Biol Invasions (2007) 9:679–691
DOI 10.1007/s10530-006-9068-7

ORIGINAL PAPER

A synopsis of suggested approaches to address potential competitive interactions between Barred Owls (*Strix varia*) and Spotted Owls (*S. occidentalis*)

Joseph B. Buchanan · R. J. Gutiérrez · Robert G. Anthony · Tim Cullinan · Lowell V. Diller · Eric D. Forsman · Alan B. Franklin

Received: 19 September 2006 / Accepted: 19 October 2006 / Published online: 16 January 2007

Abstract The conservation of Spotted Owl (*Strix occidentalis*) populations has been one of the most controversial and visible issues in United States conservation history. Coincident with declines in Spotted Owl populations over the last three decades has been the invasion of Barred Owls (*Strix varia*) throughout the range of the Northern Spotted Owl (*S. o. caurina*) and into the range of the California Spotted Owl (*S. o. occidentalis*). This invasion has confused the reasons behind recent Spotted Owl declines because anecdotal and correlative information strongly suggests that Barred Owls are a new factor influencing the declines. There is great uncertainty about all aspects of the invasion, and this has sparked discussion about appropriate management and research responses regarding the effects of this invasion on Spotted Owls. We present a set of possible responses to address the issue, and we discuss the relative merits of these with regard to their efficacy given the current state of knowledge. 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. Approaches that seem unlikely to be useful in the short-term either because they do not facilitate knowledge acquisition, are relatively costly, or would be technically less feasible, should not be considered viable at this time. We believe the consequences of the invasion are potentially dire for the Spotted Owl and that

J. B. Buchanan (✉)
Washington Department of Fish and Wildlife,
600 Capitol Way North, Olympia, WA 98501, USA
e-mail: buchajbb@dfw.wa.gov

R. J. Gutiérrez
Department of Fisheries, Wildlife and Conservation
Biology, University of Minnesota, 200 Hodson Hall,
1880 Folwell Avenue, St. Paul, MN 55108, USA

R. G. Anthony
Department of Fisheries and Wildlife, Oregon State
University, Corvallis, OR 97331, USA

T. Cullinan
Audubon Washington, 1063 Capitol Way South,
Suite 208, Olympia, WA 98382, USA

L. V. Diller
Green Diamond Resource Company, 900 Riverside
Road, Korbel, CA 95550, USA

E. D. Forsman
Forestry Sciences Laboratory, Pacific Northwest
Research Station, United States Forest Service,
3200 SW Jefferson Way, Corvallis, OR 97331, USA

A. B. Franklin
USDA/APHIS/WS National Wildlife Research
Center, 4101 Laporte Avenue, Fort Collins,
CO 80521, USA

research and management actions, including the use of adaptive management, are required to inform the near- and long-term decision-making process for conservation of Spotted Owls.

Keywords Barred Owl · Review of potential approaches to respond to Barred Owl invasion · Spotted Owl · *Strix occidentalis* · *Strix varia*

Introduction

Invasive species have the potential to disrupt or degrade ecosystems, community dynamics, or population status of individual species (Simberloff 1981, 2000; Mack et al. 2000; Townsend 2003). In many cases, invasions are not appreciated or are ignored until they are so widespread that ecological and other consequences have become obvious and opportunities to reduce impacts are limited, expensive, or impractical (Ruesink et al. 1995; Simberloff 2003). The need to address the consequences of invasive species on native species, and to develop strategies to eradicate, reduce or otherwise address them, has assumed greater urgency as altered ecosystems and mechanisms of transport continue to promote invasions (Orians 1986; Mills et al. 1994). Research and management needs are often most pronounced where invasive species impact local economies, vital ecosystem functions, and status or population performance of rare or endangered species (Ruesink et al. 1995; Born et al. 2005).

Social, economic, ecological and philosophical perspectives on biological invasions are often diverse and complex, and management efforts to deal with invasions can fall short or fail because a comprehensive strategy is not considered, or, in the absence of biological knowledge, competing interests result in management confusion (Lodge and Shrader-Frechette 2003; Simberloff 2003). The Spotted Owl (*Strix occidentalis*) has become an icon in American conservation because it represents to some the symbol of forest protection and integrity and to others the loss of timber revenue (Gutiérrez et al. 1995). With the invasion of Barred Owls (*S. varia*) into the range of the Spotted Owl, an already complex conservation issue became more difficult. Despite this daunting circumstance, we feel that the invasion presents an opportunity for scientists to provide reasoned consideration on how to respond to this new challenge. With respect to invasive species in general, we think elements of our approach should have value to others considering potential responses to biological invasions where there is uncertainty about the invader's impacts and when both species have high public interest. Throughout this document we refer to the Barred Owl ‘‘invasion,’’ using the term independently of any implication of human transport factors (Mack et al. 2000), and only in the context of potential ecological consequences to Spotted Owls resulting from the arrival of this non-indigenous species.

All three Spotted Owl subspecies (California: *Strix occidentalis occidentalis*; Northern: *S. o. caurina*; Mexican: *S. o. lucida*) are of conservation concern (e.g. United States Department of the Interior 1990, 1993). Foremost among the reasons for listing *S. o. caurina* and *S. o. lucida* as threatened taxa has been the loss or projected loss of suitable habitat (e.g. United States Department of the Interior 1990, 1992, 1993; Courtney et al. 2004). Although the application of conservation strategies has substantially reduced this threat (see reviews in Courtney et al. 2004; Noon and Blakesley 2006), the invasion of Barred Owls throughout the range of the Northern Spotted Owl and part of the range of the California Spotted Owl is a potential threat of unknown dimension (Gutiérrez et al. 2006). The nature of this invasion and its predicted consequences on Spotted Owls have been summarized by Gutiérrez et al. (2006), and while these are uncertain, it appears that the Barred Owl has the potential to impact the viability of Spotted Owls where they are syntopic.

Gutiérrez et al. (2006) recommended removal experiments as the best mechanism to ascertain the effect of Barred Owls on Spotted Owls, particularly where Spotted Owl populations are in steep decline. Nevertheless, managers and others have expressed other ideas or approaches in response to the Barred Owl invasion, and these approaches require preliminary discussion of their relative value. To this end scientists and managers convened a two-day workshop in

Arcata, California, to consider the potential threat of Barred Owls to the viability of the Spotted Owl. Consequently, this paper reflects a synthesis and development of ideas expressed at this workshop. For want of a more salient term that encompasses the broad spectrum of ideas expressed at these meetings, we use the term ‘‘approach’’ to express each of the seven topics we consider. Our inclusion of any of these approaches does not imply that they are either a feasible or wise response. Rather they span a spectrum (not an inclusive list) of possible responses that have been expressed to respond to or understand the invasion. Our intent beyond the synthesis is to suggest which are important to consider and which are not.

Overview of management approaches

‘‘Management approaches’’ as we define them below are simply a set of possible actions that could be taken to respond to the Barred Owl invasion and to learn about or manage the interactions of these two species within a comprehensive adaptive management and research framework. Although some approaches reflect management actions per se, others consider research or evaluation monitoring that would provide inference about the species’ interactions, which would inform managers. When appropriate we suggest some potential studies that could be considered starting points for development of a comprehensive research program that addresses key management questions.

Approach 1: no action

Agencies charged with protecting the Northern Spotted Owl or its habitat could take no action, which could be either a passive or deliberate response. We distinguish between active and passive approaches because the processes involved in either response are quite different. A passive approach would occur if regulatory or funding agencies were either unable to authorize or to implement a response. In contrast, a deliberate approach would occur if agencies were unwilling to authorize action. These approaches are time sensitive default actions. The no-action approach is in effect until meaningful management decisions occur. It is possible that a decision to deliberately not respond with meaningful conservation measures could be made after research suggests this is a logical decision (e.g., if removal experiments clearly show that Barred Owls are not causing or exacerbating recent declines of Spotted Owls).

We suggest that the only potential benefit of this approach (except in the case noted immediately above) is short-term economic benefits from not having to fund any management actions or a reduction in negative constituency responses to the responsible resource agencies. However, there are significant limitations of this approach. First, it would require abrogation of conservation action on behalf of a species listed as threatened under the Endangered Species Act, and for which a lack of action might result in it becoming endangered in either the ecological or regulatory sense. Second, the approach is inconsistent with the mandate of several resource management agencies in the range of the Spotted Owl, and could conflict with public expectations regarding responsible resource management. Third, the approach does not produce information to inform decisions. Finally, significant delay in implementing other approaches may increase their potential costs and reduce opportunities to make effective management decisions. We believe the only way that this approach might inform decisions would be through a thorough cost benefit/risk analysis, but this would not enhance conservation of Spotted Owls.

Approach 2: ecological studies

Approach 2 includes a large array of possible investigations to elucidate the ecology, behavior, and competitive interactions of Barred Owls and Spotted Owls. Little has been published on the ecology and behavior of Barred Owls in western North America (Mazur and James 2000; Gutiérrez et al. 2004, 2006). Studies of Barred Owl ecology would include investigations of home range size, habitat use, prey use, demography, and natal dispersal. With some notable exceptions (e.g. prey availability [Courtney et al. 2004], habitat use during dispersal [Buchanan 2005]), intensive studies of these topics have been conducted on Spotted Owls (Forsman et al. 1984; Verner et al. 1992; Gutiérrez et al. 1995; Courtney et al. 2004; Franklin et al. 2004; Anthony et al. 2006).

Species interaction studies could be designed to investigate resource partitioning where the species are sympatric and syntopic and would include comparisons of spatial and temporal use of resources. Data could 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, survival, and/or productivity of Spotted Owls (e.g., Kelly et al. 2003; Pearson and Livezey 2003; Olsen et al. 2005) in different areas throughout their range in relation to Barred Owl presence.

Radio telemetry studies are capable of generating information on spatial and temporal use of space, habitat and prey. A variety of telemetry studies are possible, which can be used to address important issues. Behavioral studies also may use telemetry, but in some cases it may not be possible to effectively use telemetry to investigate behavioral interactions (Rettie and McLoughlin 1999).

Field investigations of interactions may require a priori clarification of some potential methodological problems. For example, it is not clear that Barred Owls can be monitored like Spotted Owls. Further, there is some evidence that the presence of Barred Owls may affect vocal behavior and detectability of Spotted Owls (Olson et al. 2005; Crozier et al. 2006). Thus, the estimation of density (or measures of presence) for either species may be problematic if these issues are not understood. In addition, telemetry or other use-versus-availability studies do not necessarily establish clear relationships between habitat selection or preference and measures of fitness (Garshelis 2000). Moreover, the level of sampling required to establish a detailed understanding of behavioral interactions between the two species may be logistically demanding and costly given some of the constraints associated with telemetry (Rettie and McLoughlin 1999; Adams 2001). Finally, the temporal component of studies is also an important consideration because Barred Owls are moving (or can move) rapidly into areas occupied by Spotted Owls often with concomitant changes in densities of both species (Gutiérrez et al. 2004). For this reason, we think that these studies should be initiated without delay and should include temporal replicates (multiple years). Many of these field studies can probably be completed in 3–5 years.

Basic ecological information about Barred Owls can inform conservation direction once knowledge of interspecific interactions is quantified through ecological studies and experiments (see below). For example, identifying differential use of habitats or resource partitioning between Spotted Owls and Barred Owls in specific physiographic regions or habitat types could guide habitat management or protection efforts if it is experimentally demonstrated that Barred Owls negatively affect Spotted Owl population dynamics.

The value of observational studies is that they may provide insight into the potential mechanisms by which an invader, like the Barred Owl, may be having a negative effect on local species. This knowledge will allow development of methods to limit or eliminate the negative effects. In cases such as the one we describe herein, there is uncertainty over both the impact of the Barred Owl on Spotted Owls and, if such negative impacts occur, how best to counteract the negative effects. With respect to controlled experiments (see Approach 3 immediately following), observational studies can precede experiments to provide specific hypotheses to be tested, be conducted simultaneously with experiments to provide additional insights into experimental results, or after to provide additional insights into potential mechanisms.

Approach 3: removal experiments

Gutiérrez et al. (2006) argued that removal experiments would be the strongest scientific approach to evaluate the Barred Owl's effect on Spotted Owl population dynamics. They noted that the extant Spotted Owl demographic studies provided the foundation for comprehensive assessments of changes in Spotted Owl vital rates upon removal of Barred Owls. Removal experiments have been used to evaluate many ecological relationships and to address vexing wildlife management issues such as competitive interactions (see Wiens 1989; Abrams 2001; Martin and Martin 2001), effects of predators (Korpimaki and Norrdahl 1998; Schmidt et al. 2001) and brood parasites (Mayfield 1961; Rothstein et al. 2003; Smith et al. 2003).

Removal of Barred Owls could involve lethal or translocation methods. Removal from specific areas may require consideration of an appropriately large area around the Spotted Owl locations to maximize the potential benefit of this activity on resident Spotted Owls. Removal experiments using direct lethal control, in accordance with relevant ethical treatment protocols (Cuthill 1991) are likely the most cost effective and efficient way to undertake such experiments (see below). We concur with Gutiérrez et al. (2006) that this method holds the most promise for conducting removal experiments.

Translocation of species has been successfully used in conservation programs (e.g., DeFazio et al. 1987). Translocation might be used with different purposes and with respect to either owl species. If Spotted Owls were present only at very low densities (or absent) in some landscapes, translocation of fledged Spotted Owls to those landscapes just prior to dispersal would be a potential means to accelerate directed colonization after Barred Owl removal. However, if translocation is used in this capacity, the possible effects of translocation itself on the physiology (Sigg et al. 2005), survival (Van Zant and Wooten 2003), and adjustment to new landscapes (Woodroffe 2003) of Spotted Owls, as demonstrated in other species, also must be evaluated.

Translocation of Barred Owls away from the removal landscape is another alternative. This option would be more expensive than lethal removal, and raises the problem of where to release captured owls. Obviously they should not be released in areas having Spotted Owls. Translocating them 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. However, because Barred Owl status is of concern in some areas in eastern North America (Mazur and James 2000), the possibility of translocation should be carefully evaluated, as the use of nonlethal methods may have either more public support or diversify research and management partnerships.

Because of the complexity and controversy of removal experiments, we recommend that a panel of scientists and managers design the experiment. There are many challenging issues that would need to be considered in an experimental design of this nature, and a panel of experts would provide the breadth of research and analytical experience to consider most of them. In addition, such experiments are likely to initiate conflict that a panel format could ameliorate (Anderson et al. 1999).

Wiens (1989) elucidated several factors that may complicate the results of studies designed to evaluate competition. 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 that the response was caused by competition for food or space. These and other potential confounding factors should be evaluated in the experiment design phase. Despite the potential for confounding effects, appropriately designed removal experiments should provide the strongest inference regarding the magnitude of the Barred Owl's effect on Spotted Owls (Gutiérrez et al. 2006). We believe that these experiments should be conducted prior to any proposed habitat management or large-scale control programs (see below). Landscapes with existing monitoring or demographic data would likely provide more immediate understanding of potential competitive effects because the outcome of removal experiments could be related to existing information (Gutiérrez et al. 2006).

Approach 4: habitat management

This approach is based on the assumption that particular habitat conditions favor Spotted Owls over Barred Owls. The approach requires knowledge of owl responses to existing habitat conditions or to experimental silvicultural treatments. Unfortunately, we do not know how owls respond to silviculture in general or whether Spotted Owls are competitively superior in some habitats. Much work is currently being done in some long-term Spotted Owl studies to link demographic response to specific habitat conditions (e.g., Franklin et al. 2000; Olson et al. 2004; Dugger et al. 2005) and such information will be critical not only for understanding owl ecology, but also could facilitate a more integrated approach to balancing owl conservation, forest management and silviculture.

Once basic field studies are completed the effects of silvicultural treatments would be best implemented as true experiments designed within an adaptive management framework. Ideally, ecological field studies would be designed to provide explicit hypotheses to be tested in these experiments. Results from such studies would take longer to derive, but could be structured to test predictions about temporal and spatial relationships of forest structure and owl occupancy. A multi-scale approach may be necessary to distinguish between source and sink landscapes (Pulliam 1988) or ecological traps (Kokko and Sutherland 2001; Schlaepfer et al. 2002; Battin 2004), if they exist.

Silvicultural experiments require the modification of Spotted Owl habitat. These experiments confer several potential risks to Spotted Owls in the form of loss or reduced function of habitat if (a) the treatments fail to create the desired conditions, or (b) the resulting forest conditions favor Barred Owls. In addition, the variability of treatments may be so great as to preclude inference about response by owls to treatments. This is not an unlikely scenario because silviculture is usually based on a stand's "site prescription" which means that treatments in an experiment could be unequal in their effects. It might be possible to find existing conditions that favor Spotted Owls over Barred Owls, and then attempt to replicate those conditions. More likely, conducting experiments or locating places of differential habitat use would take decades to (a) determine either the relative quality of habitat given a specific silvicultural treatment, or (b) allow Barred Owls to saturate the range of the Spotted Owl to observe places where Spotted Owls can clearly persist. We suspect that because Spotted Owls have large home ranges, the spatial scale for meaningful implementation of forest management may be so great that it is infeasible. Regardless, strategies for silvicultural treatments, if field studies indicate that they hold promise, should be designed to minimize long-term risk to Spotted Owl habitat (Verner et al. 1992).

This approach clearly has promise for managers because it could move decision-making from the current passive strategy to active adaptive management (see Kendall 2001). Indeed, this was a goal of the Northwest Forest Plan that has not yet been realized (Johnson et al. 2004). While this approach has some utility and could serve as a catalyst that moves land management agencies into true adaptive management, we caution that it should not be engaged in an uninformed and ad hoc manner. We think that proposals to simply engage in landscape scale manipulations "to benefit" the Spotted Owl are inappropriate at this time, particularly when they have the potential to degrade habitat suitable for Spotted Owls even if such habitat is currently occupied by Barred Owls. Therefore, this approach is best considered a long-term possibility that should only be started on a limited basis, outside of currently protected Spotted Owl habitat, and in an experimental framework.

Approach 5: diversionary or supplemental feeding

This approach involves supplementing the diets of owls in one of two ways. Food could either be provided to Barred Owls to divert them from syntopic areas that support Spotted Owls (i.e., diversionary feeding) or it could be provided to Spotted Owls to augment their diets (i.e., supplemental feeding).

We considered the technique of diversionary feeding because it has been shown to be a potential strategy to reduce the predation on Red Grouse (*Lagopus lagopus scoticus*) chicks (Redpath et al. 2004). In this case, Hen Harrier (*Circus cyaneus*) predation on Red Grouse chicks was significantly reduced by providing food to nesting harriers (Amar et al. 2004). The benefits of a diversionary feeding program to benefit Spotted Owls are currently unclear, because the assumption that the two owl species are competing for prey and that other interactions are less important is untested (see also Gutiérrez et al. 2006).

Supplemental feeding has been used to investigate the importance of food supply on aspects of life history (Djikstra et al. 1982; Gjerdrum 2004) and conservation of small populations (Bretagnolle et al. 2004), and it has been investigated for many bird species (Wilson 2001; Jodice et al. 2002; Guthery et al. 2004). Among raptors, supplemental feeding may result in (a) increased mass of adults (Dewey and Kennedy 2001) or nestlings (Hipkiss et al. 2002), (b) increased nestling survival (Ward and Kennedy 1996; Dewey and Kennedy 2001; Hipkiss et al. 2002), (c) increased nest site attentiveness by adults (Dewey and Kennedy 2001), or (d) increased survival of captive-bred birds (Cade and Burnham 2003; Meek et al. 2003). Supplemental feeding also has been suggested as a potential management action for Spotted Owls in British Columbia (Chutter et al. 2004).

The efficacy of such a feeding program would require a comprehensive experimental design to better understand the relationship between the two owl species given differing levels of prey. By conducting experiments, it may be possible to determine if supplemental feeding reduces the strength of the presumed interspecific competition. Such knowledge would have value for population management, particularly where Spotted Owls have declined to very low levels.

The lack of a consistent effect of prey supplementation in other raptors (Dewey and Kennedy 2001; Hipkiss et al. 2002) suggests that knowledge of prey populations must also be understood, which would add significant cost to evaluating this approach. In addition, there is an implicit assumption that supplemental feeding will work with Spotted Owls (i.e., that owls can effectively be located when necessary and will then take offered food). An experiment to evaluate the effect of supplemental feeding on reproduction of California Spotted Owls failed because the owls would not take the same amount of food offered in alternate years (RJG, personal observation). While this approach could be effective in helping to evaluate competitive interactions of the two species, we are skeptical that any form of supplemental feeding has utility for managing Barred Owl or Spotted Owl populations because of its high cost and difficult logistics, except perhaps where Spotted Owl populations are on the verge of extirpation (e.g., in British Columbia).

Approach 6: disrupt barred owl reproduction

This approach involves using one or more of several techniques to disrupt and ultimately prevent the successful reproduction of Barred Owls either in the short- or long-term. Short-term disruption would be single season disruption of reproduction whereas long-term disruption would involve multi-annual or even lifetime 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 that disrupts nesting (e.g., climbing nest trees). Oiling of eggs and egg removal/replacement have been used to control reproductive output in Double-crested Cormorants (*Phalacrocorax auritus*; Blackwell et al. 2002) and 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 renest after failure of the initial clutch (Wood and Collopy 1993; Williams and Miller 2003). Techniques that require locating and then climbing to nests to remove or replace eggs will be time-intensive and costly. Methods that involve noise disturbance to disrupt nesting may require 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. Wildlife contraception is an expanding field and has been used with both birds and mammals (see http://www.aphis.usda.gov/ws/nwrc/research/reproductivecontrol/index.html).

There are contraceptives for birds, some of which have the potential to inhibit reproduction for an entire breeding season (Yoder et al. 2004; 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.

Long-term contraception could be achieved through surgical sterilization of individuals or through immunocontraceptive vaccines. Sterilization has been used in a variety of management contexts, including attempts to reduce predation of domestic livestock by coyotes (*Canis latrans*; Bromley and Gese 2001; see Tuyttens and MacDonald 1998) and in management of big game populations (Merrill et al. 2003). Sterilization may not be an effective primary method because it would not eliminate competition or aggressive encounters. Sterilization also would be expensive because individual owls would have to be captured, transported, housed, and then released. In addition, a veterinarian may 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). If such a vaccine could be developed and administered orally (i.e., through live mice as bait), it could possibly last for multiple breeding seasons. Research on such a vaccine should be encouraged. Like sterilization, immunocontraception would not alleviate short-term interspecific interactions but may result in long-term reductions of Barred Owl populations.

The primary benefit of this approach is that it potentially does not involve lethal removal and it could result in declines of Barred Owls. Although breeding disruption may prove effective, it seems less promising than other approaches in elucidating competitive interactions. Clearly, more information is needed on immunocontraceptive vaccines for birds that act as long-term disruptors before the benefits of this approach can be fully evaluated.

There are practical limitations to the general approach of breeding disruption. First, local breeding disruption would not necessarily reduce competition between the species in the short term. Second, noise disturbances may negatively affect non-target species. Third, the field component is intensive, making this potentially more time consuming and costly as a long-term strategy than other approaches. Thus, this option using current methods would not likely guide future management activities, would probably not result in reduction of competition or aggression by Barred Owls, and appears to have primarily short-term utility. However, with the development of immunocontraceptives specifically for use with Barred Owls, this option might impede growth of Barred Owl populations in the short term 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. With the exception of the future potential for immunocontraceptive vaccines, we therefore view this approach as not feasible at the scale that would result in long-term benefits to the Spotted Owl or other species potentially affected by the Barred Owl.

Approach 7: ongoing control of barred owls

This approach would require elimination or suppression of Barred Owl populations and ongoing control of Barred Owls from some portion of the Spotted Owl's range. This approach could be a logical decision following the results of removal experiments, and should only be considered following definitive results of adequate experiments. Eradication programs have long been used to remove invasive species (e.g., Taylor et al. 2000; Nogales et al. 2004) or to reduce impacts to endangered species (Mayfield 1961; Rothstein et al. 2003). The methods required here could include (1) lethal control, such as proposed for removal experiments, (2) a combination of lethal control combined with long-term reproductive control (e.g., immunocontraceptives), or (3) translocation.

The scale and timing of this approach would be dependent on the outcome of removal experiments, the size and accessibility of the control areas, the number or density of Barred Owls and the ultimate goal of the removal program. Eradication of Barred Owls from even portions of the Spotted Owl's range (rather than physiographic provinces or even larger areas) may prove quite costly, whereas suppression of local Barred Owl populations to the extent that it allows the existence of a viable population of Spotted Owls may be more cost effective. It will be necessary to determine the feasibility and cost of applying the methods developed in removal experiments to a larger landscape. As Barred Owls are reduced we suspect that periodic control may suffice to keep populations managed to a level such that negative impacts on Spotted Owls are reduced (i.e., maintenance control; Mack et al. 2000; Schardt 1997). This assumption needs to be evaluated.

This approach likely involves greater benefits than any other management strategy we presented. Unless it can be demonstrated that Spotted Owls and Barred Owls can coexist, or that forest management can differentially favor Spotted Owls, the only remaining approaches for Spotted Owl conservation may be a conscious decision to either remove or suppress the threat of Barred Owls, or to let the interaction between the two species play itself out without human intervention.

The primary limitations of large-scale removal are cost, risk to non-target species, and public reaction (Howald et al. 1999; Mack et al. 2000). These are important concerns. However, these concerns can be mitigated by training control personnel, which could effectively eliminate mortality of non-target species, and educating the public about the threat(s) posed by Barred Owls to Spotted Owls. Such a control program is in some respects similar to ongoing efforts to control or eliminate species such as the Brown-headed Cowbird (*Molothrus ater*), a native species whose range expansion has threatened other native species (Rothstein and Peer 2005).

This option likely informs management in limited but important ways if adopted. We believe it may be possible to evaluate maintenance control at larger spatial scales than might be used in control experiments. Moreover, if eradication (or maintenance control), even at a small spatial scale, is the only approach that will conserve Spotted Owl populations, a decision not to take this action may result in realization of Approach 1.

Discussion

We believe that our discussion of the approaches that have been suggested by various parties to address the Barred Owl invasion will provide decision-makers with a brief but reasoned assessment of their relative utility. While this is a complex issue, it is not intractable. Moreover, there is precedent in endangered species conservation to control a native species for the benefit of an endangered species should that decision be made (e.g. Courchamp et al. 2003; Rothstein and Peer 2005). While many of the approaches we described can be used to gain information or inform management, we think that the emphasis should be on intensive field studies and removal experiments. We believe that research on various aspects of Barred Owl life history and interspecific interactions (Approach 2) in combination with removal experiments (Approach 3) will be the most useful, and may be particularly valuable in terms of implementation of subsequent research and management actions. We view the relationship of these two approaches as providing two key sets of information, and thus, they are synergistic. Removal experiments could provide an answer to whether the most recent declines of Spotted Owls are being caused by Barred Owls alone. Species interaction (and other field studies of the Barred Owl) will provide insight into the mechanism of competition or interaction between the species should Barred Owl competition prove to be a cause of recent Spotted Owl declines. Knowledge of the mechanisms gained through ecological studies will help guide appropriate management responses to reverse the decline of Spotted Owls (Gutiérrez et al. 2006).

Because of the rapid spread of Barred Owls (Kelly et al. 2003) and the status of Spotted Owl populations through much of the region (Anthony et al. 2006), we believe that research activities should be implemented immediately. Management experiments should be designed to use principles of adaptive management. 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 population or habitat 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 Approaches 2 and 3). It may also be beneficial to initiate other investigations not covered here, such as potential relationships between Barred Owls and other species, or other types of ecological relationships (Korpimaki and Norrdahl 1998; D'Antonio et al. 2001; Ekerholm et al. 2004). Much knowledge on Spotted Owls has been generated in the last two decades. Consequently, it seems most logical to use sites where long-term Spotted Owl research or monitoring has been conducted for the research proposed here (Gutiérrez et al. 2006). This will expedite the research effort by using landscapes with known Spotted Owl locations, ecological history, and demographic data.

The invasion of the Barred Owl into the range of the Spotted Owl has created another layer of complexity to this long-standing conservation saga. The response of the public, timber industry, politicians, the media, environmental groups, and others to this invasion has illustrated a substantial range of issues that are both general to invasive species and specific to Spotted Owls. The Barred Owl invasion also presents scientists with an opportunity to inform the public and help guide agencies charged with management of wildlife about potential options for response. While we realize that there have been many excellent responses by scientists and managers to confront the threats of specific biological invaders, we think our attempt to disentangle competing ideas in the face of great scientific uncertainty may be useful to invasion biologists.

There is always a temptation to immediately assume specific effects when these effects have either not been documented or are hypothesized (Gutiérrez et al. 2004). Therefore, in our first step we accumulated anecdotal information, biological data, and developed theoretical predictions to create a set of hypotheses about the consequences of this invasion (Gutiérrez et al. 2004, 2006). We then participated in a workshop whose central goal was to provide a forum for discussion of the invasion. From this workshop we synthesized a set of approaches encompassing research, management, and regulatory possibilities suggested by participants. Divergent ecological, social and philosophical perspectives on the Barred Owl invasion were obvious from this meeting and reports of the media. We suggest that the role of scientists is to make qualitative or quantitative assessments of the veracity of proposed responses to invaders in a constructive manner. In this way, we believe using science (and scientists) as a mechanism to understand the problem and guide management will be time- and cost effective. Finally, when issues like removal experiments arise that have the potential to be controversial, we subscribe to the open analytic workshop approach suggested by Anderson et al. (1999). These workshops allow all parties with a vested interest to participate in an open, collegial, and rigorous analysis of either data or a situation. Following our preferred means to address the Barred Owl invasion, agencies may then choose from a variety of management options, and they and the public can be informed by good science and reason (Pullin et al. 2004).

Acknowledgments We thank Steven Courtney for organizing and facilitating the workshop that prompted the initial development of this manuscript. The workshop was held in conjunction with the 2005 meeting of the Cooper Ornithological Society in Arcata, California. Workshop attendees contributed thoughtful discussion on various aspects of the ecology of the two owl species. The U. S. Forest Service (Contract #53-91S8-5-EC15) and the Minnesota Agricultural Research Station supported the work of RJG and ABF. James W. Watson and Lorelle I. Berkeley made helpful comments that improved this manuscript.

References

Abrams PA (2001) Describing and quantifying interspecific interactions: a commentary on recent approaches. Oikos 94:209–218

Adams ES (2001) Approaches to the study of territory size and shape. Annu Rev Ecol Syst 32:277–303

Amar A, Arroyo B, Redpath S et al (2004) Habitat predicts losses of Red Grouse to individual Hen Harriers. J Appl Ecol 41:305–314

Anderson DR, Burnham KP, Franklin AB et al (1999) A protocol for conflict resolution in analyzing empirical data related to natural resource controversies. Wildlife Soc B 27:1050–1058

Anthony RG, Forsman ED, Franklin AB et al (2006) Status and trends in demography of Northern Spotted Owls, 1985–2003. Wildlife Monogr 163:1–48

Battin J (2004) When good animals love bad habitats: ecological traps and the conservation of animal populations. Conserv Biol 18:1482–1491
Blackwell BF, Stapanian MA, Weseloh DVC (2002) Dynamics of the Double-crested Cormorant population on Lake Ontario. Wildlife Soc B 30:345–353
Born W, Rauschmayer F, Braeuer I (2005) Economic evaluation of biological invasions – a survey. Ecol Econ 55:321–336
Bretagnolle V, Inchausti P, Seguin J-F et al (2004) Evaluation of the extinction risk and of conservation alternatives for a very small insular population: the Bearded Vulture *Gypaetus barbatus* in Corsica. Biol Conserv 120:19–30
Bromley C, Gese EM (2001) Surgical sterilization as a method of reducing coyote predation on domestic sheep. J Wildlife Manage 65:510–519
Buchanan JB (2005) Managing habitat for dispersing Northern Spotted Owls: are the current management strategies adequate? Wildlife Soc B 32:1333–1345
Cade TJ, Burnham W (eds) (2003) Return of the Peregrine Falcon: a North American saga of tenacity and teamwork. The Peregrine Fund, Boise
Chutter MJ, Blackburn I, Bonin D et al (2004) Recovery strategy for the Northern Spotted Owl (*Strix occidentalis caurina*) in British Columbia. Prepared for the British Columbia Ministry of the Environment, Victoria
Courchamp F, Woodroffe R, Roemer G (2003) Removing protected populations to save endangered species. Science 302:1533
Courtney SP, Blakesley JA, Bigley RE et al (2004) Scientific evaluation of the status of the Northern Spotted Owl. Sustainable Ecosystems Institute, Portland
Crozier ML, Seamans ME, Gutiérrez RJ et al (2006) Does the presence of Barred Owls suppress calling behavior in Spotted Owls? Condor 108:760–769
Cuthill I (1991) Field experiments in animal behaviour: methods and ethics. Anim Behav 42:1007–1014
D'Antonio C, Meyerson LA, Denslow JS (2001) Exotic species and conservation: research needs. In: Soulé ME, Orians GH (eds) Conservation biology: research priorities for the next decade. Island Press, Washington, DC
DeFazio JT Jr, Hunnicutt MA, Lennartz MR et al (1987) Red-cockaded Woodpecker translocation experiments in South Carolina. Annu Conf Southeast Assoc Fish Wildl Agencies 41:311–317
Dewey SR, Kennedy PL (2001) Effects of supplemental food on parental-care strategies and juvenile survival of Northern Goshawks. Auk 118:352–365
Dijkstra C, Vuursteen L, Daan S et al (1982) Clutch size and laying date in the Kestrel (*Falco tinnunculus*): effect of supplementary feeding. Ibis 124:210–213
Dugger KM, Wagner F, Anthony RG et al (2005) The relationship between habitat characteristics and demographic performance of Northern Spotted Owls in southern Oregon. Condor 107:863–878
Ekerholm P, Oksanen L, Oksanen T et al (2004) The impact of short-term predator removal on vole dynamics in a subarctic-alpine habitat complex. Oikos 106:457–468
Forsman ED, Meslow EC, Wight HM (1984) Distribution and biology of the Spotted Owl in Oregon. Wildlife Monogr 87:1–64
Franklin AB, Anderson DR, Gutiérrez RJ et al (2000) Climate, habitat quality, and fitness in Northern Spotted Owl populations in northwestern California. Ecol Monogr 70:539–590
Franklin AB, Gutiérrez RJ, Nichols JD et al (2004) Population dynamics of the California Spotted Owl (*Strix occidentalis occidentalis*): a meta-analysis. Ornithol Monogr 54:1–55
Garshelis DL (2000) Delusions in habitat evaluation: measuring use selection and importance. In: Boitani L, Fuller TK (eds) Research techniques in animal ecology: controversies and consequences. Columbia University Press, 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
Green RE, Hirons GJM (1991) The relevance of population studies to the conservation of threatened birds. In: Perrins CM, Lebreton JD, Hirons GJM (eds) Bird population studies: relevance to conservation and management. Oxford University Press, Oxford
Guthery FS, Hiller TL, Puckett WH Jr et al (2004) Effects of feeders on dispersion and mortality of bobwhites. Wildlife Soc B 32:1248–1254
Gutiérrez RJ, Franklin AB, LaHaye WS (1995) Spotted Owl (*Strix occidentalis*). In: Poole A, Gill F (eds) The birds of North America, no 179. The Academy of Natural Sciences, Philadelphia and The American Ornithologists' Union, Washington DC
Gutiérrez R, Cody M, Courtney S et al (2004) Assessment of the potential threat of the Northern Barred Owl. In: Courtney SP, Blakeley JA, Bigley RE et al (eds) Scientific evaluation of the status of the Northern Spotted Owl. Sustainable Ecosystems Institute, Portland
Gutiérrez RJ, Cody M, Courtney S et al (2006) The invasion of Barred Owls and its potential effect on the Spotted Owl: a conservation conundrum. Biol Invas (in press)
Hamer TE, Hays DL [sic], Senger CM et al (2001) Diets of Northern Barred Owls and Northern Spotted Owls in an area of sympatry. J Raptor Res 35:221–227
Hipkiss T, Hornfeldt B, Eklund U et al (2002) Year-dependent sex-biased mortality in supplementary-fed Tengmalm's Owl nestlings. J Anim Ecol 71:693–699
Hood GM, Chesson P, Pech RP (2000) Biological control using sterilization viruses: host suppression and competition between viruses in non-spatial models. J Appl Ecol 37:914–925
Howald GR, Mineau P, Elliott JE et al (1999) Brodifacoum poisoning of avian scavengers during rat control on a seabird colony. Ecotoxicology 8:431–447
Ickes SK, Belant JL, Dolbeer RA (1998) Nest disturbance techniques to control nesting by gulls. Wildlife Soc B 26:269–273

Jodice PGR, Roby DD, Hatch SA et al (2002) Does food availability affect energy expenditure rates of nesting seabirds? A supplemental-feeding experiment with Black-legged Kittiwakes (*Rissa tridactyla*). Can J Zool 80:214–222
Johnson N, Franklin J, Thomas J et al (2004) Successes and failures of the Northwest Forest Plan and suggestions for change. Ecol Soc Am Annu Meet Abstr 89:252–253
Kelly EG, Forsman ED, Anthony RG (2003) Are Barred Owls displacing Spotted Owls? Condor 105:45–53
Kendall WL (2001) Using models to facilitate complex decisions. In: Shenk TM, Franklin AB (eds) Modeling in natural resource management: development, interpretation and application. Island Press, Washington DC
Kokko H, Sutherland WJ (2001) Ecological traps in changing environments: ecological and evolutionary consequences of a behaviorally mediated Allee effect. Evol Ecol Res 3:537–551
Korpimaki E, Norrdahl K (1998) Experimental reduction of predators reverses the crash phase of small-rodent cycles. Ecology 76:2448–2455
Lodge DM, Shrader-Frechette K (2003) Nonindigenous species: ecological explanation, environmental ethics, and public policy. Conserv Biol 17:31–37
Mack RN, Simberloff D, Lonsdale WM et al (2000) Biotic invasions: causes, epidemiology, global consequences, and control. Ecol Appl 10:689–710
Martin PR, Martin TE (2001) Ecological and fitness consequences of species coexistence: a removal experiment with wood warblers. Ecology 82:189–206
Mayfield HF (1961) Cowbird parasitism and the population of the Kirtland's Warbler. Evolution 15:174–179
Mazur KM, James PC (2000) Barred Owl (*Strix varia*). In: Poole A, Gill F (eds) The birds of North America, no 508. The Birds of North America Inc, Philadelphia
Meek WR, Burman PJ, Nowakowski M et al (2003) Barn Owl release in lowland southern England: a twenty-one year study. Biol Conserv 109:271–282
Merrill JA, Cooch EG, Curtis PD (2003) Time to reduction: factors influencing management efficacy in sterilizing overabundant white-tailed deer. J Wildlife Manage 67:267–279
Miller LA, Rhyan J, Killian G (2004) GonaConT, a versatile GnRH contraceptive for a large variety of pest animal problems. Proc Vertebr Pest Conf 21:269–273
Mills EL, Leach JH, Carlton JT et al (1994) Exotic species and the integrity of the Great Lakes. BioScience 44:666–676
Noon BR, Blakesley JA (2006) Conservation of the Northern Spotted Owl under the northwest forest plan. Conserv Biol 20:288–296
Nogales M, Martin A, Tershy BR et al (2004) A review of feral cat eradication on islands. Conserv Biol 18:310–319
Olson GS, Glenn EM, Anthony RG et al (2004) Modeling demographic performance of Northern Spotted Owls relative to forest habitat in Oregon. J Wildlife Manage 68:1039–1053
Olson GS, Anthony RG, Forsman ED et al (2005) Modeling of site occupancy dynamics for Northern Spotted Owls, with emphasis on the effects of Barred Owls. J Wildlife Manage 69:918–932
Oppel S, Schaefer HM, Schmidt V et al (2004) Cowbird parasitism of Pale-headed Brush-finch *Atlapetes pallidiceps*: implications for conservation and management. Bird Conserv Int 14:63–75
Orians GH (1986) Site characteristics favoring invasions. In: Mooney HA, Drake JA (eds) Ecology of biological invasions of North America and Hawaii. Springer-Verlag, New York
Pearson RR, Livezey KB (2003) Distribution, numbers, and site characteristics of Spotted Owls and Barred Owls in the Cascade Mountains of Washington. J Raptor Res 37:265–276
Pulliam HR (1988) Sources, sinks, and population regulation. Am Nat 132:652–661
Pullin AS, Knight TM, Stone DA et al (2004) Do conservation managers use scientific evidence to support their decision-making? Biol Conserv 119:245–252
Redpath SA, Arroyo BE, Leckie EM et al (2004) Using decision modeling with stakeholders to reduce human-wildlife conflict: a raptor-grouse case study. Conserv Biol 18:350–359
Rettie WJ, McLoughlin PD (1999) Overcoming radiotelemetry bias in habitat-selection studies. Can J Zool 77:1175–1184
Rothstein SI, Peer BD (2005) Conservation solutions for threatened and endangered cowbird (*Molothrus* spp.) hosts: separating fact from fiction. Ornithol Monogr 57:98–114
Rothstein SI, Kus BE, Whitfield MJ et al (2003) Recommendations of cowbird management in recovery efforts for the Southwestern Willow Flycatcher. Stud Avian Biol 26:157–167
Ruesink JL, Parker IM, Groom MJ et al (1995) Reducing the risks of nonindigenous species introductions: guilty until proven innocent. BioScience 45:465–477
Schardt JD (1997) Maintenance control. In: Simberloff D, Schmitz DC, Brown TC (eds) Strangers in paradise. Island Press, Washington DC
Schlaepfer MA, Runge MC, Sherman PW (2002) Ecological and evolutionary traps. Trends Ecol Evol 17:474–480
Schmidt KA, Goheen JR, Naumann R et al (2001) Experimental removal of strong and weak predators: mice and chipmunks preying on songbird nests. Ecology 82:2927–2936
Sigg DP, Goldizen AW, Pople AR (2005) The importance of mating system in translocation experiments: reproductive success of released male bridled nailtail wallabies. Biol Conserv 123:289–300
Simberloff D (1981) Community effects of introduced species. In: Nitecki MH (ed) Biotic crises in ecological and evolutionary time. Academic Press, New York
Simberloff D (2000) Nonindigenous species a global threat to biodiversity and stability. In: Raven P, William T (eds) Nature and human society: the quest for a

sustainable world. National Academy Press, Washington DC
Simberloff D (2003) Confronting introduced species: a form of xenophobia? Biol Invas 5:179–192
Smith JNM, Taitt MJ, Zanette L et al (2003) How do Brown-headed Cowbirds (*Molothrus ater*) cause nest failures in Song Sparrow (*Melaspiza melodia*)? A removal experiment. Auk 120:772–783
Taylor RH, Kaiser GW, Drever MC (2000) Eradication of Norway rats for recovery of seabird habitat on Langara Island, British Columbia. Restor Ecol 8:151–160
Townsend CR (2003) Individual, population, community, and ecosystem consequences of a fish invader in New Zealand streams. Conserv Biol 17:38–47
Tuyttens FAM, MacDonald DW (1998) Fertility control: an option for non-lethal control of wild carnivores? Anim Welfare 7:339–364
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 vols. US Government Printing Office, Washington, DC
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
Van Zant JL, Wooten MC (2003) Translocation of Choctawhatchee beach mice (*Peromyscus polionotus allophrys*): hard lessons learned. Biol Conserv 112:405–413
Verner J, McKelvey KS, Noon BR et al (1992) The California Spotted Owl: a technical assessment of its current status. USDA Forest Service General Technical Report PSW-GTR-133
Ward JM, Kennedy PL (1996) Effects of supplemental food on size and survival of juvenile Northern Goshawks. Auk 113:200–208
Wiens JA (1989) The ecology of bird communities, vol 2. Processes and variations. Cambridge University Press, Cambridge
Williams TD, Miller M (2003) Individual and resource-dependent variation in ability to lay supranormal clutches in response to egg removal. Auk 120:481–489
Wilson WH Jr (2001) The effects of supplemental feeding on wintering Black-capped Chickadees (*Parus atricapillus*) in central Maine: population and individual responses. Wilson Bull 113:65–72
Wood PB, Collopy MW (1993) Effects of egg removal on Bald Eagle productivity in northern Florida. J Wildlife Manage 57:1–9
Woodroffe R (2003) Dispersal and conservation: a behavioral perspective on metapopulation persistence. In: Festa-Bianchet M, Apollonio M (eds) Animal behavior and wildlife conservation. IslandPress, Washington DC
Yoder CA, Andelt WF, Miller LA et al (2004) Effectiveness of twenty, twenty-five diazacholesterol, avian gonadotropin releasing hormone, and chicken riboflavin carrier protein for inhibiting reproduction in Coturnix quail. Poultry Sci 83:234–244