush has occurred, with replacement by annual grasslands (USDA Forest Service 2002).

Regardless of method used to control sagebrush, whether mechanical, through fire, or herbicides, removal of sagebrush is nearly always detrimental to sagebrush obligates such as sage-grouse. In areas, however, where sagebrush cover is exceptionally high (e.g., >35%), judicious removal through appropriate means may be necessary for habitat restoration (Connelly et al. 2000*c*).

Habitat degradation - grazing. Livestock grazing is frequently cited as a factor in the decline in habitat quality across the range of sage-grouse (Dobkin 1995, Braun 1998, Beck and Mitchell 2000, Connelly et al. 2000*c*, Miller and Eddelman 2000). Grazing by livestock has occurred on virtually the entire range of sage-grouse (Braun 1998), thus its influence is potentially the most pervasive of any land management practice. However, in our sample of 100 articles, only 2 empirical studies reported effects of grazing on sage-grouse (Klebenow 1982, Rasmussen and Griner 1938), and experimental research on effects of livestock on sage-grouse is lacking (noted by Braun 1987, Beck and Mitchell 2000, and Connelly et al. 2000*c*). Most studies imply negative effects of livestock grazing, for example, by noting that management practices must be conducted such that adequate herbaceous and shrub cover for nesting or brood rearing are maintained (e.g., Gregg et al. 1994, DeLong et al. 1995, Sveum et al. 1998). Effects of livestock on species composition and structure in the sagebrush community, however, have been well documented (e.g., Owens and Norton 1992, West 1999, Anderson and Inouye 2001).

Beck and Mitchell (2000) recently provided a thorough summary of potential effects of livestock grazing on sage-grouse habitats, distinguishing between indirect effects, such as shrub removal to enhance grasses for livestock forage, and direct effects, such as reductions in native understory productivity and altered species composition. In a table summarizing these effects, they cite only 4 references from their extensive literature review that provide empirical evidence of direct negative effects of livestock grazing on sage-grouse (Rasmussen and Griner 1938; Oakleaf 1971; Klebenow 1982, 1985). These effects ranged from trampling of nests to overgrazing leading to habitat degradation. Understanding the scale at which effects are studied and the long-term grazing history of a site, as well as stocking rates and season of use, is imperative to evaluate effects of grazing on sage-grouse or sagebrush habitats (Beck and Mitchell 2000). Furthermore, interactions of livestock grazing with other factors, such as predation or wildfire and the potential for invasion by cheatgrass, are complex and not widely studied.

Guthrey (1996) noted a lack of reliable knowledge on grazing effects for most upland game birds, not just sage-grouse. He referred to sage-grouse as a species for which grazing effects were “contextual,” meaning that they could be negative, neutral, or positive, depending on the habitat context in which they occurred. To our knowledge, none of the empirical studies on effects of livestock grazing on sage-grouse involved a manipulative experiment in which cause-effect relationships could be determined. Such studies, involving an array of grazing treatments and controls, are needed for future land use planning across much of the range of sage-grouse. One example of this research is underway in Wyoming (S. H. Anderson, Wyoming Cooperative Fish and Wildlife Unit, personal communication).

Sheep grazing in Idaho did not appear to disrupt use of leks by sage-grouse (Hulet 1983), but Autenrieth (1981) cautioned against having sheep grazing overlap with sage-grouse winter habitat. He also warned that livestock use of meadows occupied by sage-grouse and livestock drives in sage-grouse habitat could be detrimental to grouse.

Research in Nevada in upland meadows showed that pastures under a rest-rotation system provided better production of forbs eaten by sage-grouse than did pastures that were not rested (Neel 1980). Sage-grouse, however, also used a pasture not grazed by cattle for 10 years; the author concluded that light grazing in meadows might enhance habitat suitability for sage-grouse (Neel 1980). At the Sheldon National Wildlife Refuge in Nevada, sage-grouse used meadows grazed by cattle more than they used ungrazed meadows (Klebenow 1982, Evans 1986); this preference was apparently caused by the re-growth of forbs in the grazed areas and the longer period of succulence in these pastures. Anderson et al. (1990), in citing Evans (1986) work, noted that while livestock grazing seemed to promote better conditions for sage-grouse in mid-summer by increasing production of forbs, intensity of grazing must be carefully considered. He predicted that moderate use by livestock produces patchy mosaics of habitat in meadows that not only produce better foraging conditions, but better cover from predators as well. Research is needed to corroborate such hypotheses.

Habitat degradation - fire. Altered fire regimes across western landscapes have resulted in dramatic losses of sagebrush steppe, often coupled with the invasion of cheatgrass and other exotic vegetation (West 1999, Hemstrom et al. 2002). This problem is most severe in lower elevation, Wyoming big sagebrush (Miller and Eddleman 2000, Hemstrom et al. 2002) in the western portion of the range of sage-grouse, and is uncommon in areas such as Montana and Wyoming. Without expensive, large-scale, active restoration to alter this cycle, re-establishment of productive shrub-steppe habitats is highly unlikely (Hemstrom et al. 2002; Monsen et al., In press). It is estimated that >50% of the sagebrush ecosystem in western North America has been invaded to some extent by cheatgrass (West 1999), with losses on federal lands projected to accelerate in the future (Hemstrom et al. 2002). These continued losses of sage-grouse habitat on federal lands from wildfire and cheatgrass invasion are projected to substantially increase the likelihood of extirpation for sage-grouse populations in Oregon, Washington, and Idaho unless federal management addresses this issue more aggressively with a variety of preventive and restoration practices (Wisdom et al. 2002*a*).

Habitat degradation - herbicides and pesticides. Spraying of herbicides primarily degrades habitat for sage-grouse by increasing fragmentation. In Colorado, spraying of herbicides resulted not only in decreases in sagebrush cover and frequency of sagebrush plants and forbs, but also in lek abandonment (Braun and Beck 1977). In addition, the application of pesticides, often for grasshopper control, affects sage-grouse by killing insects otherwise used as food (Johnson 1987). Pesticides also directly poison birds after intake of contaminated insects; mortality rates directly attributable to pesticide application were 15% for sage-grouse feeding in sprayed alfalfa fields in Idaho (Blus et al. 1989, Connelly and Blus 1991).

Habitat degradation - juniper encroachment. Although loss of sagebrush habitat to juniper encroachment is not commonly addressed with regard to sage-grouse (but see Hanf et al. 1994, Commons et al. 1999, and Miller and Eddleman 2000), this issue is pertinent in some parts of the species' range, especially California and Oregon (BLM et al. 2000, Miller and Eddleman 2000). Shrub-steppe habitats have been altered through fire suppression such that rates of juniper invasion in sagebrush have increased dramatically (Miller and Rose 1995, Leavengood and Swan 1998). A recent inventory in eastern Oregon revealed that juniper forest has increased five-fold since 1936 (Gedney et al. 1999). Following removal of juniper around a lek complex in Colorado, counts of males on leks had doubled by the second year after treatment (Commons et al. 1999). Treatments to control juniper must be undertaken cautiously to ensure that adequate habitat is maintained for juniper-associated species such as the ash-throated flycatcher (*Myiarchus cinerascens*) and loggerhead shrike (*Lanius ludovicianus*) (Wisdom et al. 2000*b*) and several cavity-nesting species (Reinkensmeyer 2001). Changes in juniper communities are complex and likely related to fire suppression, livestock grazing, and recent climatic changes (Miller and Rose 1999).

Habitat fragmentation. Large-scale conversion of the sagebrush ecosystem to other land uses has led to gaps in suitable habitat for sage-grouse and other sagebrush-associated birds (Braun and Beck 1976). This loss has been particularly noticeable in Washington, where conversion of shrub steppe to agriculture has resulted in highly fragmented landscapes (Vander Haegen et al. 2000). Habitat fragmentation leads to population fragmentation, which can change a large, contiguous population to a metapopulation or a set of isolated sub-populations (Burgman et al. 1993). For species that have not evolved as a metapopulation, or as a set of isolated populations, this change in population structure can substantially increase the probability of extinction (Doak and Mills 1994). This process of population fragmentation has occurred in Washington, where the remaining sage-grouse exist as 2 isolated populations (Hays et al. 1998, Schroeder et al. 2000), resulting in a decision by the USFWS that listing of under the ESA was warranted (U.S. Government 2001*a*).

Because sage-grouse evolved and existed as an extremely large population, distributed over an expansive area of the sagebrush ecosystem in western North America, the species may not adapt well as a metapopulation or as isolated populations. Moreover, highly mobile species such as sage-grouse may have populations that can remain connected over large areas, even while habitat becomes increasingly fragmented. However, the increasingly large area over which birds must migrate, disperse, and move daily, particularly when such movements occur over expansive areas of non-habitat, can substantially increase mortality from predation, collisions with vehicles and other obstacles, and energy costs. Consequently, holistic management of expansive landscapes, composed of both summer and winter habitats in a manner that minimizes habitat fragmentation, is likely to be critical for maintenance of a healthy, well-connected population of sage-grouse in Oregon (Crawford et al. 1992).

Predation. Predation is the most commonly identified cause of mortality for sage-grouse (Schroeder et al. 1999, Connelly et al. 2000*a*) and directly affects nest success and survival of both juveniles and adults (Schroeder and Baydack 2001). Common nest predators include ground squirrels, ravens (*Corvus corax*), badgers (*Taxidea taxus*), and coyotes (*Canis latrans*). Coyotes and a suite of avian predators, especially golden eagles (*Aquila chrysaetos*), prey on adult birds.

Proper management of habitat is important in reducing predation rates on sage-grouse by providing adequate hiding cover; however, these relationships are not well studied (Schroeder and Baydack 2001). Lower rates of predation on nests in areas with taller grass cover and medium-height shrub cover indicate the importance of maintaining appropriate grass and shrub cover in nesting habitats (Gregg et al. 1994, DeLong et al. 1995). In Wyoming, Niemuth and Boyce (1995) found higher nest predation rates in areas of high density of artificial sage-grouse nests, supporting a mechanism for density-dependent population regulation through predation. However, overall predation rates were similar between high and low nest densities.

Despite correlative studies associating lower productivity in sage-grouse during times of increased abundance of predators (e.g., Willis et al. 1993), few studies exist in which manipulation of predators was attempted and the subsequent impacts on grouse populations were measured. One exception is the study by Batterson and Morse (1948), in which an area where ravens were removed showed higher nesting success compared to a control area. In a review of effects of predator control on bird populations, Cote and Sutherland (1997) found that, although predator removal often increased hatching success, increases in breeding population sizes were not significant.

Schroeder and Baydack (2001) noted that most "predator management" for sage-grouse involves manipulating habitats rather than directly reducing predators. They concede, however, that in some situations, such as isolated, small populations in fragmented habitats, predator control may be an important management option. In general, however, predator control is not a socially acceptable or biologically justified means to increase sage-grouse populations (Autenrieth 1981, Willis et al. 1993).

Interactions of predators with other factors that affect sage-grouse populations, such as weather and vegetation structure, are complex (Braun 1998). Past efforts to control or reduce predator populations were widespread and intensive across the western United States (e.g., the introduction of 1080 for coyote control) and may have resulted in sage-grouse populations that were higher in local areas than historical levels, at least in the short-term.

Disease. Sage-grouse are host to a variety of diseases and parasites (Schroeder et al. (1999). Despite the large number of infectious agents, diseases or parasites have rarely been noted as a cause for population declines, either temporary or long-term. Lack of systematically collected data, however, is a problem, as well as the need for large numbers of birds to be affected before detection occurs (Autenrieth 1981). Coccidiosis, caused by infections of a protozoan parasite (*Eimeria* spp.), is likely the most prevalent disease in sage-grouse (Autenrieth 1981, Schroeder et al. 1999). Little information has been collected on the presence of parasites or diseases in sage-grouse in Oregon. Tapeworm infestations have been reported in sage-grouse in the state (Batterson and Morse 1948, Nelson 1955); such infestations, however, have not been associated with changes in abundance of grouse.

Weather/Climate. Weather patterns frequently have been linked to sage-grouse abundance and nest success, primarily through the influence of moisture and temperature on abundance and phenology of herbaceous plants used as forage and cover (e.g., Gill 1966*b*, as reported in Schroeder et al. 1999; Hanf et al. 1994). Studies in a Wyoming big sagebrush community in central Oregon showed wide fluctuations in both forb and total herbaceous production, as well as plant species numbers, in response to variation in annual precipitation (Miller and Eddleman 2000). Willis et al. (1993) found no relationship between long-term trends in sage-grouse productivity and precipitation. Weather, however, may influence timing of seasonal movements in sage-grouse (Klebenow 1985, Fischer et al. 1996), as well as diets (Drut et al. 1994*b*). Call and Maser (1985) reported that sage-grouse densities in Oregon were greatest in areas of 25-40 cm of annual precipitation. Further analyses of relationships between long-term trends in sage-grouse productivity and weather should be conducted to better understand these interactions (Connelly and Braun 1997).

A more complex issue is the combined effect of climate and changes in fire regimes, the increasing extent of nonnative vegetation, and other disturbances since the mid-1800s (Miller and Eddleman 2000; Tausch, In press). Such changes could exert widespread influences on vegetation production, structure, and composition including both the herbaceous understory and sagebrush overstory (Miller and Eddleman 2000). Climate in the arid sagebrush-steppe ecosystem is highly variable, with long periods of drought (Miller and Eddleman 2000).

Hunter harvest. The question of whether mortality from hunting is additive or compensatory is an issue not yet fully resolved or understood for sage-grouse or other gallinaceous birds (Bergerud 1988*a*; Schroeder et al. 1999; Connelly et al. 2000*a*, *c*). Bergerud (1985) outlined 4 compelling arguments for the additive effects of hunting on natural mortality in various grouse populations. Although sage-grouse were not among the species he examined, other prairie grouse species were included (e.g., sharp-tailed grouse, *Tympanuchus phasianellus*, and greater prairie-chickens, *T. cupido*). In Oregon, Crawford (1982) found no evidence of additive mortality on sage-grouse from hunting, based on 20 years of harvest data. Similar results were found in Colorado (Braun and Beck 1985). In Nevada, fall densities of sage-grouse apparently increased between years in both a non-hunted control and in a hunted area, but the percent increase was 4 times greater in the control area (Zunino 1987). Densities in these areas were low compared to typical densities of sage-grouse across their range, and harvest rates in the hunted area were high (>25%). The author concluded that high rates of harvest on low-density populations could affect fall populations of sage-grouse in Nevada (Zunino 1987).

Sage-grouse are hunted in every state in which they still occur, with the exception of Washington; however, continued hunting of this species has been questioned by some. Opponents argue that hunting sage-grouse should be banned before other, large-scale actions are taken, such as predator control or curtailment of livestock grazing. Schroeder et al. (1999) urged caution in assuming that hunting mortality does not affect sage-grouse populations, given the declining trends of populations in many areas.

Connelly et al. (2000*c*) recommended that hunter harvest not exceed 10% of the estimated fall population, and that hunting seasons be conservative in areas with declining populations. Of the states that allow hunting of sage-grouse, 2 (California and Oregon) regulate the harvest via a permit system. The remainder regulate the harvest through season length and bag limits. Crawford (1982) found that harvest of sage-grouse in Oregon was closely related to number of hunters, and the existing permit system in the state allows close control of these numbers. Another issue related to hunting is that of differential harvest, i.e., the bias of the harvest toward females and younger birds. Evidence of such bias has been found for sage-grouse in many states, including Oregon (Braun 1981, Bergerud 1988*b*, Crawford 1992, Willis et al. 1993, Connelly et al. 2000*a*).

A substantial benefit from hunting is the wings collected from harvested sage-grouse, which provide an invaluable source of information that is otherwise unavailable. These data include age and sex composition, nest success (e.g., percent of both adult and yearling hens nesting), production (chicks/hen, for both successful hens and all hens), hatching chronology, and annual turnover rates. These data can be summarized and compared among years for trends, as well as compared among hunt units when sample sizes are adequate. Despite their apparent utility caution must be taken with population characteristics derived from wing data, which represent only hunted populations. Presumably, such populations are more robust than those closed to hunting; thus, inferences to non-hunted populations should not be made.

*Development of energy sources, fences, roads, and power lines***.** Impacts of coal mine and oil and gas field development on sage-grouse are both short- and long-term (Braun 1998, Braun et al. 2002). Braun (1987) noted that initial stages of development (e.g., site preparation, drilling, and road construction) led to decreased numbers of grouse near these sites. Although populations were sometimes reestablished over time, Braun believed that permanent, negative impacts on sage-grouse populations occur as a result of the construction of refineries, pumping stations, and other facilities associated with mineral development. In a recent study of gas field development and sage-grouse in Wyoming, Lyon (2000) found that, although nest success was similar on "disturbed" sites versus control sites, hens captured on disturbed leks had lower nest initiation rates and traveled twice as far to nest as hens on undisturbed leks. In analyzing data from northeast Wyoming, an area of extensive development of coal-bed methane wells, Braun et al. (2002) found fewer males/lek on leks within 0.4 km of wells versus counts of males on less disturbed sites.

Man-made structures such as fences, roads, and power lines also fragment habitats for sage-grouse (Braun 1998, Connelly et al. 2000*c*, Braun et al. 2002). Direct mortality from collisions of sage-grouse with cattle fencing has also been reported (Call and Maser 1985). Vehicle traffic on roads, along with the increased access roads afford to recreational users of rangelands, may lead to increased disturbance of grouse on leks or during nesting or brood rearing (Braun 1998). In Wyoming, successful hens in a natural gas field nested farther from roads than did unsuccessful hens (Lyon 2000). Road effects, however, have not been widely studied with regard to sage-grouse. Wisdom et al. (2002*b*) found that road density in the interior Columbia Basin was higher in extirpated range of sage-grouse, and lower in occupied range. The pattern of higher road density in extirpated range also coincided with lower abundance of habitat, higher human population density, increased agricultural development, and higher likelihood of exotic plant invasions (Wisdom et al. 2002*b*), suggesting a synergy of effects.

Power lines may not only increase habitat fragmentation, but also provide perches for avian predators of sage-grouse (Ellis 1987; Braun 1998; F. Hall, California Department of Fish and Game, personal communication). Although the magnitude of such effects on sage-grouse habitats and populations is unknown, sage-grouse use has been shown to increase as distance from power lines increases (Braun 1998). Studies in California revealed 3 factors associated with power lines that could decrease grouse numbers or lek use, either singly or in combination: 1) raptors, especially immature golden eagles, hunt more efficiently from perches such as towers and may harass or take adult grouse near or on leks; 2) ravens may use the towers as perches and nest sites and prey on eggs and young of sage-grouse near leks; and 3) sage-grouse respond to towers as potential raptor perch sites and thus may abandon, or decrease their use of, a lek from which towers can be seen (F. Hall, California Department of Fish and Game, personal communication).

Other sagebrush steppe obligate species

In addition to sage-grouse, many plants and animals depend on the sagebrush ecosystem (Braun et al. 1976, Paige and Ritter 1999, Suring et al. In prep.). More than 100 species of birds were identified as associated with sagebrush ecosystems in 1976 (Braun et al. 1976), and 4 were considered obligates: sage-grouse, sage sparrow (*Amphispiza belli*), sage thrasher (*Oreoscoptes montanus*), and Brewer's sparrow (*Spizella breweri*). Other species were included as "near" obligates (e.g., green-tailed towhee [*Pipilo chlorurus*] and vesper sparrow [*Pooecetes gramineus*]) and "locally important" (e.g., sharp-tailed grouse and burrowing owl [*Athene cunicularia*]) (Braun et al. 1976).

Many of these sagebrush-associated species are of conservation concern. Wisdom et al. (2000*b*) identified 26 species of terrestrial vertebrates in Oregon, including sage-grouse, that are associated with sagebrush habitats and are of concern because of declining or rare habitats or populations (Table 3). We suggest this list be used as a framework for addressing research and management needs of a larger set of sagebrush-dependent species, owing to the substantial justification previously used to identify these species as being of conservation concern, combined with the extensive summary of environmental requirements and management issues, strategies, and practices previously outlined for these species by Wisdom et al. (2000*b*).

Agency biologists (U.S. Forest Service and BLM) recently identified >350 species of plants and animals of conservation concern within the historical range of sage-grouse that are allied with sagebrush-steppe ecosystems (Suring et al., In prep.). Most of the species included are plants, and the list of vertebrates closely resembles that of Wisdom et al. (2000*b*). Similar lists have been developed by the Heritage Program and by many state and federal agencies. Yet few processes have been developed and applied to efficiently assess the needs of single species of concern, such as sage-grouse, in concert with the needs of a comprehensive set of species that depend on the sagebrush ecosystem.

The Point Reyes Bird Observatory, in cooperation with the BLM, has established 68 bird census transects in Oregon and Washington to monitor songbirds in shrubsteppe habitats of the Columbia Plateau ecoregion; nearly all of these transects are on BLM lands (Holmes and Geupel 2000). Among the goals of this work are to evaluate effects of degraded understory habitats on bird populations and to examine effects of invasions of annual grasses on use of shrub-steppe habitats by birds.

As is true for sage-grouse, large-scale conversion of sagebrush habitats is the primary issue affecting sagebrush obligates (Braun et al. 1976, Saab and Rich 1997). Shrub-steppe habitats in the interior Columbia Basin were highlighted as a management priority for neotropical migratory birds due to habitat loss, declines in species numbers, and vulnerability to human disturbances in this ecosystem (Saab and Rich 1997). Alteration of shrub-steppe habitats in Washington, primarily from conversion to agriculture, has occurred disproportionately on productive, deep soil sites (Vander Haegen et al. 2000).

In addition to habitat loss, effects of habitat degradation on sagebrush obligate species parallel those for sage-grouse. Livestock grazing has been implicated with negative, as well as positive, impacts on birds in shrub-steppe habitats (Bock et al. 1993). For example, sage sparrows appear to respond positively, whereas grasshopper sparrows (*Ammodramus savannarum*), Brewer's sparrows, burrowing owls, and vesper sparrows appear to respond negatively (Bock et al. 1993). In north-central Oregon, cattle not only trampled nests of burrowing owls, but were also the primary cause of loss of burrows due to trampling, especially in friable soils (Holmes et al., In press). Other issues related to effects of land use practices on shrub-steppe species include herbicides and other contaminants, habitat fragmentation, mining and oil/gas development, invasion of exotic vegetation, and agriculture (Finch and Stangel 1993, Paige and Ritter 1999).

The central Washington population of pygmy rabbits (*Brachylagus idahoensis*), a species whose habitats closely overlap those of sage-grouse (Table 3; Wisdom et al. 2000*b*), was proposed as endangered under an emergency listing by the USFWS in November 2001 (U.S. Government 2001*b*). This "distinct population segment" is estimated to contain <50 individuals, and has suffered from habitat loss, disease, and loss of genetic heterogeneity. Pygmy rabbits are considered a "sensitive" species in Oregon, where their distribution is discontinuous (Csuti et al. 1997). They rely heavily on tall, dense clumps of basin big sagebrush and also require friable soils for their burrows. Like sage-grouse, pygmy rabbits consume mainly sagebrush (Wilde 1978). Loss of habitat to agriculture and conversion to non-native grasslands, as well as overgrazing by livestock, are considered threats to this species in Oregon (Csuti et al. 1997) as well as Washington (U.S. Government 2001*b*).

Knowledge gaps identified in literature analysis

*Type and quality of publication***.** The 100 articles selected for formal analysis comprised the following publication types: journal articles, 52%; theses or dissertations, 18%; government agency or university reports, 13%; articles published in proceedings or transactions from symposia or workshops, 12%; and books or book chapters, 5%. The majority (72%, or 52 of 72) of articles reported results from field studies. Only 12% (n = 9) involved manipulative research, in which cause-effect relationships could be determined, and 15% (n = 11) reported qualitative, descriptive information. Seventy-two percent of the 100 citations were based on empirical studies, whereas 24% were synthesis or review articles, and 4% were bibliographies or literature reviews. Scale, referring to whether the research was directed at a portion of a population, individuals, an entire population, or multiple populations, was addressed in only 12% of the citations. Identification of research needs for sage-grouse was similarly rare and found in only 10 of the 100 articles.

*Location and time scale***.** Of the 82 articles for which a location was recorded or applicable (i.e., those reporting results of empirical data collection or summaries of data from a particular locale), the majority (n = 19, or 23%) were from Colorado, followed by Montana (n = 15, or 18%) and Idaho (n = 12, or 15%). Studies in Oregon composed 11% (n = 9) of the 82 citations. Other states and provinces less well represented in the sample were: Nevada (7%), Wyoming (6%), California (5%), Utah (4%), Saskatchewan (2%), Alberta (1%), New Mexico (1%), and Washington (1%). Study area size was reported in 21 articles; median study area size was 30,000 ha.

Of the 65 articles reporting a study length, mean duration was 3.6 years. However, the mean was strongly influenced by a few studies of exceptional duration (e.g., Braun and Beck 1996, 23 years; Giesen et al. 1982, 18 years); the median value was substantially lower, only 2 years. Only 10% of the citations described studies of ≥5 years duration. The references ranged in date from 1936 through 2001, with a median date of 1982.

*Vegetation cover type***.** In 35 articles (35%), there was no mention of any cover or habitat type. These references generally focused on behavioral experiments, physiology, or anatomy, or were review papers. "Sagebrush" was mentioned in 39 articles; in 17 of these, there was no mention of the species or subspecies of sagebrush involved. Results were reported for the sagebrush cover type in 15 articles (e.g., number of grouse locations in sagebrush versus grasslands; Table 1). Other than "sagebrush," big sagebrush was the most common vegetation type mentioned, followed by "other shrubs" and "understory/forbs" (Table 1). Noticeably absent were citations with results reported for, or even mention of, non-native vegetation; only 2 references mentioned cheatgrass (Bloom and Hawks 1982, Apa 1998), a major factor affecting current quality of sagebrush habitat in much of the species' range (Braun 1987, Schroeder et al. 1999, Connelly et al. 2000*c,* Hemstrom et al. 2002).

Of the vegetation types for which results were explicitly reported, "understory/forbs" and "understory/grasses" were the most common, followed by big sagebrush (Table 1). Despite the widely recognized differences among sagebrush subspecies as food for sage-grouse, as well as the varied responses of these subspecies to fire and other disturbances, few citations presented results for such types as Wyoming big sagebrush (*n* = 7) or mountain big sagebrush (*A. t. vaseyana*) (*n* = 6). All of these were more recent studies (since 1980).

*Season of use and life stage***.** Forty-three percent of the articles described studies that occurred during the lekking period versus 33% during nesting and 27% during brood rearing. Three articles described work conducted during spring, in which there was no distinction between the lekking and nesting periods. Twenty-three articles were associated with summer. Fall studies composed 10% of the citations, and winter studies composed 16%.

We also evaluated whether articles reported specifically on juvenile, yearling, or adult birds. The percentage of citations associated with each of these stages was: juveniles – 36%; yearlings – 30%; and adults – 59%. (These percentages do not add to 100, because many articles mentioned more than 1 stage, and others none at all.) Thirty-eight of the 100 references made no explicit mention of the age class of birds studied. Although some of these studies certainly included adults (e.g., descriptions of breeding behavior on leks), we did not assign an age class unless it was explicitly mentioned in the text.

*Land management practices***.** Among the land management practices we evaluated, herbicide/pesticide use was mentioned most often (15%). Of these, only half (*n* = 8) were based on empirical studies, and only 1 reported results of experimental manipulations (Carr 1967). Other land uses included effects of shrub removal (12%) and fire and livestock grazing (6% each). Other management practices were less frequently mentioned: mineral/oil development and water development, 4%; agriculture, 3%; seeding, 2%; and roads and recreation, 1%. None of the 100 articles sampled addressed effects of fertilization, power lines, or urban development.

*Population characteristics***.** Population growth rates of sage-grouse were mentioned in only 1 citation, a book chapter on population ecology of grouse (Bergerud 1988*b*). In contrast, reproductive rates (e.g., nest success) were addressed in 30% of the citations. Mortality or survival rates were given in 17% of the citations, and population trends or lek counts in 19%. None of the 100 randomly selected articles in our analysis focused on methods of population estimation for sage-grouse.

*Other topics***.** Of the remaining key words, the most common was habitat use/selection (30%; Table 4). Other topics commonly (≥20%) mentioned were diet, behavior, environmental requirements, and movement (Table 4). Noticeable gaps were found for many topics; those occurring in ≤5% of the citations included habitat restoration and several key words related to population viability (Appendix 1), such as connectivity/fragmentation, genetics, dispersal, and translocation.

*Summary of knowledge gaps***.** Among the states in which research was reported, Oregon and Wyoming were underrepresented in the published literature, as both, along with Montana, are among the states supporting the largest estimated breeding populations as of 1998 (>20,000 in each; Braun 1998), but ranked only 4th (Oregon) and 5th (Wyoming) in the percentage of citations. Knowledge gaps identified from our analysis included information about vegetation cover types. Nearly half the articles that mentioned "sagebrush" as occurring in the study area did not mention what species or subspecies was present. Conspicuously absent were articles referring to cheatgrass and other non-native vegetation.

Fall and winter studies were not well represented in the literature compared to studies of grouse during brood rearing, lekking, or nesting periods. Also, studies of juveniles and yearlings were less common than those of adults. Nearly all land management practices were poorly represented, with only 2 (herbicide/pesticide use and shrub removal) mentioned in >10% of the citations. Population data were scarce, particularly information on population growth rates and mortality or survival rates. Key topics that were not well studied include habitat connectivity and fragmentation, genetics, habitat restoration, dispersal, and translocation. Also lacking were published studies on effects of human activities such as construction of power lines and roads, recreation, and urban development.

Based on the median study length of 2 years it was clear that long-term studies, which are more likely to encompass the variability associated with weather and its corresponding effects on reproduction and vegetation, are lacking. Also needed are more studies based on manipulative field experiments, which represented only 9% of the citations analyzed. How data are collected for wildlife research affects not only the inference space, or applicability of the results, but also how certain the researcher can be about conclusions reached from the data (Ratti and Garton 1994). Experiments have been underused in wildlife research, but are required to examine cause-effect relations (Ratti and Garton 1994).

Knowledge of sage-grouse in Oregon: data collection

The earliest descriptions of sage-grouse in Oregon were general observations of natural history, such as Horsfall's (1920) colorful account of males on a lek in the southeastern portion of the state, or Prill's (1922) note that sage-grouse were abundant near Warner Valley. Quantitative data have been collected since the early 1940s when Batterson and Morse (1948) began investigating causes for sage-grouse declines in southeastern Oregon. Other than a master's thesis by Nelson (1955) on the Hart Mountain National Antelope Refuge, emphasizing reproduction and survival, no other research on sage-grouse was reported through 1981 (Donoho and Roberson 1985). Research needs for sage-grouse in Oregon were identified, however, as early as 1954 (Masson, as reported in Nelson 1955) and included nesting success; annual production; population trends, including accuracy of lek counts; disease; effect of tapeworms on survival of young; and population cycles. Call and Maser (1985) reviewed sage-grouse habitat requirements and effects of land management practices on the species, with particular emphasis on southeastern Oregon. Drut (1994) reviewed the status of sage-grouse, emphasizing populations in Oregon and Washington. The bulk of the research on sage-grouse in Oregon has occurred in 2 study areas, Hart Mountain National Antelope Refuge (Lake County) and the Jackass Creek area west of Frenchglen (Harney County—Fig. 1). Two government agencies (ODFW and BLM) and Oregon State University have led research efforts on sage-grouse in Oregon.

ODFW. Lek counts of sage-grouse began in 1946, and summer indices of population abundance and productivity (grouse observed/10 miles, chicks/hen, and chicks/adult) have been calculated since 1954 (Nelson 1955, Willis et al. 1993). Willis et al. (1993) summarized data collected on sage-grouse in Oregon from historical records through 1992 and reported measures of productivity and counts of adults for areas and years in which quantitative data were available. Data collection on population structure and trends has been somewhat sporadic in Oregon, due to the intermittent hunting seasons, as well as varying agency funding and emphasis on sage-grouse.

Protocols recently issued by ODFW for data collection on sage-grouse include standards for lek counts, searches, and checks; brood production surveys; setting harvest quotas; and analysis of wing and hunter harvest data (ODFW 2002). During 2001, intensive surveys were conducted using helicopters and ground counts in Lake, Harney, Deschutes, and Crook counties (Rickerson 2001); this increased survey effort was made possible through funding obtained from the Oregon Legislature's Emergency Board in 2000. Additional surveys are planned for future years, as funding is available.

A series of sage-grouse studies was started by ODFW in the mid-1980s. In 1984 a research plan was developed to examine the cause of sage-grouse declines in the state. The primary objective was to examine habitat use and selection of sage-grouse hens during nesting and brood rearing in the Jackass Creek area (Willis and Keister 1984). A second objective was to study brood habitat selection and its relationships to riparian conditions and reductions in coyote densities. Data were collected from 1984-1986, but the study was officially terminated in 1985.

A more comprehensive research project with an annual budget of >$140,000 was proposed in 1988 by ODFW for further work in Jackass Creek and Hart Mountain (ODFW 1988). Five major objectives were outlined: 1) develop a multi-agency, comprehensive research plan for sage-grouse in Oregon; 2) determine habitat selection of hens during breeding, nesting, and brood-rearing periods; 3) examine nest success and brood survival (causes and rates of mortality); 4) develop a final study plan for further sage-grouse research; and 5) investigate winter habitat use and selection in southeastern Oregon. This research began in 1988 and continued through 1992 (ODFW 1988; Willis 1989, 1990, 1991, 1992). Portions of this work were conducted through collaboration with OSU (objectives 2 and 3). Willis (1990) further developed the study plan for objective 5 to specifically examine the influence of crested wheatgrass seedings on wintering sage-grouse over a 3-year period. A study area in Malheur County (Jordan Valley and Dog Creek areas), with crested wheatgrass interspersed with native sagebrush range, was added to the 2 previous study areas to contrast winter habitat use in a converted landscape with that in more intact winter habitats. These data are currently being re-analyzed, and a manuscript for publication will be written (E. Rickerson, ODFW, personal communication).

Since 1982 (but excluding 1985-1988), sage-grouse wings have been collected by ODFW during the fall hunt to determine population structure, productivity, hatching date, and other characteristics of the harvested population (Crawford 1990, 1992; Braun 2002; Crawford et al. 2002). Wings were available from 1982-1984 and 1989-2001. These data can be used to estimate age and sex ratios, which are important indicators of trends in survival and turnover. Crawford et al. (2002) summarized data on sage-grouse wings collected from 1982-2001, with more detailed summaries of wings from 1990-2000 by ODFW management unit. Braun (2002) summarized data from wings collected during 1993-2001, combining the 12 management units into 6 data analysis units. From this analysis, Braun (2002) concluded that no changes were necessary in current data collection from harvested sage-grouse in Oregon. Because yearling sage-grouse in Oregon often molt primaries before the fall harvest, accurate classification of this age class is seldom possible (Braun 2002).

BLM. A 6-year study initiated in 1988 on the Prineville District provided information on diets, habitat use, and population trends of sage-grouse in central Oregon, an area of sage-grouse range not previously studied (Hanf et al. 1994). Because 90% of current sage-grouse habitat in Oregon is on lands managed by the BLM (Hanf et al. 1994), understanding the extent and quality of these public lands is paramount for managing habitat for the species in the state. To that end, management guidelines were recently issued for sage-grouse and sagebrush-steppe habitats on BLM lands in Oregon and Washington (BLM et al. 2000). These guidelines call for implementation monitoring of sage-grouse habitat, including the annual reporting of baseline information such as acreage of known/occupied habitat for sage-grouse, number of leks, number of leks surveyed, and miles of new roads and structures (e.g., fences) in known or occupied sage-grouse habitat. These data are currently being collected by BLM District Offices in Oregon and were submitted to the Oregon State Office early in 2002 (G. Buckner, BLM, personal communication). In addition, these guidelines prescribe specific management goals for sage-grouse on BLM lands, e.g., "Maintain sagebrush that is accessible to sage-grouse for food and cover during the winter months" (BLM et al. 2000:9).

Oregon State University. Most published research on sage-grouse in Oregon has been conducted under the auspices of Oregon State University. Twelve master's theses have been completed, 9 under the supervision of Dr. J. A. Crawford (retired) of Oregon State University. Nelson's (1955) thesis provided a general examination of life history and ecology of sage-grouse in Oregon. Most of these graduate studies were conducted at Hart Mountain National Antelope Refuge or the Jackass Creek area of southeastern Oregon. Research has focused on habitat use and selection (Gregg 1991, Drut 1992, Crawford and Davis 2002), predation (DeLong 1993, DeLong et al. 1995), diet and nutrition (Barnett 1992, Drut 1992, Pyle 1992, Barnett and Crawford 1994, Wrobleski 1999, Wirth 2000), productivity (DeLong 1993, DeLong et al. 1995, Coggins 1998, Crawford and Davis 2002), habitat restoration (Wrobleski 1999, Wirth 2000), and effects of fire (Pyle 1992, Wrobleski 1999, McDowell 2000, Wirth 2000, Byrne 2002, Crawford and Davis 2002). The role of forbs in diets of hens was emphasized in several theses (e.g., Barnett 1992, Pyle 1992, Coggins 1998, Wrobleski 1999, Wirth 2000). Most of the research focused on nesting and brood-rearing periods.

These graduate studies generated most of the journal articles published on sage-grouse in Oregon with similar areas of emphasis: habitat use and selection (Gregg et al. 1993, Drut et al. 1994*a*); predation (Gregg et al. 1994, DeLong et al. 1995); diet or nutrition (Barnett and Crawford 1994, Drut et al. 1994*b*); and fire (Pyle and Crawford 1996). Ongoing research on sage-grouse at OSU includes the doctoral work of M. Gregg, who is investigating factors affecting survival of juvenile sage-grouse, including diet quality (Gregg, In prep.).

Summary of knowledge about sage-grouse and their habitats in Oregon

Most empirical studies of sage-grouse in Oregon have been fine-scale (i.e., local population level), with none of the published research based on landscape-level analyses. Of the 89 citations related to Oregon studies, only 13 (15%) were published in journals, whereas 10 (11%) were published as theses or dissertations and 15 (17%) were government publications. Nearly half the entries (49%) were not published, but were agency reports, other “white papers,” or abstracts from proceedings. Dr. J. A. Crawford was primary author or co-author of 33% (29) of the Oregon publications, testimony to his long-standing involvement with sage-grouse research in the state. M. Willis, formerly with ODFW, was an author of 9 publications (13%), and M. S. Drut, a former student of Crawford’s, authored 8 (10%).

Population distribution, status, trends, and productivity. By 1985, the occupied range of sage-grouse in Oregon had declined 50% from its historical extent (Crawford and Lutz 1985). Several authors have interpreted population data collected in Oregon, with general agreement that declines have occurred in abundance. Population status is typically assessed through counts of males on leks. Willis et al. (1993) summarized data for the “early period” (1958-1973) versus the “late period” (1979-1992) and found no significant declines in males/lek. Crawford and Lutz (1985), however, summarized the statewide data somewhat differently and estimated a 58% decline in abundance from the late 1950s to the early 1980s. In their analyses, Connelly and Braun (1997) calculated a 30% decline in males/lek in Oregon based on the mean of recent counts (1985-1995) versus the mean of the 38 years prior to 1985. E. Rickerson (ODFW, personal communication) has indicated that from 1996-2000, males/lek declined 30% in Oregon compared to counts from 1985-1995. It is important to note that the decrease in lek counts may be related to the number of leks recently added to the annual lek counts. The largest, most visible leks were the first to be surveyed in the 1940s and 1950s. As the survey area has increased, smaller, less visible leks (possibly satellite leks) are now being counted during the annual surveys.

Willis et al. (1993) analyzed productivity of sage-grouse in Oregon, based on summer ratios of chicks/hens, and found sharp declines—2.87 (1954-1973) to 1.06 (1980-1992). Likewise, Crawford and Lutz (1985) reported a major decline in productivity based on chicks/adult from an average of 1.8 in the 1950s to 0.3 in the early 1980s. Mean productivity was 1.05 chicks/hen at Hart Mountain from 1998-2000 (Crawford and Davis 2002), similar to the statewide value reported by Willis et al. (1993) for 1980-1992. Connelly et al. (2000*c*) estimated that a ratio of ≥2.25 juveniles/hen in the fall must be maintained to result in stable or increasing populations of sage-grouse.

Edelmann et al. (1998) conducted a sensitivity analysis of sage-grouse demographic rates, using simulation methods of Wisdom and Mills (1997). Egg, chick, and juvenile survival accounted for 84% of the variation in population growth rate under the simulations, and these stages were consistently associated with highest elasticity. (Elasticity is defined as the proportionate change in population growth rate with proportional change in each life-stage parameter, or vital rate. The higher the elasticity associated with a vital rate, the greater the potential effect of that vital rate on change in growth rate [Wisdom and Mills 1997].) Other researchers concur that productivity, rather than other population characteristics (e.g., adult mortality), appears critical in maintaining sage-grouse populations (e.g., Crawford and Lutz 1985, Connelly and Braun 1997, Schroeder et al. 1999).

More recently, analyses of wings collected during the hunting season provide a somewhat more optimistic trend in productivity. As estimated from percentage of young in the harvest, productivity declined from 53% (1982) to a low in 1991 of 31%; however, productivity has subsequently increased in recent years to 54% (2001; Braun 2002). Mean productivity was 38% from 1982-1992, but increased to 48% from 1993-2001; this increase could have been due to larger sample sizes, however, and better sampling techniques (Braun 2002). Productivity based on percentage of juveniles in the harvest is likely overestimated, however, because immature sage-grouse are typically more susceptible to harvest, especially early in the season (Willis et al. 1993, Dobkin 1995, Crawford et al. 2002). Regardless of the method of analysis, continued data collection on productivity of sage-grouse in Oregon is imperative.

Annual turnover rates for males (replacement of adults and yearlings) from 1993-2001 were about 55% versus 43% for females, assuming populations were stable at the time the wings were collected (Braun 2002). Age and gender composition of the harvest, hatching dates, and production data have been calculated for individual management units (Crawford et al. 2002) and data analysis units (Braun 2002).

Agency personnel have mapped locations of leks over the years in Oregon, and maps of currently occupied leks and seasonal ranges of sage-grouse across the species' range in the state are being prepared by ODFW and BLM biologists (G. Buckner, BLM, personal communication). Intensive lek surveys from helicopters in 2001, followed by ground checks, resulted in identification of 78 potential lek sites. Ground checks confirmed 27 of these as new leks, 14 were found not to be leks, 28 were known (historical) leks, and the status of 9 could not be determined due to access problems (Rickerson 2001).

Nutrition and diet. Dr. Crawford and associated graduate students at OSU have conducted much of the seminal work documenting the importance of forbs in the diets of juveniles and pre-laying and nesting hens (e.g., Barnett and Crawford 1994; Drut et al. 1994*a*, *b*; Crawford 1997; Coggins 1998). Variation in seasonal diets across the state reflects differences in annual precipitation and inherent differences in forage quality and abundance among sites (e.g., greater reliance on sagebrush in diets of chicks in Jackass Creek, where forbs were less abundant—Drut et al. 1994*a*). Most of the research on diets has been conducted at Hart Mountain National Antelope Refuge and Jackass Creek; preliminary summer diet information also was collected during the Prineville study in central Oregon (Hanf et al. 1994). No information on diets or nutrition of sage-grouse in Oregon during winter was found in the published literature.

Effects of fire. Research on effects of prescribed fire and wildland fire in sage-grouse habitats in Oregon has revealed both positive and negative effects, and results are confounded by variation in annual precipitation. Studies of prescribed fire at Hart Mountain in mountain big sagebrush communities demonstrated that, although short-term benefits may accrue from increased abundance of certain forbs and habitat heterogeneity, sagebrush cover was reduced, potentially rendering habitat less suitable for nesting and brood rearing (Pyle 1992, Pyle and Crawford 1996, Byrne 2002). Positive results were reported from prescribed burning in Wyoming big sagebrush communities at Hart Mountain with increases in forb cover, the period of plant succulence, ant availability, and number of shoots on mature sagebrush plants (Wrobleski 1999). In addition, the resulting mosaic of burned and unburned habitats may have increased overall habitat quality for sage-grouse (Wrobleski 1999). Retrospective studies of burns at Hart Mountain and Steens Mountain revealed that key components of sage-grouse habitat used during the breeding period were present in burns ranging from 25 to 43 years old (Crawford and McDowell 1999). In sites burned in 1996 and 1997, forage quality (e.g., percentage of calcium and crude protein) was generally superior to that in control sites (Crawford and McDowell 1999).

Effects of land management practices. Management activities that potentially affect sage-grouse habitats, such as livestock grazing or brush control, generally have declined on BLM lands in Oregon since the early 1960s (BLM et al. 2000). Brush control has been reduced substantially from a high of nearly 46,000 ha in 1963 to an average of about 1,400 ha/year during the 1990s. Construction of water pipelines and fences peaked in 1968, with 260 km of pipelines and 1,152 km of fencing installed. By 2000, these numbers has declined to 22 and 220 km, respectively. In contrast, grazing by cattle has remained fairly constant since the 1960s, with a mean of 916,000 AUMs (animal unit months) from 1949-2000.

Research on effects of these land management practices on sage-grouse in Oregon has been limited. Meyers (1946) and Batterson and Morse (1948) reported on the lack of success in establishing water developments as habitat improvements for sage-grouse in the 1940s; grouse were more abundant in undeveloped water sites than in the "improved" sites. Observations of 8 radio-marked sage-grouse in central Oregon showed that hens were somewhat concentrated near water sources, and that both developed (e.g., guzzler) and undeveloped sites were used (Hanf et al. 1994).

Relationships between livestock grazing and sage-grouse are not well studied in Oregon, or elsewhere in the species' range. Although increases in sage-grouse productivity were noted on Hart Mountain following removal of livestock 4-5 years previously, precipitation was also greater during this period, leading to increased herbaceous vegetation (Coggins 1998). Based on regression analyses, Willis et al. (1993) found no relationships between sage-grouse productivity and livestock use in Harney County. Several studies in Oregon, however, have implicated livestock grazing and other management activities that reduce herbaceous cover with increased predation rates on nests (e.g., DeLong 1993, Gregg et al. 1994, DeLong et al. 1995).

Predation. DeLong et al. (1995) found lower predation rates on artificial nests at Hart Mountain were associated with tall grass cover and medium-height shrub cover. Similarly, a study at Hart Mountain and Jackass Creek showed that nonpredated nests were in areas of greater cover of residual grass, with medium-height shrubs, than were predated nests (Gregg et al. 1994). Hanf et al. (1994) noted a predation rate of 65% on nests in the Prineville area; predation of eggs and young is thought to be the single greatest cause of mortality in sage-grouse (Schroeder et al. 1999). A significant, negative relationship was found between coyote abundance and sage-grouse productivity in Harney County based on data from 1959-1991 (Willis et al. 1993). In earlier studies by ODFW, losses of nests and chicks during the first 3 weeks after hatching were believed to most influence population levels (Keister and Willis 1986); predation by coyotes and ravens was thought to be the major cause of nest failures. In the earliest research on sage-grouse in Oregon, avian predator control (primarily ravens) was associated with an increase in nest success from approximately 5 to 51% (Batterson and Morse 1948).

ICBEMP sage-grouse assessments. Recent analyses undertaken as part of the Interior Columbia Basin Ecosystem Management Project (ICBEMP) provide data that can be used to examine historical and current environmental conditions for sage-grouse in Oregon. These evaluations have been published in peer-reviewed journals; the reader is referred to these publications for details on methods and analyses. The assessments covered the entire interior Columbia Basin (hereafter referred to as basin), which includes eastern Oregon and Washington, most of Idaho, western Montana, and small portions of Wyoming, Utah, and Nevada. The following results are based on methods presented in Wisdom et al. (2000*b*, 2002*b*) and Raphael et al. (2001); however, additional analyses were conducted specifically for Oregon with data from the larger database.

Declines in sage-grouse habitat in Oregon were not as sharp as those across the range of sage-grouse in the basin. Habitat for sage-grouse was defined by Wisdom et al. (2000*b*) as including nearly all cover types and structural stages of sagebrush (e.g., mountain big sagebrush/open low-medium shrub), as well as herbaceous wetlands. Within the historical range of sage-grouse in Oregon, habitat decreased from nearly 71,000 km^2 historically (ca. 1850-1900) to about 61,000 km^2 currently. This decline (13%), while substantial, was considerably less than the 28% decline throughout the historical range of sage-grouse in the basin, an area encompassing 136,000 km^2 of sagebrush steppe (Wisdom et al. 2002*b*).

If the area occupied historically by sage-grouse is distinguished by delineating subwatersheds in which sage-grouse have been extirpated versus subwatersheds that remain occupied (referred to as extirpated versus occupied areas), further insight can be gained into the role of habitat in maintaining populations of sage-grouse (Wisdom et al. 2002*b*). Subwatersheds in the basin have a mean area of about 78 km^2, with 1,326 subwatersheds underlying the historical range of sage-grouse in Oregon. Sage-grouse have been extirpated in 375, or 28%, of these 1,326 subwatersheds (Fig. 2; map adapted from Schroeder et al. 1999). Historically, only 11,000 km^2 of habitat for sage-grouse was in the extirpated areas, versus nearly 60,000 km^2 of habitat in occupied areas. Thus, though extirpated areas composed nearly 30% of the historical range of the species in Oregon, they contained only 15% of the historical habitat.

Additional confirmation of this pattern is found through examination of the amount of habitat in each subwatershed. Historically, subwatersheds in extirpated areas contained an average of 29 km^2 of habitat, in contrast to 63 km^2 of habitat in occupied areas. Reductions in habitat from historical to current time periods further reveal differences between extirpated and occupied areas. Habitat declined nearly 30% in the extirpated areas; by contrast, habitat decline was only 11% in occupied areas. To summarize, not only did areas from which sage-grouse have been extirpated in Oregon support considerably less habitat historically than currently occupied areas, but extirpated areas have suffered a disproportionate loss of habitat.

Wisdom et al. (2002*b*) used a modeling approach to compare current environmental conditions for sage-grouse in extirpated versus occupied areas. The output of their model is an environmental index score, which is a continuous variable ranging in value from 0 to 2 (Raphael et al. 2001). The environmental index score is based on a combination of input variables that estimate habitat quality and quantity for sage-grouse in each subwatershed. In Oregon, the current mean environmental index was 0.23 for extirpated areas (Fig. 3A), compared with 0.74 for occupied areas (Fig. 3B). The model, therefore, appears to discriminate well between extirpated and occupied sites (Wisdom et al. 2002*b*). Current environmental index scores in Oregon, whether for extirpated or occupied areas, were substantially lower than historical scores, which were 0.92 for extirpated areas and 1.59 for occupied areas, signaling a decline in environmental conditions for the species throughout its historical range in Oregon. While the current mean environmental index for extirpated areas in Oregon (0.23) was slightly lower than the basinwide mean (0.25), the mean for occupied areas in Oregon (0.74) was 9% higher than that basin-wide (0.68; Wisdom et al. 2002*b*).

Summary - Research Needs for Sage-grouse in Oregon

Schroeder et al. (1999) commented on the somewhat narrow focus of sage-grouse research to date. For example, much research has focused on behavior of the species, yet few of these studies are applicable to management, and basic questions remain unanswered. Schroeder et al. (1999) recommended several areas for potential research; other authors, particularly Dobkin (1995), also have made recommendations for research (Table 5), and these sources also should be consulted. We identified the following research needs based on specific knowledge gaps in Oregon, consideration of the species' status as a game bird, and concerns about population status and viability (Appendix 1). Our list of research needs is summarized in Table 6, which includes a brief description of suitable methods and estimated costs to address each need.

Research priorities for sage-grouse should be based on the primary goal of maintaining or restoring habitats and populations to address concerns about population status, trends, and viability; that is, to assure the presence of well-distributed and abundant populations to minimize the likelihood of future extirpations (Appendix 1; Doak and Mills 1994, Raphael et al. 2001, Reed et al. 2002). Conducting research to gain knowledge needed to prevent future sage-grouse extirpations was a key premise on which a recent memorandum of understanding was approved by the Western Association of Fish and Wildlife Agencies, U.S. Forest Service, BLM, and USFWS (WAFWA 2000). That as context, our evaluation of existing knowledge of sage-grouse suggests that the following topics are key research needs. The list is loosely prioritized, beginning with the most urgent; however, decisions about when and if to address these needs will be driven by agency priorities and the availability of personnel and funding:

1. Identification of the spatial structure of populations. Whether populations of sage-grouse in Oregon exist as 1 continuous population, a metapopulation, a series of isolated populations, or some combination is unknown (Dobkin 1995). A map of this spatial structure is essential in evaluating the probability of long-term persistence of populations, and in identifying areas for focused management. Because historical populations of sage-grouse probably were large and continuous, the species may not be adapted to the more fragmented population structure that likely exists today (Doak and Mills 1994). Research to delineate the detailed spatial structure of sage-grouse populations, therefore, is imperative to understand current vulnerability to extirpation. If populations are small and isolated, they are highly vulnerable to extirpation, in contrast to a large, continuous population (Soulé 1987) or even a large metapopulation (Hanski 1999). Knowledge of population size and connectivity is lacking in Oregon and throughout most of the species' current range. For example, we found only 1 study on sage-grouse, conducted in Washington, which evaluated population structure (Schroeder 1997). Over a 1,990 km^2 area, Schroeder (1997) found no evidence for a metapopulation of subpopulations; rather, the birds were members of 1 population, with females often attending >1 lek.

Genetics research on sage-grouse will help elucidate past population structure, although more recent reductions in population connectivity may not be revealed. Benedict et al. (In review), working in California, Nevada, Oregon, and Washington, found that subspecific designations (i.e., eastern versus western) for greater sage-grouse were unwarranted based on their genetics analyses. Five populations in Oregon were sampled (Whitehorse, Steens, Warner, Wagontire, and Beatty's), and none were genetically unique based on distribution of haplotypes. Furthermore, the Oregon populations were among the lowest of all sites sampled in occurrence of novel haplotypes, suggesting relatively greater gene flow and less population isolation (Benedict et al., In review). Further research, with additional sites and birds sampled, will help to clarify the taxonomic status of sage-grouse in Oregon and the genetic relationship among sage-grouse populations in the state.

A corollary and critical research need related to population structure is to map all seasonal habitats used by sage-grouse and to characterize migration and dispersal patterns, distances, and routes, and to identify the barriers and threats to such movements by season and life stage. Determination of whether populations are migratory or nonmigratory is an important first step (Connelly et al. 2000*c*). In addition, detailed knowledge is needed about the movement of birds within and among populations and subpopulations, location and effectiveness of dispersal routes and movement corridors, and the relation between dispersal and genetic interchange. Also needed is knowledge of the effectiveness of translocations that might be used to improve the genetic health of isolated populations, and effects on genetic variability. Translocations of sage-grouse generally have not been successful (Connelly et al. 2000*c*), and further research on their effectiveness is needed.

In particular, research should be directed toward all aspects of migration and juvenile dispersal, particularly estimates of survival during such movements. Only 8 citations were located that focused on dispersal of sage-grouse, and only 2 of these were published in journals (Dunn and Braun 1985, 1986).

2. Estimation of population size and population growth rate. To assess population viability (Appendix 1), one must know the size of existing populations and whether they are growing, stationary, or declining. Lek counts, or indices of counts, traditionally have been used to make inferences about status and trends of sage-grouse populations (Willis et al. 1993, Connelly and Braun 1997, Schroeder et al. 1999, Connelly et al. 2000*c*). Identification of all occupied leks is one means that holds promise in estimating population size, and such an inventory recently has been initiated in Oregon (ODFW 2002). Conducting unbiased counts of sage-grouse on leks is necessary to estimate population growth rate over time (see Dennis et al. 1991 regarding count-based methods of assessing population viability). These counts should occur on a large number of leks, randomly sampled from all occupied leks across the current range of sage-grouse in Oregon.

Traditional methods for estimating abundance, i.e., lek counts of males and brood counts along census routes in summer or fall, exemplify 2 widespread problems in wildlife research and management (Anderson 2001). The first is "convenience sampling," in which animals are sampled in more easily accessible areas, rather than in a probabilistic manner. Both lek counts and brood counts demonstrate this type of sampling, in that both are most often conducted in areas that can be driven to with relative ease. There is little that can be inferred from this type of sampling, other than weak inference to the segment of the population of sage-grouse near roads. We need to know if the sampled areas are representative of the total area before we can confidently make formal, inductive inference to the population of sage-grouse as a whole.

The related problem of using an index of relative abundance, rather than an estimate of the real parameter of interest, is widespread in monitoring sage-grouse populations. Counts of males on leks are presumed to index the population as a whole, with average sex ratios of males:females from wing data used to obtain the total adult population estimate. A myriad of factors affect the value of the index, including observer reliability and detectability of the birds (Anderson 2001). Leks may move and their new locations remain unknown, observers might attend the lek at a time that does not correspond with peak attendance, or the percentage of males attending a lek on a given day may be unknown. Such factors would at best result in an underestimate of population size. Efforts are underway, through a series of data analysis workshops, to develop improved methods for estimating population size and trend and identifying mechanisms of population change and distribution. This work is being carried out under the auspices of the Western States Sage and Columbian Sharp-tailed Grouse Technical Committee.

Other methods of estimating population growth rate are available and may avoid a variety of potential biases associated with lek counts. These biases include non-random selection of leks, inconsistent timing of lek counts across years, and insufficient number of counts per lek in a given breeding season (Dobkin 1995). An alternative is mark-recapture methods, like that for the northern spotted owl (Forsman et al. 1996), which provide unbiased estimates of population parameters such as annual rates of survival (White and Garrott 1990). Mark-recapture methods require many birds to be marked or radio-tagged over a large area, however, to achieve sufficient statistical power and to ensure that inferences can be made credibly over a high percentage of the species' range. Regardless of method, estimation of population growth rates for sage-grouse in Oregon is required to better understand dynamics of grouse in the state.

Corollary to estimation of population size and growth rate is the need to estimate environmental variation across large areas and over long time periods, and to relate this variation to changes in vital rates, and ultimately, to effects on population growth (see discussion by Dobkin 1995). Such long-term knowledge requires unbiased estimates of both reproduction and survival for all life stages of a species, if one is to understand the contribution of each life stage to changes in population growth under long-term dynamics of environmental change. In particular, environmental variation can cause substantial fluctuations in population numbers and trends and is a major factor contributing to extinction of small populations (Morris and Doak 2002). Examples of environmental variation (stochasticity) include effects of extreme weather, alien plant invasions, wildfire, and other episodic events that are referred to as "catastrophes" or "bonanzas" (Morris and Doak 2002). Catastrophes are environmental events that cause a population to crash, whereas bonanzas cause a population to increase dramatically. The frequency and intensity of such events substantially affects the long-term probability of population persistence: bonanzas provide a population buffer against catastrophes, but catastrophes can invoke a downward spiral from which a population may not recover, especially for long-lived vertebrates (Morris and Doak 2002).

Conducting sensitivity analyses (e.g., Edelmann et al. 1998) will clarify the contribution of various life stages of sage-grouse to population growth rates. Some researchers have emphasized that productivity is the key element in maintaining sage-grouse populations (e.g. Connelly and Braun 1997, Schroeder et al. 1999). The assertion that productivity exerts a stronger effect on population growth than does subadult or adult survival deserves more attention, however, from a modeling standpoint as well as from empirical research. For example, Edelmann et al. (1998) simulated the potential effects of early life-stages (egg, chick, and juvenile survival) as a first-year age class in relation to other age classes that encompassed subadult and adult stages. Alternatively, analysis of the composite effects of multiple age classes that compose distinct life stages after age 1 (e.g., early-, mid-, and mature-aged birds) may yield different results regarding potential effects of productivity versus survival on population growth (see Table 6).

3. Analysis of cause-effect relationships between pervasive land uses and population responses of sage-grouse. The most pervasive, current land use issues for federally-managed sage-grouse habitats in Oregon include livestock grazing, road development and use, fire management, and methods of vegetation rehabilitation following wildfire. Few cause-effect studies on sage-grouse response to these dominant land uses have been conducted, and the potential interactive effects of these practices on sage-grouse populations are not well known. An exception is the past research conducted on prescribed fire and sage-grouse in Oregon, especially at Hart Mountain (see "Summary of knowledge about sage-grouse and their habitats in Oregon"), which has provided a good foundation for further studies. Controlled experiments, using these practices as treatments and treatment levels in a factorial experimental design, are needed to establish such cause-effect relationships. Treatment effects on different life stages of sage-grouse also should be determined if possible. Livestock were removed from Hart Mountain National Antelope Refuge, the site of long-term studies on sage-grouse, in 1991; however, precipitation increases since then have confounded reported effects on increased sage-grouse productivity (Coggins 1998).

A corollary research need regarding cause-effect relationships between dominant land use practices and sage-grouse populations is spatially-explicit knowledge about where these practices occur, their magnitude over seasonal and year-round habitats, and the interactions of various management practices that may act in synergistic, additive, or compensatory ways. Data on the current extent and types of management activities on sage-grouse range are being gathered by the BLM in Oregon through implementation monitoring (BLM et al. 2000) and will provide a basis for the design of experiments to better understand these interactions.

4. Assessing the extent to which quantity and quality of seasonal habitats, such as brood-rearing habitat versus winter habitat, may limit population growth. Questions have arisen about whether a shortage of winter habitat exists, and whether deficiencies in winter habitat may be responsible for declining populations of sage-grouse (e.g., Beck 1977, Swenson et al. 1987). A thorough evaluation of winter habitat in Oregon and its effect on juvenile and adult survival is needed. The majority of studies of sage-grouse have focused on spring and summer, primarily lekking and nesting activities. Relatively little research has addressed habitat use and selection during fall and winter, especially in Oregon (see Willis 1990). Few studies have estimated juvenile survival during fall, following brood break-up, and adult survival during fall and winter. Similarly, many studies have focused on habitat selection during the brood-rearing period, but almost none has estimated chick survival, particularly in relation to habitat selection. Research addressing chick survival is underway, however, in southern Oregon and northern Nevada (Gregg, In prep.).

The relative value of winter habitat has not been well studied. Eng and Schladweiler (1972) concluded that sagebrush removal on winter habitat, though it may constitute a small portion of the year-round habitat of sage-grouse, could be especially detrimental because of the relatively long periods that winter habitat may be occupied by sage-grouse. Swenson et al. (1987) found substantial declines in sage-grouse abundance in Montana when a large (30%) percentage of the winter habitat was plowed, primarily for grain production. Of the entire study area, however, only 16% was affected by plowing. The value of winter habitat in maintaining viable populations may vary across the species' range. In Oregon, wintering habitats generally are not considered limiting, due to the lower elevation and lack of snow accumulations that limit access to food during winter in harsher climates (Call and Maser 1985). In addition, natural mortality in winter is typically low compared to that during other seasons, so that survival during this period has not received much research emphasis.

Corollary to understanding the relative values of seasonal habitats is the knowledge of where such habitats are, their extent, and their juxtaposition relative to one another. Dobkin (1995) also described the need to understand the "spatial dispersion patterns of seasonally-required habitats within landscape mosaics."

5. Developing landscape methods for restoring degraded sagebrush habitats, including quantifying, mapping, and prioritizing large areas in need of habitat restoration. Although losses of the native sagebrush ecosystem have been substantial, emphasis on restoring such habitats has only recently emerged. Methods have been developed that appear to hold promise for fine-scale restoration, but successful application of these methods to large expanses of degraded sagebrush habitats is untested. Means to effectively restore habitat, especially in arid rangelands dominated by Wyoming big sagebrush, are poorly understood, but have been addressed in several recent symposia and workshops (e.g., Monsen et al., In press). In our literature analysis only 3% of the articles addressed habitat restoration, and adaptive management experiments in manipulating sagebrush range for habitat restoration for sage-grouse are urgently needed (Braun 1998).

Moreover, considerable uncertainty exists about prospects for successful restoration in sagebrush habitats invaded by exotic plants (McIver and Starr 2001; Hemstrom et al. 2002; Monsen et al., In press). Passive restoration (e.g., removal of livestock) may be successful in reversing declining trends in habitats where degradation has not been severe (McIver and Starr 2001). Once exotic plants such as cheatgrass have become established, however, only active restoration, such as aggressive seeding of native perennials, is likely to return the sagebrush system to a desirable state (McIver and Starr 2001; Hemstrom et al. 2002). Natural disturbance such as fire may hinder restoration in such degraded landscapes due to the ever-increasing presence of cheatgrass and its rapid spread with the occurrence of wildfire (Billings 1994).

Restoration of habitats for sage-grouse in the sagebrush biome will likely be complex and will require understanding of such factors as the heterogeneity of the landscape, site condition and potential, and the seasonal habitat needs of sage-grouse (Miller and Eddleman 2000). Accurate mapping of conditions across the sagebrush community is necessary before embarking on any restoration program, and will require acknowledgment of responses of undesirable plant and animal species together with responses of native and desired components of the sagebrush ecosystem (Miller and Eddleman 2000). Even if restoration is successfully accomplished in sagebrush systems, knowledge is lacking about responses of sage-grouse populations to such management, including time lags for responses by grouse and the magnitude and duration of effects. Adaptive management experiments should be used in planning such restoration, with resulting knowledge applied to new restoration efforts.

6. Understanding the role of hunting as an additive versus a compensatory factor on juvenile and adult mortality, and the subsequent effects on population growth rate. Little definitive knowledge exists regarding the potential effects of hunting on sage-grouse populations. This knowledge is critical in developing effective plans to restore populations of sage-grouse and in understanding the benefits of improving habitat versus population management. Given the many petitions filed to list sage-grouse as threatened or endangered, the question of whether legal harvest is a factor in current population declines must be addressed (Reese 2001).

In Oregon no relationships were found between population declines and harvest (Crawford 1982). Schroeder et al. (1999) summarized current studies on effects of hunting on sage-grouse populations; most of these suggest that hunter harvest has not negatively affected populations. As the authors noted, however, there are no experimental data on effects of hunting on the species, and no evidence exists that lower rates of natural mortality over winter would compensate for the increased mortality due to hunting.

Johnson and Braun (1999) used a long-term data set in Colorado to estimate viability of a hunted population of sage-grouse in that state. From their analyses, coupled with simulated population projections, they concluded that hunter harvest could be maintained, but only if habitats were restored, such that survival of juveniles and adults was improved. Total mortality and mortality of juveniles and yearlings were correlated with hunting mortality in their analyses, indicating that hunting mortality was additive (Johnson and Braun 1999). Additional evidence of additive mortality from hunting was found from review of seasonal patterns of mortality in sage-grouse (K. Reese, University of Idaho, personal communication). He concluded that if adult sage-grouse survive until fall, they are unlikely to die during winter. This finding implies that birds harvested during fall would otherwise survive the winter.

Modeling simulations, using existing survival and other demographic data from several sage-grouse populations, could be used to further explore the relationship between hunter harvest and populations growth rate. In addition, experiments to investigate potential differences in juvenile and adult survival in hunted versus non-hunted areas would help clarify the effect of hunting on sage-grouse populations in Oregon.

7. Assessing the effects of predation on changes in vital rates and population growth rate. Predators are often identified as a factor in sage-grouse population dynamics, particularly predation effects on nests and chicks, but little research has been conducted to document the extent of its effect on different life stages and on overall growth rates of populations. Moreover, the combined effects of current landscape conditions and predator management policies on predation rates of sage-grouse are not well understood (Schroeder and Baydack 2001). This knowledge is essential in identifying effective ways to manage or restore habitats and populations of sage-grouse to reduce effects of predation. For example, a key research need on predation is the role of power lines and other man-made structures as potential enhancements for avian predators. While power lines, fences, and other structures have been hypothesized to facilitate predation of sage-grouse by raptors, empirical research on this topic has not yet been published.

Estimates of predation rates on all vital rates of sage-grouse (e.g., reproduction, juvenile and adult survival) are needed to evaluate the effects of predation. Such estimates could be obtained from extensive radiotelemetry studies. These studies should be conducted in a variety of landscapes of varying habitat quality (e.g., sites with relatively good nesting cover versus those with more marginal conditions for nesting and brood rearing). Controlled experiments incorporating predator management would also help clarify the role of predation in sage-grouse population dynamics.

8. Assessing the efficacy of using sage-grouse as an umbrella species for other sagebrush-associated vertebrates. Sage-grouse have been proposed as an umbrella species for other sagebrush-dependent fauna; however, their usefulness in this role has not been substantiated. (Fleishman et al. [2001] defined umbrella species as "species whose conservation confers a protective umbrella to numerous co-occurring species.") Despite the apparent increased efficiency of multi-species planning and assessment, such approaches (e.g., umbrella species) may not be as effective as single-species approaches, particularly in species recovery (Clark and Harvey 2002).

Using 3 criteria offered by Fleishman et al. (2000) for candidate umbrella species, sage-grouse appear to offer promise. These criteria are 1) co-occurrence of the species with other species of interest; 2) its level of ubiquity; and 3) its sensitivity to human disturbance. Sage-grouse are closely allied with sagebrush habitats across their range, and thus co-occur with a host of other sagebrush obligates. Overlap of sage-grouse habitat requirements with some birds of the shrubsteppe is high. Rich and Altman (2001), citing Wisdom et al. (2000*b*), calculated >90% overlap in habitat requirements of an example set of sagebrush-dependent bird species with the requirements of sage-grouse (sage sparrow, 99%; Brewer's sparrow, 94%; and sage thrasher, 94%). In terms of abundance, a good umbrella species should be neither rare nor ubiquitous; current populations of sage-grouse appear to meet this standard. And last, sage-grouse are sensitive to anthropogenic disturbances (e.g., Aldridge 1998, Connelly et al. 2000*c*, Lyon 2000). Such disturbances are of greater concern than natural disturbances when attempting to designate umbrella species, because human disturbance and associated habitat loss pose the most severe threats to most species (Fleishman et al. 2000).

While many sagebrush-dependent bird species have requirements that overlap with sage-grouse, less is known about overlap between environmental requirements for sage-grouse and those for reptiles and mammals associated with sagebrush habitats beyond their mutual reliance on sagebrush cover types. Burrowing mammals such as pygmy rabbit and sagebrush vole (*Lemmiscus curtatus*) depend on friable soils in sagebrush habitats that allow for establishing and sustaining burrows. Recreational shooting ("plinking") is a problem for ground squirrels associated with sagebrush (e.g., *Spermophilus* spp.; Wisdom et al. 2000*b*). Finally, many species of reptiles that depend on sagebrush face the problem of collection as part of the pet industry. Wisdom et al. (2000*b*) described in detail these differences in requirements and responses to management practices.

Importantly, almost nothing is known about differences in responses of sage-grouse versus other sagebrush obligates to size and fragmentation of sagebrush patches. For example, sage grouse may use a variety of patch sizes arranged as a mosaic across the landscape, given their high mobility and large home ranges. A species like sage sparrow, by contrast, appears to require large, unfragmented patches of sagebrush (S. Knick, USGS Biological Resources Division, personal communication). Such differences suggest that better knowledge of the spatial requirements of sage grouse is needed in relation to those for other sagebrush obligates, rather than assuming the requirements are similar or equivalent.

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Table 1. Literature analysis for vegetation cover types used by sage-grouse, based on a randomly selected sample of 100 articles.

Vegetation cover type[a]	**No. articles w/mention of the type**	**No. articles in which results are reported for the type**
Sagebrush	39	15
Artemisia arbuscula	11	6
A. cana	9	2
A. tridentate	32	12
A. tridentata tridentate	9	3
A. tridentata vaseyana	14	6
A. tridentata wyomingensis	13	7
Other *Artemisia*	14	9
Other shrubs	28	8
Grasslands	19	8
Understory/forbs	27	17
Understory/grasses	23	13
Understory/exotic	1	0
Riparian	11	3
Meadow	15	6
Pinyon-juniper	6	2
Cheatgrass (*Bromus tectorum*)	2	0
Cropland[b]	10	4
Conservation Reserve Program	0	0
Crested wheatgrass (*Agropyron cristatum*)	7	3
Other non-native	1	0

[a] See Appendix 2 for more complete explanations of cover types.
[b] In nearly all instances, the crop referred to was alfalfa.

Table 2. Previously identified issues affecting sage-grouse conservation and management and associated references.

Issue	Reference(s)
Energy development (coal, oil, and natural gas)	Anonymous 1997, Braun 1987, Braun 1998, Schroeder et al. 1999, Connelly et al. 2000*c*
Declines in habitat quality from livestock grazing	Anonymous 1997, Braun 1987, Willis et al. 1993, Schroeder et al. 1999, BLM et al. 2000, Connelly et al. 2000*c*, Miller and Eddleman 2000
Habitat loss and degradation through controlled fire, wildfire, and fire suppression	Anonymous 1997, Braun 1987, Willis et al. 1993, Braun 1998, Schroeder et al. 1999, BLM et al. 2000, Connelly et al. 2000*c*, Miller and Eddleman 2000
Habitat loss and degradation through application of herbicides and pesticides	Braun 1987, Willis et al. 1993, Anonymous 1997, Braun 1998, Schroeder et al. 1999, Connelly et al. 2000*c*, Miller and Eddleman 2000
Habitat degradation through invasion of exotic plants, often a result of wildfire	Anonymous 1997, BLM et al. 2000, Connelly et al. 2000*c*, Miller and Eddleman 2000
Hunting	Anonymous 1997, Braun 1987, Schroeder et al. 1999
Human disturbance, including public viewing and recreation	Anonymous 1997, Braun 1987, Schroeder et al. 1999
Habitat loss through conversion of sagebrush to cultivated lands	Braun 1998, Schroeder et al. 1999, BLM et al. 2000, Connelly et al. 2000*c*, Miller and Eddleman 2000
Habitat loss through conversion of sagebrush for other reasons (e.g., livestock forage)	Anonymous 1997, Braun 1998, Schroeder et al. 1999, BLM et al. 2000
Habitat loss through conversion to urban or other human settlement	Anonymous 1997, Braun 1998
Habitat loss through reservoir development	Braun 1998
Roads and highways	Braun 1998
Habitat fragmentation from removal of sagebrush, fences, power lines, and roads	Willis et al. 1993, Anonymous 1997, Braun 1998, Schroeder et al. 1999, BLM et al. 2000, Connelly et al. 2000*c*
Weather/climate changes (drought)	Willis et al. 1993, Anonymous 1997, Braun 1998, Connelly et al. 2000*c*, Miller and Eddleman 2000
Predation	Willis et al. 1993, Anonymous 1997, Braun 1998, Connelly et al. 2000*c*
Water developments	Willis et al. 1993, Schroeder et al. 1999, BLM et al. 2000
Juniper (*Juniperus* sp.) expansion	BLM et al. 2000, Miller and Eddleman 2000
Habitat degradation from overgrazing by wild horses	BLM et al. 2000
Habitat degradation due to herbivory effects of wild ungulates	Anonymous 1997

Table 3. Terrestrial vertebrate species of concern in Oregon associated with sagebrush ecosystems (adapted from Wisdom et al. 2000*b*).[a]

Terrestrial family name	Common name	Scientific name	ODFW status[b]
Range mosaic	Mojave black-collared lizard	*Crotaphytus bicinctores*	SV
	Longnose leopard lizard	*Gambelia wislizenii*	SU
	Striped whipsnake	*Masticophis taeniatus*	--
	Ground snake	*Sonora semiannulata*	SP
	Ferruginous hawk	*Buteo regalis*	SC
	Burrowing owl	*Athene cunicularia*	SC[c]
	Short-eared owl	*Asio flammeus*	--[d]
	Vesper sparrow	*Pooecetes gramineus*	SC[e]
	Lark sparrow	*Chondestes grammacus*	--
	Western meadowlark	*Sturnella neglecta*	SC[f]
	Preble's shrew	*Sorex preblei*	--
	White-tailed antelope squirrel	*Ammospermophilus leucurus*	SU
	Washington ground squirrel	*Spermophilus washingtoni*	LE
	Wyoming ground squirrel	*Spermophilus elegans*	--
	Pronghorn	*Antilocapra americana*	--
Sagebrush	Greater sage-grouse	*Centrocercus urophasianus*	SV[g]
	Sage thrasher	*Oreoscoptes montanus*	--
	Loggerhead shrike	*Lanius ludovicianus*	SV[f]
	Brewer's sparrow	*Spizella breweri*	--
	Black-throated sparrow	*Amphispiza bilineata*	SP
	Sage sparrow	*Amphispiza belli*	SC
	Pygmy rabbit	*Brachylagus idahoensis*	SV
	Sagebrush vole	*Lemmiscus curtatus*	--
	Kit fox	*Vulpes macrotis*	LT
Grassland/open canopy sagebrush	Columbian sharp-tailed grouse	*Tympanuchus phasianellus columbianus*	--
	Grasshopper sparrow	*Ammodramus savannarum*	SV/SP

[a] Criteria for identifying species of concern included habitat conditions resulting in increased likelihood of population isolation, a global ranking of 1 or 2 by The Nature Conservancy, and species whose habitats were projected to increase or decrease significantly under a land management alternative as part of the Interior Columbia Basin Ecosystem Management Project. Further details in Volume I, Wisdom et al. (2000*b*).
[b] Status as of 2000. Sensitive species are those defined as "naturally reproducing native vertebrates which are likely to become threatened or endangered throughout all or a significant portion of their range in Oregon." Sensitive species codes begin with "S" and are further defined as follows: SC = critical; SP = peripheral or naturally rare; SU = undetermined status; and SV = vulnerable (Oregon Natural Heritage Program 2001). LE = listed endangered and LT = listed threatened.
[c] Status reported for western subspecies only (*A. c. hypugaea*).
[d] Denotes a species not listed as sensitive by ODFW.

[e] Status reported for Oregon subspecies only (*P. g. affinis*).
[f] Status applies to only 1 ecoregion, or a set of ecoregions, in the state, not the species' entire range in the state.
[g] Status applies only to western subspecies (*C. u. phaios*), in the Ochoco-Blue-Wallowa Mountains, Columbia Plateau, and East Cascade Range ecoregions.

Table 4. Selected key words associated with citations reviewed for a literature analysis of 100 randomly selected articles on sage-grouse.

Key word[a]	**Percentage of articles**
Anatomy/morphology	18
Behavior	21
Connectivity/fragmentation	4
Diet	22
Disease/parasites	9
Distribution/mapping	14
Environmental requirements	20
Genetics	2
Habitat restoration	3
Habitat use/selection	30
Hunting	12
Models	10
Movement	20
Movement-dispersal	5
Movement-migration	8
Physiology	11
Predation	16
Taxonomy	9
Techniques/methods	9
Translocation	4
Weather	13

[a] See Appendix 2 for more complete descriptions of criteria by which key words were included.

Table 5. Previously identified research needs for sage-grouse.

Research need	Comments	Reference
Determine whether sage-grouse populations are cyclic	Relationships between environmental factors and population trends would be better understood if reliable knowledge were gained about whether sage-grouse populations are cyclic; long-term population studies needed to address this	Braun 1987, Rich 1985
Seasonal distribution and habitat use of sage-grouse	More accurate mapping of seasonal habitats and distribution of sage-grouse across its entire range is needed, especially the dispersion of these habitats in a landscape mosaic	Drut 1994, Dobkin 1995, Schroeder et al. 1999
Impacts of land management practices and uses on habitat amount, quality, distribution, and fragmentation	Example practices include livestock grazing, prescribed burning, removal of sagebrush, seeding of exotic vegetation for livestock forage, and water developments	Drut 1994, Dobkin 1995, Schroeder et al. 1999
Relation between habitat and sage-grouse demographics		Dobkin 1995
Genetic studies to determine minimum viable population sizes		Schroeder et al. 1999
Habitat and population monitoring		Drut 1994
Genetic studies to clarify taxonomic status (e.g., delineation of subspecies)	Effective population management requires better knowledge of subspecies and population isolates	Drut 1994, Dobkin 1995
Large-scale, long-term experiments, e.g., to address effects of grazing and prescribed fire		Dobkin 1995
Habitat restoration	Effective restoration of sagebrush steppe will require long-term, multi-faceted approaches, including mapping and modeling	Dobkin 1995

Table 6. Research needs, associated estimation methods, and estimated costs for conducting such research for sage-grouse in Oregon. Suggested topics are listed below each need.

Research need	**Example estimation methods**	**Minimum estimated cost**
1. *Identification of the spatial structure of populations* - Assess sage-grouse movements by season and life stage - Map population connectivity - Map breeding, summer/brood rearing, and winter habitat, as well as year-round habitat - Clarify taxonomic status of sage-grouse in Oregon and genetic heterogeneity	* Spatially-expansive genetics analysis * Radio-tracking across large areas and across seasons and years	$200,000 annually for a combination of genetics work and radiotelemetry over several years
2. *Estimation of population size and population growth rate* -Estimate size and map locations of populations -Estimate trends in population size -Evaluate effects of vital rates on changes in population growth rate.	* Identify all leks and monitor a random sample for activity annually * Conduct unbiased, systematic counts of a random sample of leks annually	$200,000 annually for first 5 years; $100,000 for subsequent years
3. *Analysis of cause-effect relationships between pervasive land uses and population responses of sage-grouse* Example land uses: livestock grazing road development and use fire management methods of vegetation rehabilitation after wildfire, prescribed fire, and shrub control treatments - Map locations of land management practices on sage-grouse range in Oregon and identify overlaps with seasonal habitats of sage-grouse	* Conduct manipulative experiments on grazing and fire effects * Conduct opportunistic experiments on road development and use and vegetation rehabilitation after wildfire * Conduct retrospective analyses of effects of livestock grazing (season of use, system used, intensity) on sage-grouse populations	$200,000 per year for each type of practice (e.g., grazing) for approximately 5 years $100,000 per year for opportunistic experiments $50,000 to survey sites and perform analyses
4. *Assessing the extent to which quantity and quality of seasonal habitats, such as brood rearing habitat versus winter habitat, may limit population growth* - Estimate quantity and quality of habitat by life stage/season, through systematic characterization of habitats	* Map habitat areas by life stage (nesting, brood rearing, juvenile, adult) and season (spring, summer, fall, winter) * Quantify the	$100,000 annually for 5 years if done in concert with hunting or predator study (incl. modeling and analysis); $150,000

Table 6, cont.

Research need	Example estimation methods	Minimum estimated cost
	contribution of each life stage and associated habitats to changes in population growth rate	per year for at least 5 years if done alone
5. *Developing landscape methods for restoring degraded sagebrush habitats, including quantifying, mapping, and prioritizing large areas in need of habitat restoration*	* Classify and map historical range of sage-grouse according to condition; conduct broad-scale experiments with various methods of restoration (e.g., seeding, removal of exotics) * Map zones at risk of juniper encroachment and invasion by cheatgrass	$100,000 or more per year
6. *Understanding the role of hunting as an additive versus a compensatory factor on juvenile and adult mortality, and the subsequent effects on population growth rate*	* Explore plausible and likely relationships through modeling simulations with sage-grouse demographic data	$60,000 for 1 year for modeling work
	* Conduct landscape experiments that evaluate differences in juvenile and adult survival with and without hunting; minimum requirement of 1 hunted and 1 control area	$150,000 per year for at least 5 years, using radiotelemetry
7. *Assessing the effects of predation on changes in vital rates and population growth rate* - Investigate role of environmental conditions that predispose grouse to predation (e.g., vegetation structure) and document predation rates under these various conditions	* Estimate predation rates on all vital rates (reproduction, juvenile and adult survival) for example landscapes, and calculate resulting population growth rate	$100,000 per year if conducted in tandem with other research (e.g., hunting)
	* Conduct landscape experiments that evaluates response of sage-grouse population to predator management	$200,000 per year for at least 5 years for landscape-level experiments

Table 6, cont.

Research need	Example estimation methods	Minimum estimated cost
8. *Assessing the efficacy of using sage-grouse as an umbrella species for other sagebrush-associated vertebrates* - Identify areas of spatial overlap between sage-grouse and a suite of other sagebrush-associated species in Oregon	* Compare species occurrence in extirpated versus occupied range of sage-grouse.	$125,000 per year for at least 3 years for data collection and analysis
	* Compare, density, productivity, and survival of sagebrush-associated species in extirpated versus occupied range of sage-grouse.	$500,000 per year for at least 5 years for data collection and analysis
	* Compare landscape metrics (e.g., patch size, fragmentation, contagion) of areas of species overlap versus non-overlap with sage-grouse.	$125,000 for at least 2 years of mapping and analysis

Appendix 1: Concepts and Definitions of Population Viability and Related Topics

Spatially-explicit knowledge of the likelihood of population persistence is critical for effective management of species at risk. This knowledge is the foundation for population viability analysis, or PVA (Burgman et al. 1993, Reed et al. 2002), which allows managers to assess effects of a variety of environmental and quantitative factors on population persistence. We define PVA as the use of quantitative methods to assess current status, and predict future status, of a population or collection of populations in relation to population persistence or growth rate (adapted from Morris and Doak 2002). Status is the likelihood that population size or growth rate is or will remain at a desired level that minimizes extirpation events that contribute to extinction. Similarly, we define population viability as population status and change that affects population persistence, or alternatively, population extirpation and extinction.

Under our definitions, the essential aspects of PVA include the estimation of population size and growth rate and their projections in time. Implicit to estimates of size and growth rate is knowledge of whether populations are large and well connected or small and fragmented (Doak and Mills 1994). Large, well-connected populations have a low probability of extinction, in contrast to the high probability of extinction associated with small, fragmented populations. Consequently, the spatial structure of populations, that is, their distribution, size, and connectedness, is an important component of any assessment of population viability (Morris and Doak 2002).

Alternative methods to PVA also are important in assessing population structure, status, or trends and effects of vital rates on population growth, such as elasticity analysis (Mills et al. 1999), Life-stage Simulation Analysis (Wisdom et al. 2000*a*), Bayesian network models (Marcot et al. 2001), and many other spatially explicit models (e.g., Raphael et al. 1996, Edelmann et al. 1998). Most of these models, including PVA, depend on reliable estimates of reproduction and survival (e.g., Franklin et al. 1996); without these estimates for all life stages of a population or populations, credible inferences about population viability or related population characteristics oftentimes cannot be made.

Studies of vital rates in grouse populations have lagged behind those of other gallinaceous birds (Hickey 1955). We encountered almost no published sage-grouse literature that explicitly addressed these aspects of population viability (note Johnson and Braun 1999 as an exception). Although many studies provide population estimates of sage-grouse, primarily from lek counts, few studies formally estimate population growth rate (Bergerud 1988*b*, Johnson and Braun 1999). A population model has been constructed, however, which predicts population growth rate based on site-specific habitat conditions (Edelmann et al. 1998). Moreover, we found no studies that explicitly addressed population connectivity, with the exception of the recent genetics work in several western states (Benedict et al., In review) and radiotelemetry studies in Washington (Schroeder 1997). Likewise, population fragmentation has rarely been addressed, other than work on the small, highly imperiled populations in Washington (Schroeder 1994, 1995, 1997, 2000).

Schroeder (2000) recently summarized vital rate estimates for sage-grouse across the species' range. These data lend themselves to a variety of demographic analyses, including estimation of potential growth rates of populations, and assessment of the relative contribution of different vital rates, or life stages, to changes in growth rates (Reed et al. 2002). Such analyses have not been conducted for sage-grouse. Researchers at Montana State University, however, are carrying out such analyses for Montana populations of sage-grouse (D. W. Willey, Montana State University, personal communication), and similar analyses are likely to be undertaken in other states (M. A. Schroeder, Washington Department of Fish and Wildlife, personal communication).

Although not a formal PVA, Raphael et al. (2001) recently developed a landscape model to estimate extirpation risk for sage-grouse. Raphael et al. (2001) applied the model to a large area of the sagebrush ecosystem in eastern Washington, eastern Oregon, Idaho, western Montana, northwestern Wyoming, and smaller portions of northern Nevada and northwestern Utah. Results indicated a moderate probability of regional extirpation for sage-grouse existed under current conditions on federal lands. Under proposed federal management, however, the risk of regional extirpation increased to a high probability 100 years in the future. Wisdom et al. (2002*b*) tested the performance of the Raphael et al. (2001) model of extirpation risk using independent data on occupied versus extirpated areas of sage-grouse range. The model correctly predicted the highest risk of extirpation for areas where sage-grouse had been extirpated and a moderate risk in areas still occupied by the species (Wisdom et al. 2002*b*). This is the only landscape model currently available for estimation of extirpation risk in sage-grouse; use of such models complements more traditional forms of PVA that are also lacking for sage-grouse.

Appendix 2. Key to sage-grouse literature analysis fields.

The following table lists the fields in a Paradox database used to characterize sage-grouse literature. When a field is blank in the database (i.e., no value entered), that field is not applicable to the article (e.g., a synthesis article would generally not have an entry for length of study, because the article contains summaries of data collected in other studies).

Unless otherwise noted, a value of "1" for a key word in the database denotes that the key word applies; a blank indicates that the key word does not apply. For "1" to be entered for a key word, that topic (e.g., fire) must be a primary focus of the article (i.e., the issue is not just summarized from other literature or commented upon in a general way).

Field	Type	Description	Values	Value description
RecNo	N[1]	Record number in master ProCite database; this is a key field	10-7500+	Records are added sequentially in increments of 10
Author	A	Last name of primary author(s)		
Year	N	Year of publication	4-digit	
Location1	A	Primary location of work (i.e., state or province)	2 char.	Postal abbreviation; if absent, the article is a synthesis or not applicable to any specific locale
Location2	A	Additional location	"	"
Length	N	Length of study, to nearest year	Integer ≥1	If article presents results of >1 study, the minimum length of study is reported
Quality	N	Proxy for scientific "rigor;" applies to empirical studies only (type = 3), otherwise blank	1	Field or manipulative experiment, or integrated research process
			2	Field study, not experimental (replicated or only pseudo-replicated; quantitative)
			3	Descriptive natural history (qualitative)
Type	N		1	Synthesis of existing knowledge or of several studies, or conservation guidelines article
			2	Bibliography, literature review, or status report
			3	Empirical study
Publication outlet	N		1	Journal article
			2	Book or book chapter
			3	Thesis or dissertation
			4	Government or university publication (part of a numbered series)

Appendix 2, cont.

Field	Type	Description	Values	Value description
			5	Symposium/workshop proceedings or transactions; if publication is in a proceedings but also part of a numbered govt. series (e.g., a USFS Gen. Tech. Report), it was entered as a government publication rather than a symposium proceedings
			6	Unpublished report (incl. state agency Federal Aid reports, unnumbered government publications, white papers, etc.)
			7	Popular magazine (e.g., Wyoming Wildlife)
Study area, size	N	Size of study area		Integer; note that this is often larger than the actual area over which data are actually collected
Study area, units	A	Units for size measurement, e.g. acres		
Sagebrush	N	No specific habitat types given other than "sagebrush"	Blank, 1, 2	Blank signifies that no description or mention of habitat type is given, usually true only for review articles or non-field (e.g., lab) studies; a "1" denotes that the habitat type is mentioned in the study area description, but that results are not explicitly given for that type; and a "2" denotes that results are reported for that particular habitat type
ARAR	N	Study occurs in low sagebrush habitats (*Artemisia arbuscula*)		
ARCA	N	Study occurs in silver sagebrush habitats (*Artemisia cana*)		
ARTR	N	Study occurs in big sagebrush habitats (*Artemisia tridentata*)		Note that this field is entered as "1" only if subspecific designations for big sagebrush are not mentioned in the text
ARTRTR	N	Study occurs in basin big sagebrush habitats (*Artemisia tridentata* ssp. *tridentata*)		
ARTRVA	N	Study occurs in mountain big sagebrush habitats (*Artemisia tridentata* ssp. *vaseyana*)		
ARTRWY	N	Study occurs in Wyoming big sagebrush habitats (*Artemisia tridentata* ssp. *wyomingensis*)		
Other *Artemisia*	N	Study mentions other *Artemisia* spp. than the ones listed above (e.g., *tripartita, longiloba*)		
Other shrubs	N			
Grasslands	N	Occurs, at least in part, in native grasslands		
Understory-forbs	N	Understories in sagebrush dominated by forbs		

Appendix 2, cont.

Field	Type	Description	Values	Value description
Understory-grasses	N	Understories in sagebrush dominated by grasses		
Understory-exotic	N	Understories in sagebrush dominated by exotic vegetation		
Riparian	N	Study occurs in riparian habitats		
Meadow	N	Study occurs in meadow habitats		
Pinyon-juniper	N	Study occurs in pinyon or juniper habitats		
Cheatgrass (*Bromus tectorum*)	N	Study either reports occurrence of sage-grouse in cheatgrass or describes conversion of native habitats to cheatgrass		
Cropland	N	Reports use of croplands, e.g., alfalfa, by grouse		
CRP	N	Use in Conservation Reserve Program (CRP) lands		
Crested wheatgrass	N	Study occurs in crested wheatgrass plantings		
Other non-native vegetation	N	Describes or reports results in non-native habitats other than cheatgrass, cropland, or crested wheatgrass; not understory		
Lekking	N	Study occurs during the lekking season; entered also if "pre-laying" is period of study		Assume if this field is checked that the study involves adult (non-juvenile) birds in breeding habitat
Nesting	N	Study covers the nesting season		
Brood rearing	N	Study covers the brood-rearing season		
Spring	N	Study occurs during spring, but no reporting by lekking/nesting/brood rearing		
Summer	N	Study occurs after the lekking season but before brood breakup; refers only to males or non-brooding hens during this period, otherwise would be nesting/brood rearing		

Appendix 2, cont.

Field	Type	Description	Values	Value description
Fall	N	Period following brood breakup but prior to any movements that may occur to winter habitat		
Winter	N	Study occurs on winter habitat		Encompasses from brood breakup until initiation of breeding/lekking behavior in spring, unless fall period is described separately
Year-round	N	Study occurs on year-round habitat, or does not report seasonal use		
Juvenile	N	Study applies to juvenile grouse		Juvenile is any bird <1 yr, i.e., chicks are not distinguished from other juveniles
Yearling	N	Applies to 1-yr old birds		
Adult	N	Study applies to adult grouse; if no mention of age, assumed adult		
Connectivity-fragmentation	N	Study reports impacts of fragmentation on sage-grouse and/or connectivity between habitats or populations		
Diet	N			
Anatomy-morphology	N			
Behavior	N			
Physiology	N			
Disease-parasites	N			
Distribution-mapping	N	Article includes range maps and/or distribution records		Not necessary that original data be used in maps
Habitat use-selection	N			
Environmental requirements	N	Reports requirements of birds, e.g., for food, cover		
Movement	N	Study reports general movements of sage-grouse		
Movement-dispersal	N	Study describes dispersal of grouse		
Movement-migration	N	Study reports or addresses migratory movements of sage-grouse		
Herbicides-pesticides	N	Study describes effects of herbicides or pesticides on sage-grouse or their habitats		

Appendix 2, cont.

Field	Type	Description	Values	Value description
Fire	N	Study discusses effects of prescribed fire or wildfire on sage-grouse or their habitats		
Livestock grazing[2]	N	Study discusses effects of grazing on sage-grouse or their habitats		
Agriculture	N	Study discusses effects of agricultural development on sage-grouse or their habitats		
Roads	N	Study discusses effects of roads, vehicles, or vehicular access on sage-grouse or their habitats		
Mineral-oil development	N	Study discusses effects of mineral, gas, or oil field exploration on sage-grouse or their habitats		
Power lines	N	Study discusses effects of power lines on sage-grouse or their habitats		
Recreation	N	Study discusses effects of recreational activities (e.g., off-road vehicle use, recreational shooting) on sage-grouse or their habitats		
Seeding forage	N	Study discusses effects of seeding forage for livestock (e.g., non-native perennial grasses) on sage-grouse or their habitats		
Fertilization	N	Study discusses effects of fertilization on sage-grouse or their habitats		
Urbanization	N	Study discusses effects of urban development on sage-grouse or their habitats		
Water development	N	Study discusses effects of water developments for livestock on sage-grouse or their habitats		
Shrub removal	N	Study discusses effects of sagebrush removal (e.g., from herbicides or mechanical treatment) for range improvement on sage-grouse or their habitats		

Appendix 2, cont.

Field	Type	Description	Values	Value description
Habitat restoration	N	Study describes habitat restoration activities as related to sage-grouse, including active restoration (e.g., prescribed fire, seeding of desired non-natives and native plant species), passive restoration (e.g., livestock removal, road access), and general habitat improvement techniques		
Translocation	N	Study involves translocations of sage-grouse		
Hunting	N	Study discusses effects of hunting on sage-grouse populations; also entered if article reports hunter harvest data, e.g., for wing analysis		
Predation	N	Study discusses effects of predation on sage-grouse populations		
Population growth rate	N	Study reports a measured population growth rate (i.e., lambda)		
Reproduction	N	Study reports quantitative measures of reproductive rates (e.g., fecundity, fertility, nest success)		
Mortality-survival	N	Study reports mortality or survival rates for a population(s)		
Population trends-lek counts	N	Study includes an assessment of population trends or abundance		
Genetics	N			
Techniques-methods	N	Study focuses on describing a new technique (e.g., trapping) or application of an existing technique specifically for sage-grouse		
Weather-climate	N	Study describes effects of weather on sage-grouse, e.g., survival or mortality, or of longer term climate patterns on changes in habitat quality		
Taxonomy	N			

Appendix 2, cont.

Field	Type	Description	Values	Value description
Models	N	Reports use or development of a model for sage-grouse populations or habitats		
Research needs	N	Reports and describes research needs for sage-grouse and their habitats		
Scale	N	Population scale	Blank, 1, 2	Blank denotes no mention of scale, when it would have been appropriate/helpful; a "1" denotes that some mention of scale occurs, whether of the individual (e.g., home range), a single population, or multiple populations; a "2" denotes that scale is not mentioned, but is not applicable in the article (e.g., a review article)
Comments	A	General field to note scope of work or issues		

[1] N = numeric; A = alphanumeric.

[2] Factors with gray shading ("Livestock grazing" through "Shrub removal") relate to traditional management and other land use practices that may occur on sagebrush-steppe habitats on public lands and thus may affect sage-grouse habitat or populations or both, but that are not undertaken specifically for the benefit of sage-grouse.

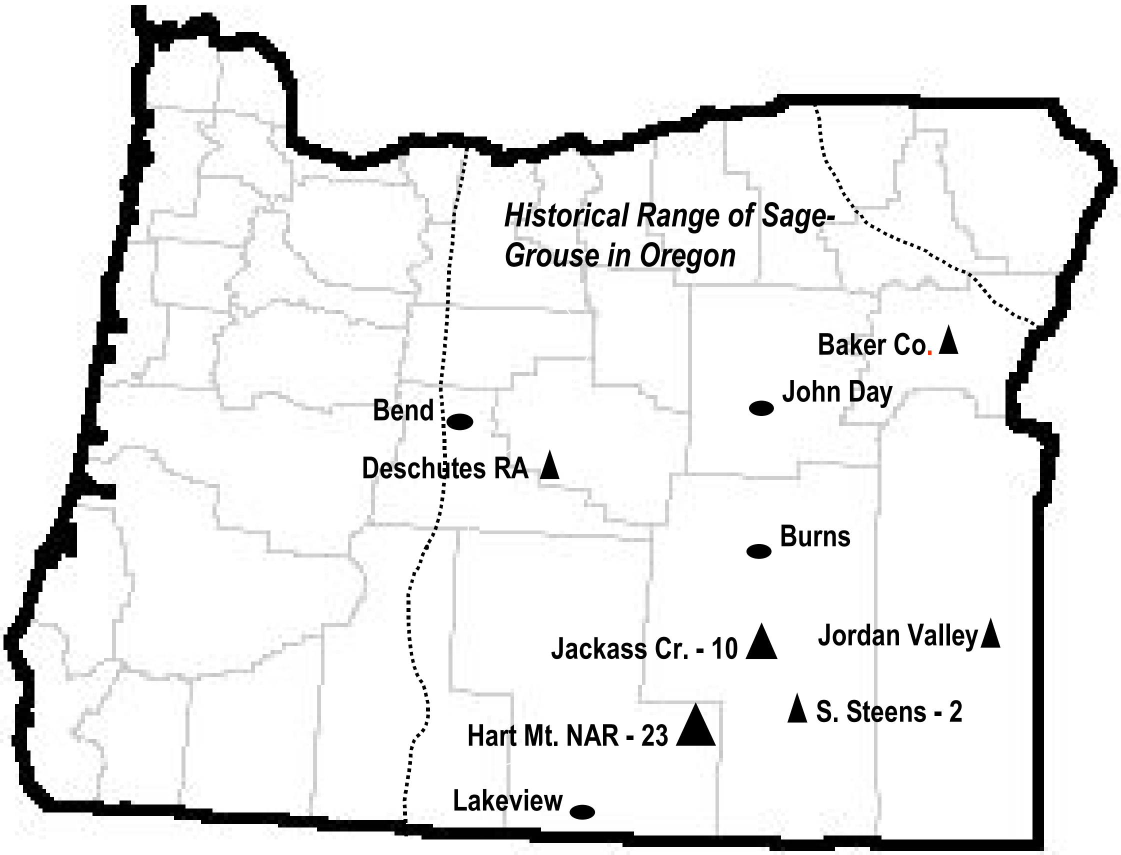

Fig. 1. Location of study areas (triangles) for sage-grouse research in Oregon. Numbers refer to number of publications and not to individual studies. State-wide surveys, such as lek counts and wing collections, are not included. Historical range is from Crawford and Lutz (1985).

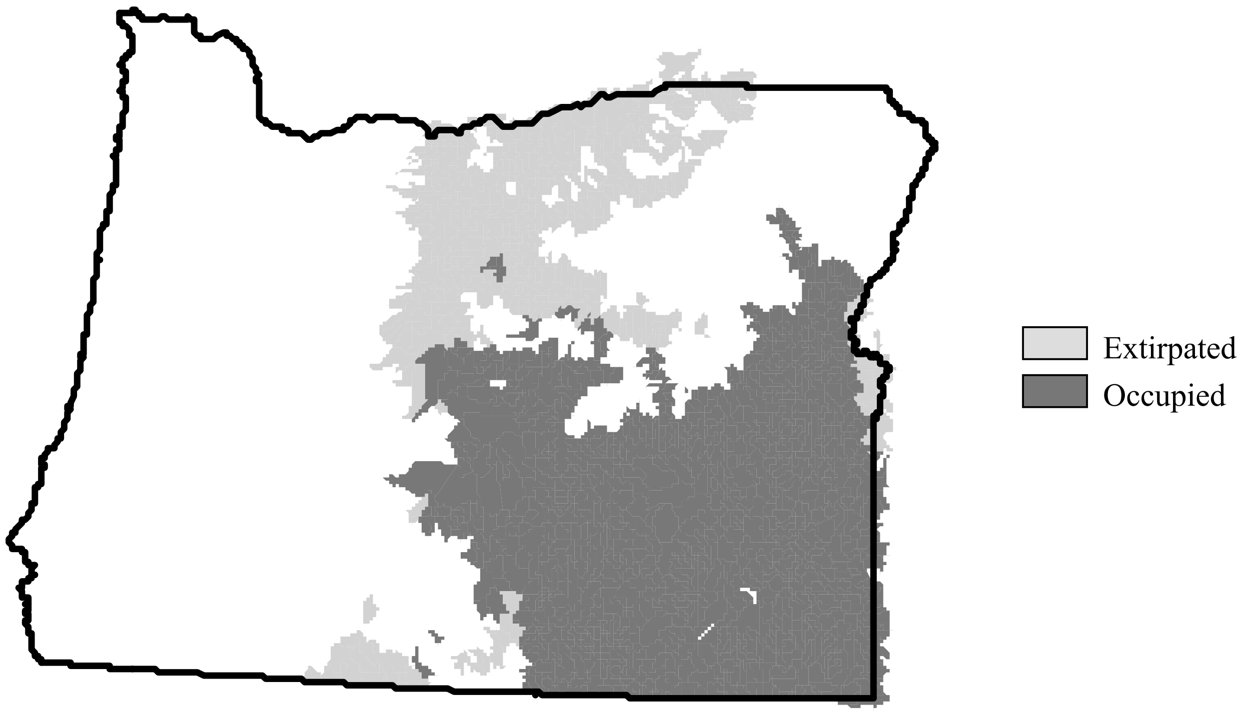

Fig. 2. Boundaries of extirpated versus occupied range of greater sage-grouse in Oregon (range map adapted from Schroeder et al. 1999).

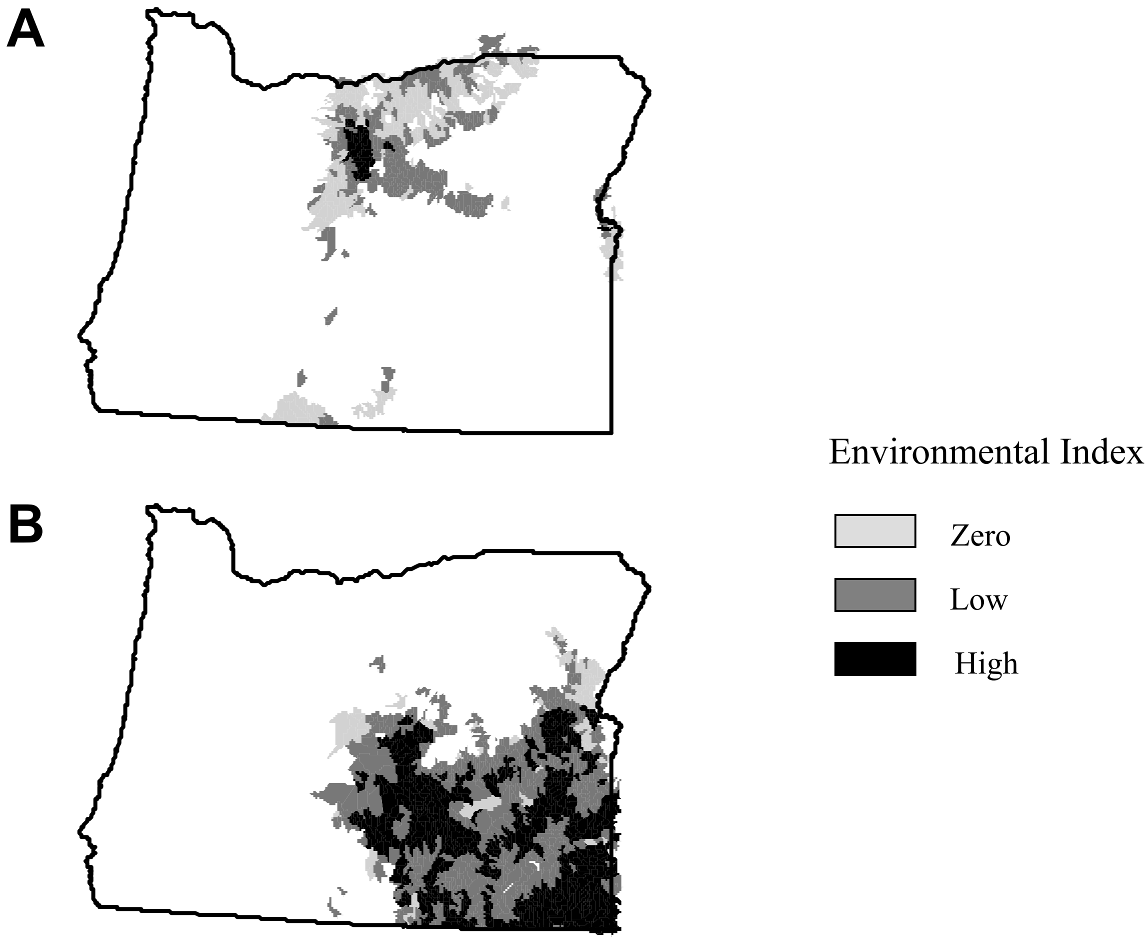

Fig. 3. Environmental index states of zero, low, and high for greater sage-grouse within (A) extirpated and (B) occupied subwatersheds in Oregon (current time period). Environmental index values ranged from 0 to 2, and states were classified as follows: >1, "high;" >0.1 but ≤1, "low;" and ≤0.1, "zero." Environmental index values were generated from the environmental index model developed by Raphael et al. (2001) for sage-grouse.