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RESEARCH AND MANAGEMENT OPTIONS TO ADDRESS INTERSPECIFIC
RELATIONSHIPS BETWEEN BARRED OWLS (*STRIX VARIA*) AND
SPOTTED OWLS (*S. OCCIDENTALIS OCCIDENTALIS* AND *S. O. CAURINA*)

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Abstract. The conservation of Spotted Owl (*Strix occidentalis*) populations in western North America has been one of the most controversial and visible conservation issues in United States history. At a time when Spotted Owl populations were declining coincident with losses of suitable habitat, the closely related Barred Owl (*Strix varia*) began to invade the northern regions of the Spotted Owl's range, after expanding its range across the North American continent in the last century. In the last three decades the Barred Owl's range has expanded southward essentially through the entire range of the Northern Spotted Owl (*S. o. caurina*) and a substantial portion of the range of the California Spotted Owl (*S. o. occidentalis*). Barred Owls are prey and habitat generalists, and relative to Spotted Owls appear to be stronger dispersers, have smaller home ranges, and have higher reproductive output. Anecdotal and correlative information strongly suggests that Barred Owls may be a new factor influencing the decline of some Spotted Owl populations. However, there is great uncertainty about the interspecific relationships of these two species where they are sympatric in British Columbia, Washington, Oregon and California. We posit that interspecific relationships are likely spatially and temporally dynamic. If this is a valid assumption, the effects of Barred Owls on Spotted Owl populations should vary geographically and will require region-specific data to understand the relationship between the two species. We believe the situation is potentially dire and that rapid research and management actions are required to inform the near- and long-term decision-making process for conservation of Spotted Owls.

In this document we outline 7 distinct research and management options to help scientists and managers better understand the relationship between these two species and effectively establish management strategies that favor Spotted Owls. We developed each option and then qualitatively evaluated its strengths, limitations, and ability to inform decision-making. We strongly advocate an active approach to addressing this issue, and therefore do not support an uninformed no-action option. Although some research on Barred Owl ecology has been conducted in eastern North America, only a few studies have been published on this species in the range of the Spotted Owl. We recommend that research specifically aimed at learning more about the interspecific relationships of these two owls throughout the range of sympatry should begin immediately. These studies should focus on comparative investigations of life history traits in conjunction with measures of animal density, habitat structure and prey populations. Studies in which Barred Owls are physically removed from selected study areas are potentially the most powerful way to understand the impact of Barred Owls on Spotted Owls. Given the continuing decline of Spotted Owl populations and the rapid rate of colonization by Barred Owls, natural history studies and removal experiments should be conducted concurrently, but in different areas. Ideally, experiments should occur in landscapes, or portions thereof, that are currently (or were recently) used for long-term demography research on Spotted Owls. Although we did not conduct a budget analysis for these projects, the costs of Barred Owl ecology studies could be similar to those realized in the last two decades of intensive research on Spotted Owls. We encourage the use of adaptive management principles to provide opportunities to learn quickly and modify research or management actions as needed.

INTRODUCTION

All 3 Spotted Owl subspecies (California, *Strix occidentalis occidentalis*; Northern, *S. o. caurina*; Mexican, *S. o. lucida*) are of conservation concern. Populations within all three subspecies are experiencing declines (California: Blakesley et al. 2001, LaHaye et al. 1994; northern: Anthony et al. 2005, Forsman et al. 1996; Mexican: Seamans et al. 1999). The Northern Spotted Owl and Mexican Spotted Owl are listed as threatened species under the provisions of the Endangered Species Act (United States Department of the Interior 1990, 1993). Although a recent petition to list the California Spotted Owl was rejected (United States Department of the Interior 2003), recent litigation has forced a reassessment of this petition denial. Declines in some populations coincided with, and were likely related to, the loss of suitable habitat resulting from commercial forest management (e.g. United States Department of the Interior 1990, 1992; Courtney et al. 2004).

In the decades prior to listing of the Northern Spotted Owl as a threatened species (1990), the range of the Barred Owl was expanding across the northern part of the North American continent. Barred Owls first came into contact with Spotted Owls in British Columbia (see Campbell 1973) and Washington (see Reichard 1974), perhaps in the 1960s, although the exact date is unknown. Since that time, Barred Owls have increased (Dunbar et al. 1991), exhibiting a post-colonization pattern typical of invading species (Sakai et al. 2001), and quickly expanding southward through Oregon and northern

California (Taylor and Forsman 1976, Dark et al. 1998). The distribution of Barred Owls now appears to completely overlap that of the Northern Spotted Owl (Gutiérrez et al. 2004). In addition, this range expansion has continued southward into the range of the California Spotted Owl, where a hybrid Barred Owl x Spotted Owl was recently documented in Placer County in the Sierra Nevada Mountains (Seamans et al. 2004).

The potential threat of Barred Owls to Spotted Owl populations was recognized as early as 1974 (Taylor and Forsman 1974), and then in subsequent species listing and draft recovery plan documents (Thomas et al. 1990; United States Department of the Interior 1990, 1992). Barred Owls are larger and apparently more aggressive than Spotted Owls, have comparatively smaller home ranges (Hamer 1988) and potentially greater reproductive output (J. Acker, personal communication), and they are considered habitat and prey generalists (Mazur and James 2000, Hamer et al. 2001). Barred Owls are strong dispersers (Mazur and James 2000; T. Fleming, personal communication), with numerous records far exceeding the dispersal distance reported for Spotted Owls (Forsman et al. 2002). The life history attributes of Barred Owls are characteristic of successful invaders (Sakai et al. 2001), and the ecological differences between the two species may place Barred Owls at a competitive advantage over Spotted Owls. It is also believed that Barred Owls may prey on Spotted Owls (Leskiw and Gutiérrez 1998), and although the extent of such predation is unknown, research on intraguild predation (Polis et al. 1989, Hakkarainen and Korpimäki 1996, Sergio et al. 2003) suggests that this threat has consequences similar to those resulting from competition (Lima and Dill 1990). Hybridization between the two species has been documented (Hamer et al. 1994, Kelly and Forsman 2004). This threat generally is considered less serious than resource and interference competition, although it may be significant if Spotted Owls become rare (see Randler 2002). Despite the absence of Barred Owls within the United States portion of the Mexican Spotted Owl's range, competition with Barred Owls was identified as a potential threat in the recovery plan for that subspecies (United States Department of the Interior 1995).

A competitive interaction that strongly favors Barred Owls could have serious consequences for Spotted Owls. Ongoing research indicates declining subpopulations of Spotted Owls in multiple demography study areas throughout the species' range (Anthony et al. 2005). The preponderance of evidence suggests these declines historically were related to the declining quantity of suitable Spotted Owl habitat resulting from timber harvest (United States Department of the Interior 1990). A substantive negative effect resulting from resource competition with Barred Owls could exacerbate this decline, and may already have contributed to it (Gutiérrez et al. 2004). For example, rates of decline for Spotted Owl subpopulations are highest in Washington, where densities of Barred Owls are believed to be highest within the range of sympatry (Anthony et al. 2005). Also, Barred Owl presence appeared to have a negative influence on Spotted Owl survival, particularly in Washington study areas (Anthony et al. 2005). Recent information also indicates a reduced probability of Spotted Owl occupancy when Barred Owls are present within 0.8 km of the Spotted Owl site center (Kelly et al. 2003). Several investigations have demonstrated some overlap in habitat (Hamer 1988, Herter and Hicks 2000, Pearson and Livezey 2003, Buchanan et al. 2004; see Gutiérrez et al.

2004) and prey use (Hamer et al. 2001) between the two owl species. None of the field studies or demography analyses, however, demonstrated a cause and effect relationship linking Barred Owls to the Spotted Owl population decline. Additional hypotheses to explain the continuing decline in Spotted Owl populations have yet to be tested (Gutiérrez et al. 2004).

Numerous studies have sought to demonstrate competitive interactions among closely related species. Nonetheless, there has been substantial controversy as to whether competition significantly shapes the structure of avian communities (Wiens 1983). Much of this controversy was due to inconsistent definitions of (and the resulting levels of emphasis placed on) factors such as shared resource use; resource limitation; and ecological, behavioral or fitness effects (Wiens 1989). In short, standards for demonstrating competition were not rigorous, and many studies that claimed a competitive effect were based on inference from observational or correlative analyses (Wiens 1989). For the purposes of the discussions herein, we followed Wiens (1989:7-8) in defining interspecific competition as “an interaction between members of two or more species that, as a consequence either of exploitation of a shared resource or of interference related to that resource, has a negative effect on fitness-related characteristics of at least one of the species.” Wiens (1989) presented criteria to verify, with differing levels of certainty, the occurrence of interspecific competition. These criteria, ordered from the least to most persuasive, are as follows: 1) observed patterns are consistent with those expected from predictions about the outcome of the interaction, 2) suspected competitive species overlap in their use of important resources, 3) demonstrability of intraspecific competition, 4) exploitation or interference competitive effects driven by one species results in reduced availability of limiting resources for another species, 5) one or more species is negatively affected by the suspected competitor, and 6) plausible alternate hypotheses are evaluated and rejected (Wiens 1989). The best way to demonstrate with reasonable certainty the occurrence of interspecific competition is to use experiments that manipulate resources or the density of the allegedly competing species. In a review of such studies, Wiens (1989) found that density studies more often than resource studies provided strong evidence of competition. The assessment below is based on this understanding of the analytical approaches used to demonstrate the existence of interspecific competition.

Some species have attributes that make them excellent candidates to successfully invade the ranges of other species. Among these attributes are the following: strong dispersal ability, high fecundity, healthy source population, dietary flexibility, and generalist habitat requirements (Ehrlich 1989, Sakai et al. 2001, Sol et al. 2002). In addition to these factors, however, certain ecological conditions act to control or limit the expansion of invasive species. Habitat requirements and landscape structure will dictate the potential colonization range for many species (Sakai et al. 2001). Expansion far from the source of the original population may be limited by gene flow that prevents adaptations in peripheral areas (Kirkpatrick and Barton 1997). In some cases, species interactions may favor native predators and therefore influence the rate or pattern of expansion (Sakai et al. 2001). Given the possibility that the influence of Barred Owls on Spotted Owls may vary geographically in response to a variety of such conditions and

that the interaction may be manifested in differing ways throughout the range of sympatry (see Table 1), we evaluated the research and management options with this uncertainty in mind.

The need to evaluate the efficacy of management activities and opportunities and to subsequently implement them is driven by the belief among many biologists that Barred Owls are influencing Spotted Owl subpopulations to one extent or another over much of the sympatric range. The activities and strategies presented in this document are largely based on this belief. We recognize the existence of substantial uncertainty on various aspects of this issue (Table 1), and certain other environmental and ecological factors should be included in investigations and not discounted until appropriately evaluated. For this reason, some research and management options described below ultimately should encompass more issues than Barred Owl-Spotted Owl interactions. We also recognize that the outcome of research and management actions may be more or less effective than anticipated. In this document we provide an overview of the variety and potential effectiveness of a suite of research and management options that are available to resource agencies, managers and landowners to evaluate the interspecific relationships between Barred Owls and Spotted Owls. These options could be used as tools to conserve populations of the latter species.

OVERVIEW OF MANAGEMENT OPTIONS

The management options contained in this report are representative of broad categories of possible actions that could be taken in a comprehensive research program. The list of options, originally presented by RJG at a workshop on Barred Owl and Spotted Owl management in June 2005, is not exhaustive, but we believe it captures the range of possibilities such that other, similar options not contained in the report can readily be evaluated with respect to those described. Some of the options are quite broad in their potential application. For this reason, some options are presented in greater detail to capture the most essential range of possible relevant actions. Even though some options may appear – inappropriately in our view – to be strictly management actions, all should be thought of in a research or monitoring context, and in some cases involving adaptive management (Holling 1978, Walters 1986). The options are presented sequentially to approximately coincide with the likely severity of effects on Barred Owl individuals or populations.

Within each option, a number of potential studies are suggested. These lists of potential studies are not meant to be exhaustive nor are they listed in terms of their priorities for gathering useful information to inform management. Rather, these potential studies are meant as a starting point for development of a structured research program that would be initiated to address the key management questions that eventually would be formulated. For presentation purposes, each option is mutually exclusive of other options in this document. We believe, however, that in some situations certain aspects of the options may be implemented together.

MANAGEMENT OPTION 1: NO ACTION

Description of option. The option to take no action can occur via two possible courses of inactivity: 1a) passive, or 1b) deliberate. This distinction is made because the processes involved to realize either outcome are quite different (see below).

Methods, logistics, timeframe. The general reason for Option 1a, passive inactivity, would be that regulatory or funding agencies or organizations were either unable to implement effectively or to authorize management action. Similarly, Option 1b, deliberate inactivity, would occur if regulatory or funding agencies or organizations made a deliberate decision not to implement or authorize management actions. It seems likely that Option 1b would be chosen if regulatory or funding agencies or organizations decided that management activities would be futile or that the cost of obtaining data required to inform decisions was greater than the potential value of subsequent conservation or management activities.

Option 1 contains a particularly sensitive time element, because it is the default option. This option is in effect until the timely implementation of other options that result in meaningful management decisions. A delay in implementation of other options results in default “adoption” (even if only temporarily) of Option 1 (and this applies to either sub-option). In addition, it is possible that Option 1b could be realized after other options had been implemented and evaluated. For example, if the results of research or management experiments suggest that an active role in management will not likely be successful or is unnecessary, a course of no-action might be considered appropriate.

Benefits of option. The only potential benefit of this option is short-term economic benefits to the responsible resource agencies, because the substantial costs associated with implementation of other options would not be required.

Limitations of option. There are a number of limitations of this option. First, it would involve taking a passive role in the management of a species that is considered threatened under the Endangered Species Act and may soon be endangered (in either the ecological or regulatory sense). Second, the option is inconsistent with the mandate of several resource management agencies in the region, and this could result in conflict with public expectations regarding responsible resource management. Third, the option does not produce information to inform decisions. Finally, significant delay in implementing other options may increase their potential costs and reduce the opportunity to make effective management decisions based on scientific data.

How option output might inform management decisions. The only output from this option that might inform decisions is related to an assessment of cost savings or future cost risk. Option 1b could contain an economic analysis of the estimated cost of full implementation of the various options across the sympatric range of the two owl species. This could be seen as an analysis of cost savings. On the other hand, a somewhat similar cost assessment could be done to predict, albeit with less certainty, the potential cost associated with delaying implementation of other options and the risk that future costs would be higher because of reduced opportunities.

MANAGEMENT OPTION 2: NON-EXPERIMENTAL ECOLOGICAL STUDIES

Description of option. Option 2 includes a vast array of possible investigations that could attempt to understand various aspects of the ecology and behavior of Barred Owls and Spotted Owls or to understand more specifically the relationships between the two species. For the purposes of discussion we have recognized two sub-options: 2a) observational studies on Barred Owl and Spotted Owl ecology, and 2b) observational studies on interactions between Barred Owls and Spotted Owls. Many of the studies possible under options 2a and 2b are potentially similar. The exception to this generality is that the study of a species' ecology often involves collection of data with little focus on the presence or influence of a species interaction whereas interaction studies are designed to address the interaction.

Methods, logistics, timeframe. Little has been published on the ecology and behavior of Barred Owls in western North America (Mazur and James 2000, Gutiérrez et al. 2004). Studies of Barred Owl ecology that should produce useful information include investigations of home range size, habitat use, prey use, demography (see particularly alternative hypotheses 2, 6, and 9 in Table 1), and aspects of natal dispersal (spatial patterns of travel, prey use, habitat use). Studies on many of these topics have been conducted on the Spotted Owl throughout much of its range (Verner et al. 1992, Gutiérrez et al. 1995, Courtney et al. 2004). Surprisingly, there is comparatively little information on prey availability, despite its range-wide variability (Verner et al. 1992, Gutiérrez et al. 1995, Courtney et al. 2004) and the likely influence of prey selection on habitat use (Newton 1979; see Zabel et al. 1995). Similarly, the habitat requirements of Spotted Owls during the dispersal period are poorly understood (Buchanan 2005, Miller et al. 1997) and warrant investigation given that Barred Owls and Spotted Owls may compete during dispersal. The geographic variability exhibited in most aspects of Spotted Owl life history from southwestern British Columbia to southern California (Verner et al. 1992, Gutiérrez et al. 1995, Courtney et al. 2004), coupled with the suspected plasticity of life requisites of the Barred Owl, suggests a similar pattern for the Barred Owl and a concomitant need for a wide geographic base of life history information on this species.

Species interaction studies (Option 2b) would include the topics mentioned above, but the research would be designed to investigate resource partitioning between the two species. These studies would need to occur where the species are sympatric and would include comparisons of spatial and temporal use of resources by the two species. Data would be obtained using intensive surveys or radio telemetry and should include comparative assessments of resource use (e.g. Hamer et al. 2001) or measures of occupancy or productivity of Spotted Owls in areas with differing levels of Barred Owl presence (e.g., Kelly et al. 2003, Pearson and Livezey 2003).

With the exception of demography research, many of these field studies can be completed in relatively short time periods, say 2 – 4 field seasons, although in some instances more time may be required. Such time periods may suffice for studies of

Barred Owl life history characteristics such as home range size, habitat use, and prey use. However, such short time periods for field studies requires one to assume static use of resources by Barred Owls (or Spotted Owls). If resource use by either species is density dependent (Fretwell and Lucas 1970), studies will need to be conducted over longer temporal scales (or with temporal replicates) to adequately measure variability that exists in a study area. This is likely an essential consideration in landscapes with changing densities of Spotted Owls and Barred Owls and to determine if source habitats (Pulliam 1988) become “ecological traps” (Delibes et al. 2001, Kokko and Sutherland 2001, Battin 2004). The recent and ongoing demography studies on Northern Spotted Owls required a minimum of 4 years of data to obtain one estimate of lambda (Burnham et al. 1996), with the 14 Spotted Owl studies having a mean of 14.5 yrs of data through 2003 (Anthony et al. 2005). Although many field studies of Spotted Owls were only 2 – 4 years in duration, some of these have been extensions of previous projects, which means that studies have often been much longer. In addition, some studies of resource use may require 1 – 3 years of pre-project surveys to document locations of owl territories (Forsman 1983). Landscapes with changing densities of owls will require ongoing survey or monitoring efforts. It is not reasonable to assume that we can attain as high a level of knowledge of Barred Owl ecology in a short period of time as we have for Spotted Owls, but we can gain important comparative information in a 4 – 6 year period.

Radio telemetry studies are uniquely capable of generating information on spatial and temporal use of resources of nocturnal species. A variety of telemetry studies is possible, and can be used to address issues relative to Options 2a and 2b. All telemetry data contain error, and most telemetry studies acknowledge this error in the analysis of the data. Potential sources of error include that associated with triangulation (particularly with respect to movement by birds between signal recordings), spatial scale of inferred patch use, and classification of used locations in heterogeneous cover types (Rettie and McLoughlin 1999). Investigations of interspecific interactions using radio telemetry will require addressing these sources of error, as well as temporal factors (Beyer and Haufler 1994), sample size considerations and related issues of sample independence (Swihart and Slade 1985a, 1985b). Behavioral studies may require more data to better understand temporal and spatial aspects of sympatry. In some cases, it may not be possible to effectively use telemetry to investigate behavioral interactions (Rettie and McLoughlin 1999).

Prior to conducting field investigation there may be some basic methodological issues to address that have bearing on important field procedures used to study the owls. For example, it is not clear that Barred Owls respond as readily to Spotted Owl calls as they do to taped or imitated Barred Owl calls. Results of surveys for Barred Owls will be most effective and meaningful when response rates strongly reflect the actual density of Barred Owls in a landscape. Similarly, there is some evidence that Spotted Owls are more difficult to detect, on a per visit basis, when Barred Owls are present compared to when Barred Owls are not known to be present (Olson et al. 2005), a hypothesis that can be tested experimentally (Crozier et al. In Review). Understanding the relationship between Barred Owl presence and Spotted Owl detection probability will influence the outcome of species interaction studies where the ability to find resident birds will be a

key study design component. Finally, studies have shown that some owls respond differently to a suspected “stranger” than to a familiar “neighbor” (Galeotti and Pavan 1993, Waldo 2002).

Benefits of option. Compared to the Spotted Owl we know little about Barred Owls in western North America (Gutiérrez et al. 2004). Investigations of Barred Owl ecology (Option 2a) would provide additional information that could be used to infer relationships between this species and the Spotted Owl, and consequently have value for scientific and management purposes. Studies that focused on interspecific relationships (Option 2b) would likely allow for comparatively stronger inference than those in Option 2a. Basic autecological studies, such as examination of dietary overlap and competition for habitat and space between the two species, are still needed to better understand the potential for competition. Moreover, these studies might provide the basic avenue for developing non-lethal management strategies. For example, discovery of significant differential use of habitats or resource partitioning between Spotted Owls and Barred Owls in specific physiographic regions or habitat types could direct management efforts toward those areas.

Limitations of option. The types of studies included in this option do not elucidate causal relationships because they do not control confounding effects. Although a substantial amount of natural history information may be generated, some of which may be strongly suggestive of a negative competitive relationship, neither competition nor its underlying mechanisms will be identified by these studies.

There are also potential limitations in the methodologies used to collect and analyze data in Option 2 studies. For example, telemetry or other use vs. availability studies do not necessarily establish clear relationships between selection or preference of habitats and measures of fitness (Garshelis 2000). In addition, the level of sampling required to establish a detailed understanding of behavioral interactions between the two owls may be logistically demanding given some of the constraints associated with telemetry (Rettie and McLoughlin 1999, Adams 2001).

The temporal component of Option 2 may also be a limitation because Barred Owls are moving rapidly into more areas occupied by Spotted Owls with concomitant changes in densities of both species (Gutiérrez et al. 2004). If Barred Owls are negatively impacting Spotted Owls, these rapid changes in range and density may influence the relationship between the two owl species prior to the development of meaningful knowledge from research projects, which would reduce the opportunity to effectively implement certain management actions. For this reason, activities in Option 2 should be initiated without delay and should include temporal replicates.

How option output might inform management decisions. There are a number of ways in which observational studies might produce information that informs decisions. We believe that research could produce information relative to several of the alternate hypotheses developed to describe the potential consequences of Barred Owl range expansion on Spotted Owl populations (in particular, hypotheses 2, 4, 5, 6, 7, 8 and 9 in

Table 1). In addition, results from some of these studies may guide aspects of projects within other options. For example, observational studies would provide the necessary background natural history and ecological information to better develop research hypotheses and designs in the experimental approaches that we have suggested.

MANAGEMENT OPTION 3: HABITAT MANAGEMENT THAT FAVORS SPOTTED OWLS

Description of option. This option is based on the assumption that particular habitat conditions favor Spotted Owls over Barred Owls. The option has two suboptions: 3a) observational assessments of species responses to extant habitat conditions, and 3b) responses of species to experimental silvicultural treatments. Option 3a is a passive approach that evaluates differences in occupancy or demographic parameters as a function of specific aspects of habitat use. In contrast, Option 3b is an active endeavor that seeks to understand owl responses to experimental silvicultural treatments that favor Spotted Owls.

Methods, logistics, timeframe. The two approaches contained in this option use different methods to understand and potentially identify habitat conditions that favor Spotted Owls. Option 3a would rely on descriptive habitat studies and ongoing site monitoring, such as those identified in Option 2, which link quantitative measures of forest structure with owl occupancy or demography. This option takes advantage of situations where we know or suspect that Barred Owls are uncommon or absent in landscapes that continue to support Spotted Owls. Such areas currently exist throughout the range of the Spotted Owl (Gutiérrez et al. 2004).

The more experimental Option 3b involves actively attempting to create forest conditions that favor Spotted Owls over Barred Owls. For example, it is theoretically, if not practically, possible to manage forests in such a way as to test the hypothesis that forests with dense canopies or certain kinds of tree structure are more likely to be occupied by Spotted Owls than by Barred Owls (hypothesis 7 in Table 1). This suboption should be linked to demography data as a measure of whether conditions favor Spotted Owls. Investigation would likely focus on habitats used within the home range, although habitat use during natal dispersal may also provide valuable information for management given that the two species may compete for resources during dispersal. Both suboptions likely require radio telemetry to monitor owls and estimate their use of forest areas; issues identified in Option 2 with respect to challenges involving spatial and temporal use of resources apply here as well. Each suboption potentially addresses hypotheses 4, 6, and 7 (Table 1).

It is beyond the scope of this document to propose specific silvicultural treatments that should be used in an attempt to identify conditions that favor Spotted Owls. The first indicators of habitat conditions that favor Spotted Owls – should such conditions exist – will likely be derived at a coarse scale from territory occupancy and at a finer scale from radio telemetry studies of owls in landscapes where the two owl species are sympatric (Option 3a). Efforts to locate such habitat conditions will require broad sampling

because favorable conditions may be unique to geographic regions or forest associations. Coarse-scale data currently exist from ongoing demography studies. However, the temporal component of Option 3a for fine scale studies could easily involve a decade or more of field time. In addition, experimental tests of the effects of silvicultural treatments on large predators like Spotted Owls and Barred Owls would necessarily require the coordinated application of the same treatment to many, very large experimental units, involving treatment of hundreds or thousands of acres within each owl home range, with careful attention to the spacing of the treatments relative to known nest sites and roost areas. It is unknown whether this is possible within the context of current laws and regulations regarding management of Spotted Owl habitat. In addition, we caution that silvicultural treatments should only be conducted for this purpose when there is information to guide the development of treatments. Such information could be generated as results from research conducted under Option 2 (see below).

Once the favorable conditions are identified (assuming they exist), we recommend that a formal adaptive management program that attempts to replicate these conditions be implemented, but only within the context of a management plan that takes into account all of the objectives for the management area (Option 3b). The amount of time required to implement a meaningful silviculture strategy will be influenced by the type of silviculture used and the factors that dictate rates of harvest, including, but not limited to unit layout, road construction, area management strategies, and market conditions. Single treatments that remove forest structure to create the necessary conditions might be accomplished in comparatively short time periods (years), whereas activities that require subsequent forest growth and development will take far longer (decades). But even at longer scales, predictions can be made about trajectories of tree growth, species composition and forest structure, and then monitored over time. Such monitoring will provide evidence about the efficacy of the strategy well before it reaches its final destiny. Considered at a spatial scale needed to create conditions to support Spotted Owl subpopulations, these activities could take multiple decades before desired conditions are realized; evaluating whether the experiments were successful could take even longer. Due to localized use of much younger forests in parts of northern California (Folliard et al. 2000), the time frame for this element may be shorter there than elsewhere in the range of the Spotted Owl. Regardless, studies examining the effects of silvicultural treatments would be best implemented as a true experiment designed within an adaptive management framework. In addition, some of the proposed observational studies in Option 2, which describe Barred Owl habitat use, would be necessary to develop and refine specific silvicultural prescriptions used as treatments.

Identifying and evaluating forest conditions that favor Spotted Owls must be conducted at different spatial scales. This multi-scale approach will be necessary to distinguish between source and sink landscapes (Pulliam 1988) or to recognize the presence of ecological traps (Kokko and Sutherland 2001, Schlaepfer et al. 2002, Battin 2004). Identification of favorable landscape-level conditions could change if Barred Owl densities change and latter colonists use the favored habitat conditions. For this reason, the initial value assessment of a forest type, a spatial configuration of patches, or a certain

density of trees could change through time. This possibility would require continued monitoring of the effectiveness of the favorable habitat condition (in either suboption).

Benefits of option. This option requires a critical evaluation of the relationship between stand structure and habitat quality as measured by fitness. This is currently being done on some of the Spotted Owl demography study areas. Such information is critical not only for understanding of owl biology, but also could facilitate a more integrated approach to balancing owl conservation and forest management, particularly on nonfederal lands.

The current Northern Spotted Owl demographic studies are at a point in their development that the information needed to evaluate these relationships are now becoming available. Linking fitness traits of owls with forest conditions has always been a primary goal of these long-term monitoring projects (e.g., Franklin et al. 2000), but because of the longevity of Spotted Owls and the slow rate of forest change it has taken many years to accumulate sufficient temporal variation in these factors to allow meaningful analyses. Thus, the value of the owl demographic studies to management questions regarding the Barred Owl invasion increases greatly with each passing year. It is therefore imperative that these studies continue as an integrated part of an overall Spotted Owl and Barred Owl management strategy.

Limitations of option. A number of components to this option could substantially limit its usefulness. Our inability – beyond a rather coarse-level understanding – to clarify the relationship between stand structure and habitat quality for Spotted Owls suggests that deriving a fine-grained understanding of Barred Owl habitat use may be very difficult. In addition, sufficient autecological information on habitat use by both Spotted Owls and Barred Owls would be needed to identify the specific silvicultural treatments to be used and evaluated. Thus, Option 2 would likely need to be implemented before this option could be considered.

There are potentially important temporal and spatial issues associated with Option 3. Although it might be possible to find existing conditions that favor Spotted Owls in the short-term, creating forest conditions that favor the owl would likely require a longer time period and would be less certain in their outcome. In long-lived species like Spotted Owls and Barred Owls, treatment effects are ideally measured over long periods of time based on changes in survival or reproductive rates of owls on the experimental plots. Short-term studies in which owls are observed for only a few years pre- and post-treatment may provide little useful information regarding the effects of the treatment. In addition, conditions that appear to favor Spotted Owls may change through time if Barred Owl densities increase and these favored areas become more attractive to Barred Owls and are also invaded. A potential complication related to spatial scale could exist if the spatial extent of forest patches favored by Spotted Owls and not used by Barred Owls is patchy (and this seems likely), allowing Barred Owls to exist between or adjacent to patches and therefore reducing the benefit of the patch to Spotted Owls. Finally, the spatial scale for meaningful implementation of forest management that favors Spotted Owls over Barred Owls may be so great that it is infeasible to produce.

Option 3b is active and requires the modification of owl habitat. The risks of this approach are that a) the treatments may fail to create the desired conditions, b) the forest conditions resulting from treatments may eventually be used by Barred Owls if their densities increase, and c) the variability of forestry treatments may be so great as to preclude inference on response to treatments. The risk of conducting treatments in Spotted Owl habitat could be addressed by conducting the experiments in federal matrix lands or nonfederal Habitat Conservation Plan areas where “take” has been authorized by the U.S. Fish and Wildlife Service. In addition, the California Spotted Owl technical assessment team developed a strategy that minimized the long-term risk to owl habitat (Verner et al. 1992), and strategies developed within the context of Barred Owl/Spotted Owl interactions could consider the development of strategies with respect to minimizing long-term risk. For example, experiments treating areas formerly occupied by Spotted Owls and currently occupied by Barred Owls could examine whether such treatments are useful in determining abandonment of areas by Barred Owls and re-occupation by Spotted Owls due to habitat changes favoring Spotted Owls.

The final issue to consider is a management constraint. A search for areas where habitat conditions favor Spotted Owls over Barred Owls, if such areas exist or can be identified, may identify lands that are not designated for protection (regardless of ownership). This management issue is beyond the scope of this document, but it does represent a potentially important issue that may prove difficult to resolve.

How option output might inform management decisions. This option clearly has promise for managers because it can help move decision making from the current relatively passive strategy into the realm of active adaptive management. Indeed, this was one of the goals of the Northwest Forest Plan, which has not been realized (Johnson et al. 2004). Therefore, despite limitations outlined above, this option could serve as a catalyst to moving land management agencies into the arena of true adaptive management.

MANAGEMENT OPTION 4: DIVERSIONARY OR SUPPLEMENTAL FEEDING

Description of option. This option involves supplementing the diets of target species in one of two ways. In Option 4a, food would be provided to Barred Owls in such a way as to divert them from sympatric areas that support Spotted Owls (i.e., diversionary feeding). In Option 4b, food would be provided to Spotted Owls to augment their diets (supplemental feeding).

Methods, logistics, timeframe. Little work has been conducted on the use of diversionary feeding in birds. The most noteworthy work that used diversionary feeding in a management application occurred in the United Kingdom, in response to conflicts over raptor predation of Red Grouse (*Lagopus lagopus scoticus*), an important game species (Redpath et al. 2004). In this system, Hen Harriers (*Circus cyaneus*) prey most heavily on grouse during their most vulnerable juvenile stage. The mortality inflicted on grouse can be severe enough to depress populations greatly. Therefore, an experiment

was designed where harriers were provided carcasses of rats primarily at feeding stations within the territories of breeding harrier pairs. As a result, the harriers took these provisions as a consistent and readily available source of food (Amar et al. 2004). This artificial feeding produced a critical diversion from predation of Red Grouse chicks during their most critical life stage. The result was that populations of Red Grouse increased due to reduced predation of chicks by experimental diversionary feeding (i.e., Hen Harrier territorial pairs, which were not fed, preyed heavily on grouse chicks and depressed overall grouse populations).

Supplemental feeding has commonly been used to investigate the importance of food supply on life history features such as abundance, reproduction timing, growth, survival, productivity and dispersion (e.g. Dijkstra et al. 1982, Gjerdrum 2004), as well as to address conservation issues essential to species with small populations (e.g. Bretagnolle et al. 2004). Research and application has involved a divergent group of bird species, including passerines, game birds, seabirds and raptors (Wilson 2001, Jodice et al. 2002, Guthery et al. 2004). Among raptors, recent work using supplemental feeding has shown that providing extra food may a) increase mass of adults (Dewey and Kennedy 2001) or nestlings (Hipkiss et al. 2002) at the breeding site, b) increase nestling survival (although not necessarily in all years; Ward and Kennedy 1996, Dewey and Kennedy 2001, Hipkiss et al. 2002), c) increase nest site attentiveness by adults (Dewey and Kennedy 2001), or d) increase survival of captive-bred birds near release sites (Meek et al. 2003). In addition, the success of efforts to reintroduce Peregrine Falcons (*Falco peregrinus*) to the North American continent was to some extent dependent on the ability to increase the likelihood of survival of juveniles at hack sites via provisioning of food (Cade and Burnham 2003). Supplemental feeding of a small number of dispersing Spotted Owls has been conducted in British Columbia (Jared Hobbs, Ministry of Water, Land and Air Protection; personal communication).

A program of supplemental feeding of Spotted Owls could include feeding in at least three situations: 1) at the nest site during the breeding season, 2) during the non-breeding season (i.e., adults on winter portion of home ranges; juveniles during natal dispersal), and 3) in any season following release of captive-reared or captive maintained birds. All situations would involve locating the owls and then offering them food in a manner similar to that done during surveys in which biologists feed live mice to owls in order to document nesting status (Forsman 1983). Supplemental feeding at nest sites would be more efficient (in terms of field effort) than in other seasons because locations of many nest sites are known, so logistics would be comparatively reduced in that season. Feeding in other seasons, particularly in regions where annual home ranges are very large, would necessarily involve use of radio telemetry to efficiently find owls on a regular basis without attracting predators or competitors (Godbois et al. 2004). This option is likely to be most effective as a short-term action. Monitoring would be needed to investigate responses such as productivity, nestling growth rates, fledging rates, mass retention (during winter or dispersal), or survival. A comprehensive experimental design would allow a better understanding of the relationship between the two owl species given differing levels of prey.

Benefits of option. Well-designed experiments using supplemental prey should shed light on the relationship between the two owl species. By conducting such experiments in different seasons it may be possible to determine whether the strength of the interspecific interaction varies seasonally, or potentially in response to other factors (e.g. seasonal differences in habitat use, winter weather conditions, elevation). Such knowledge would have value for population management, particularly where populations of Spotted Owls have declined to very low levels. Monitoring in captive release programs that use supplemental feeding may generate information on physical condition (e.g. body mass) that improves program effectiveness. This option may be valuable in the short-term until better information from other options becomes available. Benefits of a diversionary feeding program are not clear at this time.

Limitations of option. A basic assumption under this option is that the two owl species are competing for prey and that other interaction factors are less important; this assumption has not been evaluated. The most powerful scientific inference relating to the competitive relationship of the two owl species that is possible under this option will require the simultaneous control of factors such as prey availability. The lack of a consistent effect of prey supplementation, as demonstrated in studies of other raptors (Dewey and Kennedy 2001, Hipkiss et al. 2002), requires knowledge of prey populations. Prey availability studies will add substantially to the basic costs of the option (e.g. radio telemetry). In addition, there is an implicit assumption that supplemental feeding will work with Spotted Owls (i.e., that owls can effectively be located and when located will take offered food). However, in one experimental attempt to evaluate the effectiveness of supplemental feeding on California Spotted Owls, the experiment failed because the owls did not use the same amount of food offered in alternative years (M. Seamans, Z. Peery, and R. J. Gutiérrez, personal observation). Finally, this option is most likely effective only in helping to evaluate competitive interactions of the two species and not as an ongoing management strategy, as it would otherwise require active management in perpetuity, and would not necessarily address the primary causal factor.

How option output might inform management decisions. The results of experimentation contained in this option could clarify the relationship between the two owl species (but see above). However, we are skeptical as to whether this option has utility for managing Barred Owl or Spotted Owl populations, except perhaps where Spotted Owl populations have experienced extreme reductions (e.g. in British Columbia). From a management perspective, the cost and effectiveness of providing supplemental prey should be compared with removal experiments and strategies. Given the results of a limited experiment above, the cost of supplemental feeding will likely be much more than removal experiments and this is especially compelling when the strength of inference from the result is considered.

MANAGEMENT OPTION 5: DISRUPT BARRED OWL REPRODUCTION

Description of option. This option involves using one or more of several techniques to disrupt and ultimately prevent the successful reproduction of Barred Owls.

Methods, logistics, timeframe. This option involves either short-term or long-term disruption. Short-term disruption would be single season disruption of reproduction whereas long-term disruption would be multiple or even life-time prevention of reproduction by individuals. Short-term disruption could be accomplished through avian reproductive contraceptives, oiling or removal of eggs, egg replacement, and possibly disturbance activities that disrupt nesting (e.g. climbing nest trees). Oiling of eggs has been used to control reproductive output in Double-crested Cormorants (*Phalacrocorax auritus*; Blackwell et al. 2002). Egg removal and egg replacement have been used in efforts to manage urban-nesting gull (*Larus* spp.) populations (Ickes et al. 1998). Egg replacement may be a more practical means to influence reproduction than egg removal because some species will lay additional eggs after failure of the initial clutch (Wood and Collopy 1993, Williams and Miller 2003); Barred Owls may renest after a failed clutch, although there is little information on their re-nesting probability (Mazur and James 2000). All these techniques require a field component to locate nests. Removing eggs or egg replacement will require tree climbers. Methods that involve noise disturbance to disrupt nesting may require a greater field effort because the amount of disturbance necessary to disrupt nesting may involve multiple visits to the nest, whereas egg removal/replacement can be done in a single visit. If eggs are taken early in incubation, visits to determine whether renesting has occurred will be necessary; greater efficiency may be realized by taking eggs later in incubation.

Wildlife contraception is an expanding field and has been utilized in both birds and mammals (see www.aphis.usda.gov/ws/nwrc/research/reproductive_control/index.html). There are a number of contraceptives for birds, some of which have the potential to inhibit reproduction for an entire breeding season (Yoder et al. 1998, Yoder et al. 2004; see Hood et al. 2000). A potential route for delivering contraceptives to Barred Owls is through feeding of live mice that have been treated with the contraceptive. Similar techniques, but using nontreated mice, are used to determine Spotted Owl reproductive rates in the field (Forsman 1983).

Long-term disruption could be achieved through surgical sterilization of individuals or through immunocontraceptive vaccines. Sterilization has been used in a variety of management contexts, including efforts to reduce predation of domestic livestock by coyotes (*Canis latrans*; Bromley and Gese 2001; see Tuytens and MacDonald 1998), and in management of big game populations (Merrill et al. 2003). Sterilization is not likely to be an effective primary method to evaluate competitive effects because it does not control the competitive effect. However, if sterilizing territorial Barred Owls on the perimeter of the experimental removal area reduces the likelihood of Barred Owls reinvading the area, this technique may have utility. Sterilization could also be expensive because individual owls would have to be captured, transported, housed, and then re-released using approved methods. In addition, it is likely that a veterinarian would be required to perform the necessary surgery. Recently, an immunocontraceptive vaccine has been developed for mammals, which requires only a single dose that lasts up to 2 years (Miller et al. 2004). For long-term disruption of Barred Owl reproduction, an ideal solution would be a single dose immunocontraceptive vaccine that can be delivered orally (i.e., through live mice as bait) and that lasts for

multiple breeding seasons. Research on such a vaccine through another agency (e.g., USDA/APHIS/ National Wildlife Research Center) that has already been working on similar vaccines for wildlife should be encouraged.

Benefits of option. The primary benefit of this management approach is that it potentially does not involve lethal removal. Initially, this option could be useful in buffer zones established adjacent to experimental removal landscapes. However, buffer zones only provide a benefit if failed breeders remain on territory and subsequently reduce the amount of colonization pressure from external Barred Owls on the removal areas. Documentation of reproductive behavior by Barred Owls following short-term disruption would provide new information about the annual reproductive capability of the species (see Mazur and James 2000) whereas the effects of long-term disruptors on Barred Owl populations would provide new information for similar problems with other wildlife species. Clearly, more information is needed on immunocontraceptive vaccines for birds that act as long-term disruptors before the benefits of this option can be fully evaluated. If use of such a vaccine were a viable alternative, predictive modeling of Barred Owl populations under various vaccination scenarios would be useful to determine the efficacy of this option.

Limitations of option. There are a number of practical limitations – both ecological and logistical – to this option. First, the described methods for disrupting Barred Owl reproduction serve only to limit recruitment into Barred Owl subpopulations via local reproduction, and do not address the potential effects of interference competition between Spotted Owls and Barred Owls. However, in the short-term this option might impede growth of Barred Owl populations and, in the long-term, diminish or cause extinction of Barred Owl populations, depending on the availability and strength of long-term disruptors and levels of outside recruitment. This may not be a serious limitation in areas of low Barred Owl densities. Also, the option does not account for the effects of Barred Owl recruitment via dispersal from external breeding areas. Noise disturbances necessary to disrupt Barred Owl nesting may be substantial and would likely disturb other species, potentially including Spotted Owls. In addition, this approach requires locating Barred Owl nests, a field effort that would likely be time-consuming. Finally, it appears likely that some short-term disruption (e.g. nest disruption) will be more time consuming (and perpetual), more costly, and less effective than the methods for which it is an alternative (e.g. removal experiments).

How option output might inform management decisions. This option does not produce a body of knowledge that would likely guide future management activities. This option is primarily directed toward controlling Barred Owl populations and appears to have primarily short-term utility.

MANAGEMENT OPTION 6: REMOVAL EXPERIMENTS

Description of option. A direct experimental approach to determine the influence of Barred Owls on Spotted Owls would be to remove Barred Owls from areas occupied by Spotted Owls, and then evaluate the following: a) the population trajectory of Spotted

Owls in areas with and without Barred Owls; b) rates of reproduction and survival of Spotted Owls in removal and non removal areas; c) changes in occupancy rates of Spotted Owl sites; d) population responses of Spotted Owls in demographic study areas before and after removal of Barred Owls; e) characteristics of the relationship between Barred Owls and Spotted Owls in areas of sympatry; and f) feasibility of using removal as a management option.

Methods, logistics, timeframe. Removal activities have been used to evaluate many ecological relationships and to address vexing wildlife management issues. Competitive interactions between species in numerous studies have been investigated using removal experiments (see Wiens 1989, Abrams 2001). Typically, in the design of these studies one species was removed (or its density modified) and then the response of another species in terms of its social status, resource use (territory or food) or fitness was measured (Wiens 1989, Martin and Martin 2001). Other studies have removed predators or brood parasites to evaluate their influence on the population dynamics of target species (Korpimaki and Norrdahl 1998, Schmidt et al. 2001, Smith et al. 2003), or to address species management conflicts. Examples of such removal activities include control of Brown-headed Cowbirds (*Molothrus ater*) to reduce brood parasitism of endangered species such as Kirtland's Warbler (*Dendroica kirtlandii*; Mayfield 1961) and Least Bell's Vireo (*Vireo bellii pusillus*; Rothstein et al. 2003) and removal of Common Ravens (*Corvus corax*) and other predators to protect nesting Sandhill Cranes (*Grus canadensis*; Littlefield and Ivey 2002).

The two most likely approaches to a removal study that evaluates the effects of Barred Owls on Spotted Owls would be lethal removal or translocation. The primary methods for lethal removal of Barred Owls would include trapping and shooting; use of either approach will require use of decoy lures to attract the owls and would be done in accordance with relevant ethical treatment protocols (Cuthill 1991). After the Barred Owls within a certain area have been removed, repeated monitoring would be necessary to prevent or minimize colonization by other Barred Owls. This may pose a paradoxical challenge in that monitoring may require techniques designed to attract owls (e.g. decoy lures) to the removal landscape; it may be necessary to establish lure and removal buffers around control landscapes to minimize any effect of this activity on resident Spotted Owls. A removal experiment using direct lethal control is by far the most cost effective and efficient way to undertake this experiment. We believe this method holds the most promise for conducting removal experiments.

Translocation has been successfully used in other species conservation programs, one of the more notable examples being that of the Red-cockaded Woodpecker (*Picoides borealis*) (DeFazio et al. 1987). Translocation might be used, with different purposes, with respect to either owl species. If Spotted Owls were present only at very low densities in some landscapes, translocation would be a potential means to accelerate colonization after Barred Owl removal. However, if translocation was used in this capacity, the possible effect of translocation itself also must be evaluated. This is an important consideration because translocated animals may experience changes in physiology (Sigg et al. 2005) or survival rates (Van Zant and Wooten 2003), and must

adjust to their new landscapes (Woodroffe 2003). Fostering has also been used as a means to manage populations (Wallace and Buchholz 2001, Cade and Burnham 2003), and may have utility in the present context.

The other application of translocation would involve Barred Owls. Translocation of Barred Owls away from the removal landscape would be expensive, and raises the problem of where to release the birds. For example, Barred Owls could not be released in areas having Spotted Owls for obvious reasons. Translocating Barred Owls to other regions may result in the inappropriate infusion of genetic traits into other resident populations, and would result in intraspecific competition with resident Barred Owls in release areas. These concerns should be evaluated, however, as the use of nonlethal methods may have more public support or engage more diverse research partnerships.

Removal activities to evaluate interspecific relationships between Barred Owls and Spotted Owls should be conducted with an experimental design that includes random assignment of treatment and controls, replication, and blocking of confounding factors. If such a study is undertaken, we recommend that a committee of scientists and managers be convened to design the experiment. Factors to consider in the design would be appropriate sampling units, response variables (e.g. occupancy, survival), confounding factors, critical design features, and so on. Clearly, such a design must be considered carefully and critically and different alternatives need to be explored. For example, if Barred Owls are thought of as being analogous to a disease, there might be experimental designs and approaches in the medical literature that could be applied here. Landscapes with existing monitoring data would likely provide more immediate understanding of potential competitive effects because the outcome of removal experiments could be related to estimates of occupancy, survival and reproductive activity used in existing demographic research (Anthony et al. 2005).

Spotted Owls in some areas will move substantial distances from the breeding area during the nonbreeding season (Forsman et al. 1984, Hamer 1988), and this movement may require additional considerations for experimental design. For example, it should be comparatively easier to control for year-round effects of competition with Barred Owls for those Spotted Owls with relatively contiguous areas of use in the breeding- and nonbreeding seasons compared to Spotted Owls that have distinctly separate areas of use during the breeding and nonbreeding periods. This may be particularly relevant if the non-breeding areas of use exist outside the landscape where Barred Owls are controlled or their densities are documented. In either case, radio telemetry may be necessary to determine patterns of space use in order to determine the spatial extent of the removal required. Removal experiments to evaluate the ability of juveniles to survive or maintain body condition during dispersal would obviously have to occur in large landscape areas and may be exceptionally difficult to implement.

If such large-scale experimental removal is not possible, inference can likely be made with respect to removal during the breeding season in the immediate vicinity of the nest. Inference derived from this type of study design may be influenced by the season of greatest competitive effects. If competition is operational in all seasons Barred Owl

competition during the nonbreeding season could potentially influence Spotted Owl condition such that an effect might not be detectable even with complete control in the breeding area. For example, it is possible that Spotted Owls may not breed even in the absence of Barred Owls if they were in poor condition after competing with the latter for resources prior to the breeding season. On the other hand, if competition is significant only during the breeding season (e.g. via interference competition) it may be possible to derive strong inference following removal of Barred Owls from the vicinity of Spotted Owl nests.

The time frame for conducting removal experiments will vary in response to a number of factors. First, the level of effort will be influenced by knowledge of known site locations. If the work is conducted in landscapes where Spotted Owl sites are already known, there will be little start-up time. Conversely, conducting removal in landscapes that have not been surveyed will require more time to locate all the Spotted Owl sites so they can be monitored. We assume that using landscapes with known site histories or at least known site locations would be desirable because this improves the likelihood of demonstrating an effect, if one exists. For example, a before-after-treatment-control design where treatment is removal of Barred Owls is one experimental design that may be useful. However, this type of design would necessitate using landscapes, such as some of (or portions of) the existing Spotted Owl demographic study areas, where pre-treatment data have been collected.

Second, the ability to recognize an effect, if one is present, will also depend on the density of Spotted Owls in the study area or on their ability to colonize the study area from nearby sites. In landscapes that currently support Spotted Owls, we would expect to see rapid increases in measures of occupancy following the removal of Barred Owls, as Spotted Owls recolonize the areas from which Barred Owls have been removed. These increases may be evident immediately, although annual variation in occupancy and productivity of Spotted Owls (Forsman et al. 1996, Anthony et al. 2005) may obscure some patterns in the short term. In contrast, in landscapes with no Spotted Owls, a reduction of Barred Owls may not produce a noticeable effect in the short-term because the landscape first must be repopulated with Spotted Owls. Given that Barred Owls are essentially ubiquitous, their presence and density may influence dispersal behavior by Spotted Owls and the process of study area recolonization. This factor must be addressed to distinguish between the absence of a competitive effect associated with the breeding area and an effect associated with recolonization difficulties.

The density of Barred Owls may influence our ability to recognize a competitive effect and therefore expand temporal requirements necessary to recognize unambiguous patterns or relationships. If the competitive interaction between owl species is weak in landscapes with low densities of Barred Owls, recognizing an effect following the removal of Barred Owls may be difficult or require an extended study period. For this reason, the outcome of removal experiments in landscapes that support higher densities of Barred Owls should provide greater confidence in the relationships revealed. The “ideal” density of Barred Owls necessary to demonstrate an effect following removal will

likely vary in response to a variety of environmental conditions; it may be difficult or undesirable to account for this source of variability.

In summary, the amount of time that might be required to identify a competitive effect of Barred Owls on Spotted Owls could be influenced by the density or isolation of either owl species and the amount of existing information on the location of known sites. In addition, other factors that may influence the ability to understand the interspecific interactions include management directives associated with certain land designations. For example, an ideal study landscape may include or be adjacent to an area where control of Barred Owls would be valuable but not possible due to resource management philosophy. Given the suite of conditions outlined above, it may be possible to see an effect almost immediately, but a reasonable time frame to capture variation in survival or productivity and to account for unknown complications might be on the order of 4-6 years. As in all the other options, we advocate use of an adaptive process whereby management experiments are initiated and then modified in stages based on the outcome of specific treatments. We also stress the importance of developing a comprehensive, large-scale experimental design before removal experiments are initiated. Nevertheless, the importance of conducting a removal experiment is to partition the decline in Spotted Owls among confounding factors (e.g. Barred Owls vs. habitat loss, vs weather effects).

Benefits of option. Researchers have attempted to demonstrate the presence of competitive interactions in nature for years. Many of these investigations were based on weak inference or did not control for the effects of other factors, and the value of these investigations has been hotly debated in the scientific community (Connell 1983, Schoener 1983, Wiens 1989, Laska and Wootton 1998, Berlow et al. 1999, Abrams 2001). While the existence of competition is not doubted, Wiens (1989) cautions that only the most carefully designed and executed studies will demonstrate this unambiguously. Studies that control for the potential significance of ecological factors have the greatest utility to demonstrate competition. For this reason, Option 6 provides the only way, unless confounded by unanticipated factors, to specifically identify whether Barred Owls have a negative effect on Spotted Owls and the magnitude of that effect. Removal of Barred Owls in an experimental approach would be an efficient treatment and would provide reliable information more quickly than descriptive studies. We anticipate that the level of effort, and therefore potentially the cost, to conduct a removal experiment may be less than that of ecology studies.

Limitations of option. Wiens (1989) pointed out several factors that may complicate the results of studies designed to evaluate competitive effects. These factors included: a) the masking of competitive effects due to unrealized strength of intraspecific competition, b) inappropriate spatial or temporal considerations, c) an unanticipated response to the treatment, and d) the influence of other species that may compete with one of the target species. In addition, a removal experiment that resulted in changes in occupancy or reproduction in Spotted Owls may not be definitive if it was not clear whether the response was caused by competition for food or space. These and other potential confounding factors should be evaluated in the design phase of experiments.

How option output might inform management decisions. This management option should provide the strongest inference regarding the magnitude of the competitive interaction. For this reason, the option may provide the most immediate information of value to managers. It should also be possible to generate estimates of cost and feasibility to modify the experimental treatments to more large-scale control programs.

MANAGEMENT OPTION 7: ONGOING CONTROL OF BARRED OWLS

Description of option. This option would use removal techniques to eliminate Barred Owls from some portion of the Spotted Owl's range. This option differs from Option 6 by extending beyond the experimental phase to a longer-term or permanent control of Barred Owls in the particular landscape. We assume that this option would be instituted only upon effects demonstrated through removal experiments.

Methods, logistics, timeframe. Eradication programs have been used to remove invasive species that were impacting native species and/or ecosystems. Some well-documented programs have included removal of feral cats (*Felis catus*) and Norway rats (*Rattus norvegicus*) from islands that support seabird colonies (Nogales et al. 2004, Taylor et al. 2000). These programs have used trapping, hunting, poisoning, or disease introduction, sometimes in combination (Taylor et al. 2000, Nogales et al. 2004), to exterminate predators. The islands where these eradication programs were employed were generally small (Taylor et al. 2000); for example, about 80% of the islands where feral cat control had occurred were <5 km² (Nogales et al. 2004). Many of the eradication programs were successful in removing the target invasive species and preliminary results indicate that seabird populations have responded favorably (Nogales et al. 2004). Other eradication programs have also generally been small in spatial scale (Mack et al. 2000).

Methods required for this option include some of those outlined for Option 6. The two relevant methods include lethal and non-lethal removal. The latter approach adds costs and ecological concerns to the program for the same reasons outlined in the discussion of the translocation method under Option 6.

The timeframe for this option is dependent on the outcome of removal experiments, the size and accessibility of the control area and the number or density of Barred Owls. It is currently unknown if removal experiments will unambiguously demonstrate competitive relationships between the two owl species. Assuming that a competitive relationship is demonstrated, it will only be at that time that the feasibility and cost of using the methods developed in the removal experiment at a larger landscape scale can be estimated. Obviously, removal efforts will be more difficult and time-consuming in remote landscapes where access is limited. We expect that the cost or effort to remove Barred Owls will be density dependent at first, as more Barred Owls will be encountered (initially) in high-density areas than in low-density areas. We suspect that periodic control may suffice to substantially modify populations, but this needs to be evaluated. If experimental removals cause Spotted Owl populations to increase, and a decision is made to adopt this method as a management tool, the timeframe for extending the removal to

larger landscapes will depend on funds and staffing. Also, any decision to implement Barred Owl removal at the scale of entire landscapes or regions would require a full assessment of the pros and cons of such a drastic measure to decide if it is feasible and ecologically defensible.

Preparation for possible control may prove beneficial, for example, should Barred Owls show susceptibility to West Nile Virus, a disease known to affect this species (Fitzgerald et al. 2003, Gancz et al. 2004), or to other diseases that may occur. If Barred Owls are equally or more sensitive to West Nile Virus than Spotted Owls, it may be possible to protect Spotted Owls and initiate removals on disease-impacted and reduced populations of Barred Owls.

Benefits of option. This option likely involves greater benefits than any other of the options we evaluated. Unless it can be demonstrated that Spotted Owls and Barred Owls can coexist, or that certain forest cover types or structures favor Spotted Owls and can be managed to that end, the only remaining options for Spotted Owl conservation may be a conscious decision to either remove the threat of Barred Owls, or to let the interaction between the two species play itself out without direct human intervention. Should the decision be to remove Barred Owls, this option can be implemented in conjunction with removal experiments or could be coupled with long-term disruptors of reproduction to reduce the extent of lethal control.

Limitations of option. The primary limitation to this option is that related to cost. Given the contiguous distribution of Barred Owls across North America (Mazur and James 2000) and their substantial dispersal capability (T. Fleming, personal communication), population control areas will always be within the range of source populations that would provide a constant supply of colonizers. The solution, in this case, would be to develop an ongoing “maintenance control” program (Mack et al. 2000, Schardt 1997). The cost of this program would reflect the spatial extent of permanent population control desired.

Additional considerations involve risk to non-target species (Howald et al. 1999) and the palatability of a control program to the public (Mack et al. 2000). These are important but not insurmountable concerns, however, because training of control personnel could effectively eliminate mortality of non-target species, and it should be possible to educate the public about the threat(s) posed by Barred Owls in the region. Such a control program is in some respects similar to ongoing efforts, acceptable to the public, to control or eliminate species such as the European Starling (*Sturnus vulgaris*).

How option output might inform management decisions. As this option is the penultimate action possible it does little to inform management decisions if adopted. The only possible exception to this is that it may be possible to evaluate “maintenance control” at larger spatial scales than might be used in control experiments. If eradication (or maintenance control), even at a small spatial scale, is the only option that will conserve Spotted Owl populations, a decision not to take this action results in realization of Option 1.

DISCUSSION

When presented with these options, will decision-makers have a clear path on which to move forward with Spotted Owl conservation and management? We believe the answer to this question is “yes.” Before summarizing the research and management options and making recommendations, we briefly review the management of Brown-headed Cowbirds in North America, with the intent of drawing on the experience of researchers and managers in that arena and identifying similar issues of concern that relate to Barred Owl/Spotted Owl interactions.

The Brown-headed Cowbird is an obligate brood parasite that is known to lay eggs in the nests of other passerines, including endangered species (Lowther 1993). Cowbird nestlings are larger than their host nest-mates and this provides them a competitive feeding advantage over the host-species nestlings (Lowther 1993). For this reason, cowbird parasitism can reduce the nest success of hosts. This is a concern to managers because: a) a substantial number of host species are experiencing population declines, and b) the distributional range of the Brown-headed Cowbird has expanded on the North American continent in the past century (Rothstein and Peer 2005). These two concerns are similar to those associated with the relationship between Barred Owls and Spotted Owls.

Programs to manage Brown-headed Cowbird parasitism of host species remain controversial (Rothstein and Peer 2005). First and foremost, evidence linking cowbird nest parasitism to declines in host populations is ambiguous, and other factors, typically those related to habitat, are often identified as more credible factors limiting population growth or stability. It is likely, however, that Brown-headed Cowbirds limit local populations even when other factors are influential. Second, information indicating a positive response by host species to local control of cowbirds is ambiguous, again suggesting the likely importance of other factors. Third, cowbird population trends are declining in some parts of North America and cowbird parasitism rates vary regionally, indicating that widespread control efforts may not be warranted. Fourth, some view cowbird control as a permanent program while to others it is considered a stop-gap measure until proximate factors are adequately addressed through management. Fifth, some interest groups have used cowbird control as a mitigation measure at the expense of actions designed to address proximate factors. Finally, there is little information on the effectiveness of cowbird control programs to benefit species of management concern (Rothstein and Peer 2005). Some components of the Brown-headed Cowbird management story parallel those of the current situation involving Barred Owls and Spotted Owls; other components are obvious pitfalls that must be avoided.

In the face of uncertainty and controversy involving the Brown-headed Cowbird control effort, Rothstein and Peer (2005) identified several prerequisites to engaging in control or other management efforts. Most of the factors they identified apply in some way to the current management situation involving interactions between Barred Owls and Spotted Owls. We slightly modified Rothstein and Peer’s (2005) original questions in a

manner relevant to the Barred Owl/Spotted Owl situation: 1. Are Barred Owls the primary factor causing declines in Spotted Owl populations? 2. What are the demographic thresholds that should trigger Barred Owl management? 3. What are the explicit goals of a Barred Owl control program? 4. Can landscape-level features reduce the competitive effects of Barred Owls on Spotted Owls? 5. Can we model Spotted Owl demography well enough to determine whether Barred Owl control can be ended if Spotted Owl populations stabilize or increase? Using what we know about Barred Owls and Spotted Owls, assessing the risks associated with current trends in Spotted Owl populations, and using lessons derived from ongoing Brown-headed Cowbird control efforts, we recommend the following strategy to address the interaction between Barred Owls and Spotted Owls.

We recommend a variety of approaches be used, but with an emphasis on experimentation, to better understand the interactions between Barred Owls and Spotted Owls. Research on various aspects of Barred Owl life history should prove useful, and may be particularly valuable in terms of implementation of subsequent research and management actions. Most significantly, we believe that decisive, unambiguous results are most desirable, and for this reason recommend the use of a strongly experimental approach, one that includes removal experiments to measure the strength of interspecific interactions. Consequently, Option 6 is potentially the most powerful source of inference, and the answers to the questions raised in the preceding paragraph may be most effectively provided with such experimentation. Options 2 and 3 provide the greatest potential for improving our understanding of Barred Owl ecology and habitat use, although Option 3 has potentially substantial spatial and temporal limitations. Options 4 and 5 have lesser and more short-term utility, although Option 5 may have promise for longer-term non-lethal control. Although Options 2 – 5 have the potential to directly support Options 6 or 7, none of them provide the same level of certainty. We do not endorse uninformed implementation of Option 1.

Because of the rapid spread of Barred Owls and the status of Spotted Owl populations through much of the region (Anthony et al. 2005, Gutiérrez et al. 2004), we believe that research and management activities should be implemented immediately. Management experiments should be designed to use principles of adaptive management where appropriate. We recommend that a panel of scientists be convened to design research projects that incorporate removal experiments. To avoid unnecessary delays that may result in undesirable complications due to changing conditions (Green and Hirons 1991, D'Antonio et al. 2001, Oppel et al. 2004), both short- and long-term actions should be initiated simultaneously (i.e., particularly options 2 and 6). It may also be beneficial to initiate other investigations that are not covered by this overview (e.g. potential relationships between Barred Owls and other species, or other types of ecological relationships; Korpimäki and Norrdahl 1998, D'Antonio et al. 2001, Ekerholm et al. 2004).

A great amount of knowledge on Spotted Owls has been generated throughout much of the region in the last two decades. Consequently, it seems most logical to use some of the areas used in these research or monitoring efforts for research and

management activities involving Barred Owls. This will expedite the research effort by using landscapes with known Spotted Owl locations and by providing estimates of baseline ecological and demographic conditions. It may be wise to develop predictive models to evaluate potential risks in other landscapes (Mikami and Kawata 2004, Norris 2004).

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LITERATURE CITED

- Abrams, P.A. 2001. Describing and quantifying interspecific interactions: a commentary on recent approaches. *Oikos* 94:209-218.
- Adams, E.S. 2001. Approaches to the study of territory size and shape. *Annual Review of Ecology and Systematics* 32:277-303.
- Amar, A., B. Arroyo, S. Redpath, and S. Thirgood. 2004. Habitat predicts losses of Red Grouse to individual Hen Harriers. *Journal of Applied Ecology* 41:305-314.
- Anthony, R.G., E.D. Forsman, A.B. Franklin, D.R. Anderson, K.P. Burnham, G.C. White, C.J. Schwarz, J. Nichols, J.E. Hines, G.S. Olson, S.H. Ackers, S. Andrews, B.L. Biswell, P.C. Carlson, L.V. Diller, K.M. Dugger, K.E. Fehring, T.L. Fleming, R.P. Gerhardt, S.A. Gremel, R.J. Gutiérrez, P.J. Happe, D.R. Herter, J.M. Higley, R.B. Horn, L.L. Irwin, P.J. Loschl, J.A. Reid, and S.G. Sovern. 2005. Status and trends in demography of Northern Spotted Owls, 1985-2003. *Wildlife Monographs* 163. [in press]
- Battin, J. 2004. When good animals love bad habitats: ecological traps and the conservation of animal populations. *Conservation Biology* 18:1482-1491.
- Berlow, E.L., S.A. Navarette, C.L. Briggs, M.E. Powers, and B.A. Menge. 1999. Quantifying variation in the strengths of species interactions. *Ecology* 80:2206-2224.
- Beyer, D.E. and J.B. Haufler. 1994. Diurnal versus 24-hour sampling of habitat use. *Journal of Wildlife Management* 58:178-180.
- Blackwell, B.F., M.A. Stapanian, and D.V.C. Weseloh. 2002. Dynamics of the Double-crested Cormorant population on Lake Ontario. *Wildlife Society Bulletin* 30:345-353.
- Blakesley, J.A., B.R. Noon, and D.W. Shaw. 2001. Demography of the California Spotted Owl in northeastern California. *Condor* 103:667-677.
- Bretagnolle, V., P. Inchausti, J.-F. Seguin, and J.-C. Thibault. 2004. Evaluation of the extinction risk and of conservation alternatives for a very small insular population: the Bearded Vulture *Gypaetus barbatus* in Corsica. *Biological Conservation* 120:19-30.

- Bromley, C. and E.M. Gese. 2001. Surgical sterilization as a method of reducing coyote predation on domestic sheep. *Journal of Wildlife Management* 65:510-519.
- Buchanan, J.B. 2005. Managing habitat for dispersing Northern Spotted Owls: are the current management strategies adequate? *Wildlife Society Bulletin* 32:1333-1345.
- Buchanan, J.B., T.L. Fleming, and L.L. Irwin. 2004. A comparison of Barred and Spotted Owl nest-site characteristics in the eastern Cascade Mountains, Washington. *Journal of Raptor Research* 38:231-237.
- Burnham, K.P., D.R. Anderson, and G.C. White. 1996. Meta-analysis of vital rates of the Northern Spotted Owl. *Studies in Avian Biology* 17:92-101.
- Cade, T.J. and W. Burnham (editors). 2003. Return of the Peregrine Falcon: a North American saga of tenacity and teamwork. The Peregrine Fund, Boise, Idaho.
- Campbell, R.W. 1973. Coastal records of the Barred Owl for British Columbia. *Murrelet* 54:25.
- Connell, J.H. 1983. On the prevalence and relative importance of interspecific competition: evidence from field experiments. *American Naturalist* 122:661-696.
- Courtney, S.P., J.A. Blakesley, R.E. Bigley, M.L. Cody, J.P. Dumbacher, R.C. Fleischer, A.B. Franklin, J.F. Franklin, R.J. Gutiérrez, J.M. Marzluff, and L. Sztukowski. 2004. Scientific evaluation of the status of the Northern Spotted Owl. Sustainable Ecosystems Institute, Portland, Oregon.
- Crozier, M.L., M.E. Seamans, R.J. Gutiérrez, P.J. Loschl, R.B. Horn, S.G. Sovern, and E.D. Forsman. In Review. Does the presence of Barred Owls suppress calling behavior in Spotted Owls? *Condor*.
- Cuthill, I. 1991. Field experiments in animal behaviour: methods and ethics. *Animal Behaviour* 42:1007-1014.
- D'Antonio, C., L.A. Meyerson, and J.S. Denslow. 2001. Exotic species and conservation: research needs. Pages 59-80 in Soulé, M.E. and G.H. Orians (editors). *Conservation biology: research priorities for the next decade*. Island Press, Washington, DC.
- Dark, S.J., R.J. Gutiérrez, and G.I. Gould, Jr. 1998. The Barred Owl (*Strix varia*) invasion in California. *Auk* 115:50-56.
- DeFazio, J.T., Jr., M.A. Hunnicutt, M.R. Lennartz, G.L. Chapman, and J.A. Jackson. 1987. Red-cockaded Woodpecker translocation experiments in South Carolina. *Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies* 41:311-317.
- Delibes, M., P. Gaona, and P. Ferreras. 2001. Effects of an attractive sink leading into maladaptive habitat selection. *American Naturalist* 158:277-285.
- Dewey, S.R. and P.L. Kennedy. 2001. Effects of supplemental food on parental-care strategies and juvenile survival of Northern Goshawks. *Auk* 118:352-365.
- Dijkstra, C., L. Vuursteen, S. Daan, and D. Masman. 1982. Clutch size and laying date in the Kestrel (*Falco tinnunculus*): effect of supplementary feeding. *Ibis* 124:210-213.
- Dunbar, D.L., B.P. Booth, E.D. Forsman, A.E. Hetherington, and D.J. Wilson. 1991. Status of Spotted Owl, *Strix occidentalis*, and Barred Owl, *Strix varia*, in southwestern British Columbia. *Canadian Field-Naturalist* 105:464-468.

- Ehrlich, P.R. 1989. Attributes of invaders and the invading processes: vertebrates. Pages 315-328 in Drake, J.A., H.A. Mooney, H.A. DiCastrì, R.H. Groves, F.J. Kruger, M. Rejmánek, and M. Williamson (editors). *Biological invasions: a global perspective*. Wiley and Sons, New York, New York.
- Ekerholm, P., L. Oksanen, T. Oksanen, and M. Schneider. 2004. The impact of short-term predator removal on vole dynamics in a subarctic-alpine habitat complex. *Oikos* 106:457-468.
- Fitzgerald, S.D., J.S. Patterson, M. Kiupel, H.A. Simmons, S.D. Grimes, C.F. Sarver, R.M. Fulton, B.A. Steficek, T.M. Cooley, J.P. Massey, and J.G. Sikarskie. 2003. Clinical and pathologic features of West Nile Virus infection in native North American owls (family Strigidae). *Avian Diseases* 47:602-610.
- Folliard, L.B., K.P. Reese, and L.V. Diller. 2000. Landscape characteristics of Northern Spotted Owl nest sites in managed forests of northwestern California. *Journal of Raptor Research* 34:75-84.
- Forsman, E.D. 1983. Methods and materials for locating and studying Spotted Owls. USDA Forest Service General Technical Report PNW-162.
- Forsman, E.D., R.G. Anthony, J.A. Reid, P.J. Loschl, S.G. Sovern, M. Taylor, B.L. Biswell, A. Ellingson, E.C. Meslow, G.S. Miller, K.A. Swindle, J.A. Thraikill, F.F. Wagner, and D.E. Seaman. 2002. Natal and breeding dispersal of Northern Spotted Owls. *Wildlife Monographs* 149:1-35.
- Forsman, E.D., S. DeStephano, M.G. Raphael, and R.J. Gutiérrez (editors). 1996. Demography of the Northern Spotted Owl. *Studies in Avian Biology* 17.
- Forsman, E.D., E.C. Meslow, and H.M. Wight. 1984. Distribution and biology of the Spotted Owl in Oregon. *Wildlife Monographs* 87:1-64.
- Franklin, A.B., D.R. Anderson, R.J. Gutiérrez, and K.P. Burnham. 2000. Climate, habitat quality, and fitness in Northern Spotted Owl populations in northwestern California. *Ecological Monographs* 70:539-590.
- Fretwell, S.D. and H.L. Lucas, Jr. 1970. On territorial behavior and other factors influencing habitat distribution in birds. I. Theoretical development. *Acta Biotheoretica* 19:16-36.
- Galeotti, P. and G. Pavan. 1993. Differential responses of territorial Tawny Owls (*Strix aluco*) hooting of neighbours and strangers. *Ibis* 135:300-304.
- Gancz, A.Y., I.K. Barker, R. Lindsay, A. DiBernardo, K. McKeever, and B. Hunter. 2004. West Nile Virus outbreak in North American owls, Ontario, 2002. *Emerging Infectious Diseases* 10:2135-2142.
- Garshelis, D.L. 2000. Delusions in habitat evaluation: measuring use, selection, and importance. Pages 111-164 in Boitani, L. and T.K. Fuller (editors). *Research techniques in animal ecology: controversies and consequences*. Columbia University Press, New York, New York.
- Gjerdrum, C. 2004. Parental provisioning and nestling departure decisions: a supplementary feeding experiment in Tufted Puffins (*Fratercula cirrhata*) on Triangle Island, British Columbia. *Auk* 121:463-472.
- Godbois, I.A., M.L. Conner, and R.J. Warren. 2004. Space-use patterns of bobcats relative to supplemental feeding of Northern Bobwhites. *Journal of Wildlife Management* 68:514-518.

- Green, R.E. and G.J.M. Hirons. 1991. The relevance of population studies to the conservation of threatened birds. Pages 594-633 in Perrins, C.M., J.-D. Lebreton, and G.J.M. Hirons (editors). Bird population studies: relevance to conservation and management. Oxford University Press, Oxford, United Kingdom.
- Guthery, F.S., T.L. Hiller, W.H. Puckett, Jr., R.A. Baker, S.G. Smith, and A.R. Rybak. 2004. Effects of feeders on dispersion and mortality of bobwhites. *Wildlife Society Bulletin* 32:1248-1254.
- Gutiérrez, R., M. Cody, S. Courtney, and D. Kennedy. 2004. Assessment of the potential threat of the Northern Barred Owl. Chapter 7 in Courtney, S.P., J.A. Blakeley, R.E. Bigley, M.L. Cody, J.P. Dumbacher, R.C. Fleischer, A.B. Franklin, J.F. Franklin, R.J. Gutiérrez, J.M. Marzluff, and L. Sztukowski. Scientific evaluation of the status of the Northern Spotted Owl. Sustainable Ecosystems Institute, Portland, Oregon.
- Gutiérrez, R.J., A.B. Franklin, and W.S. LaHaye. 1995. Spotted Owl (*Strix occidentalis*). Pages 1-28 in Poole, A. and F. Gill (editors). The birds of North America, No. 179. The Academy of Natural Sciences, Philadelphia, PA, and The American Ornithologists' Union, Washington, DC.
- Hakkarainen, H. and E. Korpimäki. 1996. Competitive and predatory interactions among raptors: an observational and experimental study. *Ecology* 77:1134-1142.
- Hamer, T.E. 1988. Home range size of the Northern Barred Owl and Northern Spotted Owl in western Washington. Master's thesis, Western Washington University, Bellingham, Washington.
- Hamer, T.E., E.D. Forsman, A.D. Fuchs, and M.L. Walters. 1994. Hybridization between Barred and Spotted Owls. *Auk* 111:487-492.
- Hamer, T.E., D.L. [sic] Hays, C.M. Senger, and E.D. Forsman. 2001. Diets of Northern Barred Owls and Northern Spotted Owls in an area of sympatry. *Journal of Raptor Research* 35:221-227.
- Herter, D.R. and L.L. Hicks. 2000. Barred Owl and Spotted Owl populations and habitat in the central Cascade Range of Washington. *Journal of Raptor Research* 34:279-286.
- Hipkiss, T., B. Hornfeldt, U. Eklund, and S. Berlin. 2002. Year-dependent sex-biased mortality in supplementary-fed Tengmalm's Owl nestlings. *Journal of Animal Ecology* 71:693-699.
- Holling, C.S. 1978. Adaptive environmental assessment and management. John Wiley and Sons, New York, New York.
- Hood, G.M., P. Chesson, and R.P. Pech. 2000. Biological control using sterilization viruses: host suppression and competition between viruses in non-spatial models. *Journal of Applied Ecology* 37:914-925.
- Howald, G.R., P. Mineau, J.E. Elliott, and K.M. Cheng. 1999. Brodifacoum poisoning of avian scavengers during rat control on a seabird colony. *Ecotoxicology* 8:431-447.
- Ickes, S.K., J.L. Belant, and R.A. Dolbeer. 1998. Nest disturbance techniques to control nesting by gulls. *Wildlife Society Bulletin* 26:269-273.
- Jodice, P.G.R., D.D. Roby, S.A. Hatch, V.A. Gill, R.B. Lanctot, and G.H. Visser. 2002. Does food availability affect energy expenditure rates of nesting seabirds? A

- supplemental-feeding experiment with Black-legged Kittiwakes (*Rissa tridactyla*). *Canadian Journal of Zoology* 80:214-222.
- Johnson, N., J. Franklin, J. Thomas, and J. Gordon. 2004. Successes and failures of the Northwest Forest Plan and suggestions for change. *Ecological Society of America Annual Meeting Abstracts* 89:252-253.
- Kelly, E.G. and E.D. Forsman. 2004. Recent records of hybridization between Barred Owls (*Strix varia*) and Northern Spotted Owls (*Strix occidentalis caurina*). *Auk* 121:806-810.
- Kelly, E.G., E.D. Forsman, and R.G. Anthony. 2003. Are Barred Owls displacing Spotted Owls? *Condor* 105:45-53.
- Kirkpatrick, M. and N.H. Barton. 1997. Evolution of a species' range. *American Naturalist* 150:1-23.
- Kokko, H. and W.J. Sutherland. 2001. Ecological traps in changing environments: ecological and evolutionary consequences of a behaviorally mediated Allee effect. *Evolutionary Ecology Research* 3:537-551.
- Korpimäki, E. and K. Norrdahl. 1998. Experimental reduction of predators reverses the crash phase of small-rodent cycles. *Ecology* 76:2448-2455.
- LaHaye, W.S., R.J. Gutiérrez, and H.R. Akcakaya. 1994. Spotted Owl metapopulation dynamics in southern California. *Journal of Animal Ecology* 63:775-785.
- Laska, M.S. and J.T. Wootton. 1998. Theoretical concepts and empirical approaches to measuring interaction strength. *Ecology* 79:461-476.
- Leskiw, T. and R.J. Gutiérrez. 1998. Possible predation of a Spotted Owl by a Barred Owl. *Western Birds* 29:225-226.
- Lima, S.L. and L.M. Dill. 1990. Behavioral decisions made under the risk of predation: a review and prospectus. *Canadian Journal of Zoology* 68:619-640.
- Littlefield, C.D. and G.L. Ivey. 2002. Sandhill Crane recovery plan. Washington Department of Fish and Wildlife, Olympia, Washington.
- Lowther, P.E. 1993. Brown-headed Cowbird (*Molothrus ater*). Pages 1-24 in Poole, A. and F. Gill (editors). *The birds of North America*, No. 47. The Academy of Natural Sciences, Philadelphia, PA, and The American Ornithologists' Union, Washington, DC.
- Mack, R.N., D. Simberloff, W.M. Lonsdale, H. Evans, M. Clout, and F.A. Bazzaz. 2000. Biotic invasions: causes, epidemiology, global consequences, and control. *Ecological Applications* 10:689-710.
- Martin, P.R. and T.E. Martin. 2001. Ecological and fitness consequences of species coexistence: a removal experiment with wood warblers. *Ecology* 82:189-206.
- Mayfield, H.F. 1961. Cowbird parasitism and the population of the Kirtland's Warbler. *Evolution* 15:174-179.
- Mazur, K.M. and P.C. James. 2000. Barred Owl (*Strix varia*). Pages 1-20 in Poole, A. and F. Gill (editors). *The birds of North America*, No. 508. The Birds of North America, Inc., Philadelphia, Pennsylvania.
- Meek, W.R., P.J. Burman, M. Nowakowski, T.H. Sparks, and N.J. Burman. 2003. Barn Owl release in lowland southern England: a twenty-one year study. *Biological Conservation* 109:271-282.

- Merrill, J.A., E.G. Cooch, and P.D. Curtis. 2003. Time to reduction: factors influencing management efficacy in sterilizing overabundant white-tailed deer. *Journal of Wildlife Management* 67:267-279.
- Mikami, O.K. and M. Kawata. 2004. Does interspecific territoriality reflect the intensity of ecological interactions? – A theoretical model for interspecific territoriality. *Evolutionary Ecology Research* 6:765-775.
- Miller, G.S., R.J. Small, and E.C. Meslow. 1997. Habitat selection by Spotted Owls during natal dispersal in western Oregon. *Journal of Wildlife Management* 61:140-150.
- Miller, L.A., J. Rhyan, and G. Killian. 2004. GonaConT, a versatile GnRH contraceptive for a large variety of pest animal problems. *Proceedings of the Vertebrate Pest Conference* 21:269-273.
- Newton, I. 1979. *Population ecology of raptors*. Buteo Books, Vermillion, South Dakota.
- Nogales, M., A. Martin, B.R. Tershy, C.J. Donlan, D. Veitch, N. Puerta, B. Wood, and J. Alonso. 2004. A review of feral cat eradication on islands. *Conservation Biology* 18:310-319.
- Norris, K. 2004. Managing threatened species: the ecological toolbox, evolutionary theory and declining-population paradigm. *Journal of Applied Ecology* 41:413-426.
- Olson, G.S., R.G. Anthony, E.D. Forsman, S.H. Ackers, P.J. Loschl, J.A. Reid, K.M. Dugger, E.M. Glenn, and W.J. Ripple. 2005. Modeling of site occupancy dynamics for Northern Spotted Owls, with emphasis on the effects of Barred Owls. *Journal of Wildlife Management* 69:918-932.
- Oppel, S., H.M. Schaefer, V. Schmidt, and B. Schroeder. 2004. Cowbird parasitism of Pale-headed Brush-finch *Atlapetes pallidiceps*: implications for conservation and management. *Bird Conservation International* 14:63-75.
- Pearson, R.R. and K.B. Livezey. 2003. Distribution, numbers, and site characteristics of Spotted Owls and Barred Owls in the Cascade Mountains of Washington. *Journal of Raptor Research* 37:265-276.
- Polis, G.A., C.A. Myers, and R.D. Holt. 1989. The ecology and evolution of intraguild predation: potential competitors that eat each other. *Annual Review of Ecology and Systematics* 20:297-330.
- Pulliam, H.R. 1988. Sources, sinks, and population regulation. *American Naturalist* 132:652-661.
- Randler, C. 2002. Avian hybridization, mixed pairing and female choice. *Animal Behaviour* 63:103-119.
- Redpath, S.A., B.E. Arroyo, E.M. Leckie, P. Bacon, N. Bayfield, R.J. Gutiérrez, and S.J. Thirgood. 2004. Using decision modeling with stakeholders to reduce human-wildlife conflict: a raptor-grouse case study. *Conservation Biology* 18:350-359.
- Reichard, T.A. 1974. Barred Owl sightings in Washington. *Western Birds* 5:138-140.
- Rettie, W.J. and P.D. McLoughlin. 1999. Overcoming radiotelemetry bias in habitat-selection studies. *Canadian Journal of Zoology* 77:1175-1184.
- Rothstein, S.I., B.E. Kus, M.J. Whitfield, and S.J. Sferra. 2003. Recommendations of cowbird management in recovery efforts for the Southwestern Willow Flycatcher. *Studies in Avian Biology* 26:157-167.

- Rothstein, S.I. and B.D. Peer. 2005. Conservation solutions for threatened and endangered cowbird (*Molothrus* spp.) hosts: separating fact from fiction. *Ornithological Monographs* 57:98-114.
- Sakai, A.K., F.W. Allendorf, J.S. Holt, D.M. Lodge, J. Molofsky, K.A. With, S. Baughman, R.J. Cabin, J.E. Cohen, N.C. Ellstrand, D.E. McCauley, P. O'Neil, I.M. Parker, J.N. Thompson, and S.G. Weller. 2001. The population biology of invasive species. *Annual Review of Ecology and Systematics* 32:305-332.
- Schardt, J.D. 1997. Maintenance control. Pages 229-243 in Simberloff, D., D.C. Schmitz, and T.C. Brown (editors). *Strangers in paradise*. Island Press, Washington, DC.
- Schlaepfer, M.A., M.C. Runge and P.W. Sherman. 2002. Ecological and evolutionary traps. *Trends in Ecology and Evolution* 17:474-480.
- Schmidt, K.A., J.R. Goheen, R. Naumann, R.S. Ostfeld, E.M. Schaubert, and A. Berkowitz. 2001. Experimental removal of strong and weak predators: mice and chipmunks preying on songbird nests. *Ecology* 82:2927-2936.
- Schoener, T.W. 1983. Field experiments on interspecific competition. *American Naturalist* 122:240-285.
- Seamans, M.E., J. Corcoran, and A. Rex. 2004. Southernmost record of a Spotted Owl x Barred Owl hybrid in the Sierra Nevada. *Western Birds* 35:173-174.
- Seamans, M.E., R.J. Gutiérrez, C.A. May, and M.Z. Peery. 1999. Demography of two Mexican Spotted Owl populations. *Conservation Biology* 13:744-754.
- Sergio, F., L. Marchesi, and P. Pedrini. 2003. Spatial refugia and the coexistence of a diurnal raptor with intraguild owl predator. *Journal of Applied Ecology* 72:232-245.
- Sigg, D.P., A.W. Goldizen, and A.R. Pople. 2005. The importance of mating system in translocation experiments: reproductive success of released male bridled nailtail wallabies. *Biological Conservation* 123:289-300.
- Smith, J.N.M., M.J. Taitt, L. Zanette, and I.H. Myers-Smith. 2003. How do Brown-headed Cowbirds (*Molothrus ater*) cause nest failures in Song Sparrow (*Melospiza melodia*)? A removal experiment. *Auk* 120:772-783.
- Sol, D., S. Timmermans, and L. Lefebvre. 2002. Behavioural flexibility and invasion success in birds. *Animal Behaviour* 63:495-502.
- Swihart, R.K. and N.A. Slade. 1985a. Testing for independence of observations in animal movements. *Ecology* 66:1176-1184.
- Swihart, R.K. and N.A. Slade. 1985b. Influence of sampling interval on estimates of home range size. *Journal of Wildlife Management* 49:1019-1025.
- Taylor, A.L., Jr. and E.D. Forsman. 1976. Recent range extensions of the Barred Owl in western North America, including the first records for Oregon. *Condor* 78:560-561.
- Taylor, R.H., G.W. Kaiser, and M.C. Drever. 2000. Eradication of Norway rats for recovery of seabird habitat on Langara Island, British Columbia. *Restoration Ecology* 8:151-160.
- Thomas, J.W., E.D. Forsman, J.B. Lint, E.C. Meslow, B.R. Noon, and J. Verner. 1990. A conservation strategy for the Northern Spotted Owl. USDA Forest Service, USDI Bureau of Land Management, USDI Fish and Wildlife Service, and USDI National Park Service. Portland, Oregon.

- Tuystens, F.A.M. and D.W. MacDonald. 1998. Fertility control: an option for non-lethal control of wild carnivores? *Animal Welfare* 7:339-364.
- United States Fish and Wildlife Service. 2004. Northern Spotted Owl five-year review: summary and evaluation. United States Fish and Wildlife Service, Portland, Oregon.
- United States Department of the Interior. 1990. Endangered and threatened wildlife and plants; determination of threatened status for the Northern Spotted Owl. *Federal Register* 55:26114-26194.
- United States Department of the Interior. 1992. Recovery plan for the Northern Spotted Owl - final draft (2 volumes). U.S. Government Printing Office, Washington, D.C.
- United States Department of the Interior. 1993. Endangered and threatened wildlife and plants; final rule to list the Mexican Spotted Owl as a threatened species. *Federal Register* 58:14248-14271.
- United States Department of the Interior. 1995. Recovery plan for the Mexican Spotted Owl (*Strix occidentalis lucida*). U.S. Fish and Wildlife Service, Albuquerque, New Mexico.
- United States Department of the Interior. 2003. Endangered and threatened wildlife and plants; 12-month finding for a petition to list the California Spotted Owl (*Strix occidentalis occidentalis*). *Federal Register* 68:7580-7608.
- Van Zant, J.L. and M.C. Wooten. 2003. Translocation of Choctawhatchee beach mice (*Peromyscus polionotus allophrys*): hard lessons learned. *Biological Conservation* 112:405-413.
- Verner, J., K.S. McKelvey, B.R. Noon, R.J. Gutiérrez, G.I. Gould, Jr., and T.W. Beck. 1992. The California Spotted Owl: a technical assessment of its current status. USDA Forest Service General Technical Report PSW-GTR-133.
- Waldo, S.L. 2002. Song discrimination of neighbors and strangers by male Northern Spotted Owls (*Strix occidentalis caurina*). MS thesis, Humboldt State University, Arcata, California.
- Wallace, M.T. and R. Buchholz. 2001. Translocation of Red-cockaded Woodpeckers by reciprocal fostering of nestlings. *Journal of Wildlife Management* 65:327-333.
- Walters, C.J. 1986. Adaptive management of renewable resources. MacMillan Publishers, New York, New York.
- Ward, J.M. and P.L. Kennedy. 1996. Effects of supplemental food on size and survival of juvenile Northern Goshawks. *Auk* 113:200-208.
- Wiens, J.A. 1983. Avian community ecology: an iconoclastic view. Pages 355-403 in Brush, A.H. and G.A. Clark, Jr. (editors). *Perspectives in ornithology*. Cambridge University Press, Cambridge, United Kingdom.
- Wiens, J.A. 1989. The ecology of bird communities. Volume 2. Processes and variations. Cambridge University Press, Cambridge, United Kingdom.
- Williams, T.D. and M. Miller. 2003. Individual and resource-dependent variation in ability to lay supranormal clutches in response to egg removal. *Auk* 120:481-489.
- Wilson, W.H., Jr. 2001. The effects of supplemental feeding on wintering Black-capped Chickadees (*Parus atricapillus*) in central Maine: population and individual responses. *Wilson Bulletin* 113:65-72.

- Wood, P.B. and M.W. Collopy. 1993. Effects of egg removal on Bald Eagle productivity in northern Florida. *Journal of Wildlife Management* 57:1-9.
- Woodroffe, R. 2003. Dispersal and conservation: a behavioral perspective on metapopulation persistence. Pages 33-48 *in* Festa-Bianchet, M. and M. Apollonio (editors). *Animal behavior and wildlife conservation*. Island Press, Washington, DC.
- Yoder, C.A., W.F. Andelt, L.A. Miller, J.J. Johnston, and M.J. Goodall. 2004. Effectiveness of twenty, twenty-five diazacholesterol, avian gonadotropin releasing hormone, and chicken riboflavin carrier protein for inhibiting reproduction in Coturnix quail. *Poultry Science* 83:234-244.
- Yoder, C.A., L.A. Miller, W.F. Andelt, and K.A. Crane. 1998. Potential oral contraceptives for birds. Pages 14-15 *in* Curtis, P.D. and R.J. Warren, organizers. *A workshop on the status and future of wildlife fertility control*, The Wildlife Society Annual Conference, Buffalo, New York.
- Zabel, C.J., K.S. McKelvey, and J.P. Ward, Jr. 1995. Influence of primary prey on home-range size and habitat use patterns of Spotted Owls (*Strix occidentalis*). *Canadian Journal of Zoology* 73:433-439.

Table 1. Alternative hypotheses regarding possible consequences of the Barred Owl invasion of the range of the Northern and California Spotted Owls. These hypotheses were originally developed by Gutierrez et al. (2004) for the Northern Spotted Owl, but are here slightly adapted and applied to both subspecies.

Hypothesis No.	Explanation
1	Barred Owls will replace Spotted Owls throughout their range (behavioral and competitive dominance hypothesis).
2	Barred Owls will replace Spotted Owls in the northern, more mesic areas of its range (moisture-dependent hypothesis).
3	Barred Owls will replace Spotted Owls over much of their range, but the Spotted Owl could persist in some areas with management intervention (management hypothesis).
4	Barred Owls will replace Spotted Owls over much of their range, but the Spotted Owl will persist in refugia (refugia hypothesis).
5	Barred Owls will replace Spotted Owls in parts of its range, but the Spotted Owl will maintain a competitive advantage in habitats where its prey is abundant and diverse (specialist vs. generalist hypothesis).
6	Barred Owls will replace Spotted Owls only where weather and habitat changes have placed Spotted Owls at a competitive disadvantage (synergistic effects hypothesis).
7	Barred Owls will replace Spotted Owls in some habitats, but not in others (habitat hypothesis based on structural elements of forest, which confer a maneuverability advantage to the smaller Spotted Owl).
8	Barred Owls and Spotted Owls will compete, with the outcome being an equilibrium favoring Barred Owls in most but not all of the present Spotted Owl range (interference competition hypothesis).
9	Barred Owls will increase to a peak number, then decline or stabilize at a lower density, which will permit coexistence (dynamics hypothesis).