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Chapter 7

MANAGING PREDATORS TO PROTECT ENDANGERED SPECIES AND PROMOTE THEIR SUCCESSFUL REPRODUCTION

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ABSTRACT

Predation critically threatens many rare species, with the deleterious impacts of predation losses compounded by habitat loss. Predators of endangered species are frequently invasive species or artificially over-abundant native species. Often, predation is most damaging to a species' ability to reproduce. We use examples from the tropics to the tundra with which we have been involved to demonstrate how predator management can be a highly effective and economically efficient means to protect populations of rare species and enhance their reproduction.

Management of predators, like all wildlife management, must be carried out within finite fiscal and human resources. Examination of the predator populations in response to management actions only provides an indicator of success. The true measure of success is improvement of the endangered species as a result of the management action. Moreover, a vital means to establish the success of an endangered species protection program is to demonstrate that the benefits to the protected species exceed the cost of the program. To

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this end, methods to monetarily value rare species allow species improvement to be assessed in the same metric as the costs for the protection.

Predator management to aid conservation of rare species requires is much more likely to succeed if: 1) applied by skilled/trained personnel able to focus on the task, 2) management efforts are timed so the most favorable impact can be achieved, 3) the effort is applied with sufficient intensity that the desired effect can be achieved, 4) predator population information is used for optimizing the timing, distribution and intensity of management efforts, and 5) adaptive management strategies are applied to changing circumstances through time. If predator management is not being applied effectively, then predator management is not taking place. It would be a disservice to a species in need of protection to discount predator management as useful because it was ineffectively applied.

INTRODUCTION

Predation not only threatens many rare species (Hecht and Nickerson, 1999), but the deleterious impacts of predation losses are compounded by habitat loss (Reynolds and Tapper, 1996). Alien predators tend to be more dangerous than native predators to prey populations (Salo et al. 2007). In the USA, exotic species have played a role in the listing of 42% of the species protected by the Endangered Species Act (Stein and Flack 1996). Moreover, predators increase the risk of extinction of prey populations as a result of catastrophic events (Schoener et al. 2001). Therefore, rare species in a state such as Florida may be particularly vulnerable considering: extensive development has depleted many of the native habitats on which rare species depend: the state has one of the two most severe invasive species problems, with many of the exotic species being significant predators; and the state is subject to catastrophic hurricanes. While Florida offers a severe and broad example of the negative impacts of predation on rare species, countless other examples from diverse habitats, especially islands, demonstrate the negative impacts of predation, and the positive effects of predator management when appropriately applied.

Small or declining populations may benefit the most from reductions in predation if numbers are increased quickly and variability in productivity and survival rates are reduced (Hecht and Nickerson 1999). Reducing predation rates through predator control may be an essential component of a management plan to achieve recovery objectives for a species of concern (Bodenchuk and Hayes 2006). In many cases, if not most, seasonal control efforts may accomplish management goals while optimizing the efficiency of human and material resources, and funding. Application of predator control when a rare species is most vulnerable to predation may be as effective as year-round techniques. Moreover, in some instances compensatory mitigation for reducing predation during breeding may help compensate for losses in other life stages from a variety of mortality sources (Wilcox and Donlan 2007).

One of the complicating factors in the application of predator control for the benefit of a rare species is that removal of predators to conserve rare species sometimes places wildlife managers and the public in the uncomfortable position of choosing between removal of a charismatic predator species or conserving an endangered species, possibly allowing it to go extinct without sufficient predator management. While some significantly destructive predators of rare species receive little affection from the public, such as brown treesnakes or rats, many predators are held in high esteem in the public consciousness, especially predators such as raptors, wolves, or even raccoons, while other significant predators of rare species include feral domesticated animals commonly beloved pets such as cats and dogs. From a purely logical perspective, this would be an uncomplicated, straightforward decision. From an emotional point of view, it can be an unpleasant choice, especially when the public, usually without a full understanding of all ramifications and practical options, protests predator removal, especially lethal removal, even if the alternative would be significant harm or possibly extinction for a rare species in need of protection.

ECONOMIC ANALYSES OF CONSERVATION THROUGH PREDATOR MANAGEMENT

A key aspect in considering conservation approaches is the economics involved, especially the return on a conservation investment. Funding is finite for recovery and conservation of species and habitats, and must be carefully applied to maximize the positive impact on the protected resource. Economic analyses of management actions can provide managers with a logical working basis for selecting and implementing the most cost-effective conservation methodologies. While the direct costs for a conservation approach, such as predator management, may be relatively easy to identify and quantify because they can be measured by the budgetary outlay for implementation, the rewards from those budgetary allocations are measured in terms of resource improvements, such as population growth. To effectively evaluate the returns on the expenditures, they must be in the same metric as the expenditures. That is, the resource improvement must also be monetarily valued.

Determination of monetary values for rare species is not a straight-forward nor precise process. As an illustration, consider that values of endangered or threatened species have been deemed "incalculable" in U.S. Supreme Court case law (Tennessee Valley Authority vs. Hill, 1978), the opinion going so far as to say "it would be difficult for a court to balance the loss of a sum certain - even $100 million - against a congressionally declared 'incalculable' value, even assuming we had the power to engage in such a weighing process, which we emphatically do not." Nevertheless, infinite or astronomically high monetary species valuations would be unlikely to be widely viewed as credible. Credible monetary values for rare species can be estimated through the variety of means.

While contingent valuation, a method based on survey results, has been applied to create natural resource valuations (e.g., Loomis and Walsh 1997), the scenarios are hypothetical, the validity of the responses to a contingent valuation is unsure, and the results may not reflect the people's true willingness to pay (WTP), either because people do not have a realistic sense of how much they would pay, or because they have incentives to dishonestly report their WTP (Loomis and Walsh 1997). Nevertheless, we have found other methods of great use for defining societal values for rare species.

Legislatively designated values are a useful method for assigning societal values to resources (Engeman et. al 2004, Bodenchuk et al. 2002). Wildlife management agencies use estimates of economic values based on contributions to the economy by individual game species to derive their monetary values (Bodenchuk et al. 2002), and develop civil financial penalties for illegal kills (Bodenchuk et al. 2002). However, rare and endangered species do not have civil financial penalties assigned in relation to their contributions to the economy as "renewable" resources, because they are rarely, if ever, exploited in a financially measurable fashion such as through the sale of hunting or fishing licenses and sportsman equipment. Nevertheless, rare and endangered species are almost universally protected with civil penalties set forth legislatively. Such species likely will have more than one value available from multiple enabling legislations (e.g., United States federal and individual state laws). A conservative benefit-cost analysis is obtained when the minimal applicable value is employed. However, this could substantially under-value a species, especially when considering that all civil financial penalties from the different enabling legislations could apply simultaneously. Consider the example of predator depredations on marine turtle nests in Florida by Engeman et al. (2002). Their analyses chose the conservative route of applying a minimum legislative value of $100 from Florida statutes. However, the Florida Wildlife Code specified a value of $500 per life unit, and the federal Endangered Species Act (ESA) allows for civil penalties up to $25,000 per life unit. Thus, the monetary benefits accrued from the predator management approaches could have ranged by a factor of 250 (Engeman et al. 2002).

Captive Breeding costs provide an empirically observed measure of value actually paid to produce new individuals for a species. Captive breeding is not only a management strategy for assisting the recovery of a rare species, but it also provides data for placing a value on a species. The use of captive breeding costs as a means for monetarily valuing rare species is a simple concept, because those monies spent to produce animals in captivity are empirically explicit demonstrations of a willingness to pay for new animals. The costs of captive breeding divided by the number of healthy individuals produced defines a value for the species (e.g., Bodenchuk et al. 2002). Nevertheless, the valuing process is not quite as straight-forward as this seems. There may be multiple captive breeding facilities for the same species, each with its own budget (e.g., Engeman et al. 2003b). A facility may remain in operation year-in and year-out, but its temporal budget and animal production may fluctuate substantially, resulting in fluctuating species values. The most conservative analysis is obtained if the minimum cost per production of a healthy individual is used, whereas use of the maximum value provides the empirical peak expenditure to produce an individual of the species. Use of the median value for an individual provides an analysis representing the central tendency for valuing the species. A parallel concept to applying captive breeding costs to determine species values is to value species based on populations and budgetary outlay for refuges or preserves designated to protect and conserve a specific species. The population subject to budgetary outlay for its conservation thereby defines an empirically spent per-unit amount for the individuals.

PREDATOR MANAGEMENT IN ACTION FOR RARE SPECIES CONSERVATION

There are virtually countless examples in the literature demonstrating the value of predator management in conserving endangered species. Conversely, there are numerous examples where predator management did not appear to help the situation. Direct control can locally reduce predator populations, but the removal of animals does not always correlate well to the magnitude of damage reduction (e.g., Conner *et al.* 1998). Understanding the dynamics of the damaging species with the affected resource can lead to more efficient and effective strategies for protecting the resource (e.g., Knowlton et al. 1999; Ramsey and Wilson 2000). Just because a predator is identified as negatively impacting an endangered species does not guarantee that managing the predator will be an effective, efficient, or cost-effective means to help conserve the listed species. Predator management requires a thorough understanding of when and why predation takes place, and understanding the circumstances that make the endangered prey most vulnerable to predation. Optimizing predator management for application during the circumstances of greatest vulnerability of the endangered prey produces a great benefit for the endangered species while maximizing the benefit-cost ratio for expenditures of conservation funds.

We use a variety of situations from tropical rainforests to arctic tundra in which we have been involved to demonstrate how broadly effective predator management can be for conserving populations and/or bolstering reproduction of threatened and endangered species. In doing so, we also are demonstrating that predator management must be applied judiciously and effectively to obtain the desired positive effect for the endangered species. A haphazard application of predator management that consequently shows little conservation value may discourage a manager from its use in the future, when, in fact, it could be the essential tool for saving the species if applied prudently. Sometimes biological systems are viewed so complexly that a straight-forward application of predator management is overlooked as potentially solving a problem. On the other hand, the positive response to predator management is sometimes difficult to observe directly and its evaluation for efficacy is difficult without a thorough understanding of the techniques, which may include a combination of lethal control, predator harassment, and barriers (physical and behavioral). Throughout, if predators are removed, efficacy of predator removal is not judged by the number of predators removed, but rather by improvements in population or reproduction of the rare species to be conserved.

Protecting Sea Turtle Nests at a High Density Nesting Beach: An Informed Approach

The beach at Hobe Sound National Wildlife Refuge (HSNWR) on Florida's east coast is a high-density nesting beach (up to 1600 nests in 5.3 km) serving three species of threatened and endangered sea turtles: loggerhead (*Caretta caretta*), leatherback (*Dermochelys coriacea*), and green (*Chelonia mydas*) turtles. HSNWR is located in one of most important marine turtle nesting areas in Florida (Meylan et al. 1995), and is in the center of loggerhead nesting activity in the U.S. Historically, up to 95% of turtle nests at HSNWR were lost to predation (Bain *et al.* 1997) by raccoons (*Procyon lotor*), an over-abundant native species, and armadillos (*Dasypus novemcinctus*), an invasive species. Consequently, predator control was identified as the most important conservation tool at HSNWR (Bain *et al.* 1997; USFWS 2000).

Predator control had been carried out at HSNWR since 1972 (Bain *et al.* 1997). Through 1998, predator control had primarily been carried out by refuge staff in addition to their primary duties (Engeman et al. 2003a). Nest predation was reduced, but still was at an unacceptable level of 48.4% when the refuge developed a 1 person-month agreement with the US Department of Agriculture, Wildlife Services (USDA/WS) to have specialists carry out the predator control, resulting in a reduction in predation to 41.6% (Engeman et al. 2003a).

This was a step in the right direction, but greater reductions in predation were desired. For the 2000 nesting season, it was hoped that predator control in advance of the nesting season would eliminate the problem before it began. This was also the season that a passive tracking index (PTI) was applied to monitor the size and distribution of the predator populations along the beach (Engeman et al. 2003a).

The first result from incorporating the PTI information into control activities was to discover that the predators for the most part were not at the beach until the turtles began nesting in full force. Thus, the concept of applying predator control prior to turtle nesting would have resulted in expending the 1 person-month of control without effectively addressing the predators drawn to the beach during nesting, and probably would have resulted in very high levels of predation. The PTI methodology further indicated when the predators became active, where they were the greatest problem, and when their activity declined so that the control could be temporarily halted until needed later in the nesting season, thereby extending the timeframe of the 1 person-month agreement (Engeman et al. 2003a). Optimization of the timing and placement of predator control activities in this manner reduced predation to a remarkably (at that time) low 27.7% (Engeman et al. 2003a). To put these results in perspective, it was estimated this approach resulted in almost 84,000 more hatchlings into the ocean over historical high predation rates, over 62,000 more hatchlings than when the refuge was carrying out control, and nearly 54,000 more hatchlings than control specialists achieved prior optimizing their efforts with the population information from the PTI (Engeman et al. 2003a). Using conservative monetary valuations for sea turtles, The economic improvements over the previous predator control approaches ranged from $1.7 million to $8.4 million, depending on the approach used for comparison (Engeman et al. 2003a). These returns were achieved for a predator control agreement of approximately $10,000.

The success story does not end here. In 2002, the design of the PTI was improved so that armadillos could be better monitored, and therefore, more efficiently controlled. The outcome was another significant drop in predation to 9.4%, a level not believed achieved achievable (Engeman et al. 2005). Further increases in hatchling numbers and corresponding economic returns were produced beyond previous accomplishments (Engeman et al. 2005). Additional improvements appeared to be on the horizon initially in 2004, but predator control was removed midway through the nesting season due to budgetary shortfalls, and predation soared as a result (Engeman et al. 2006). The experience at HSNWR demonstrates that knowledge about the predator population can be shrewdly applied to maximize efficacy of predator management efforts while obtaining the greatest return for the conservation dollar, while halting a successful technique results in conservation reversals.

Conserving the Critically Endangered Puerto Rican Parrot

The Puerto Rican parrot (*Amazona vittata*) is one of the 10 most endangered birds in the world, and predation has been identified as one of the factors limiting Puerto Rican parrot productivity in the wild. The loss of a very few birds or a nest can have a great impact on the species. Management of red-tailed hawks (*Buteo jamaicensis*), and invasive mammals including black rats (*Rattus rattus*), feral cats (*Felis catus*) and small Indian mongooses (*Herpestes javanicus*) offers significant benefit to the parrot population. Each of these species is potentially a story unto itself and a key to conserving a bird this vulnerable and rare. For brevity, we only consider here lessons from the portion concerning black rats, but that does not imply a priority, as management of all predators is necessary for such a rare species (around 30-40 birds in the wild at the time of the described research).

Rats are primarily a threat to parrot nests. They may predate the eggs or chicks, or they may harass the parent birds sufficiently to deter adequate care of the nest, leading to its failure. Tracking plates, bait blocks, and trapping were applied to index black rats in the parrot nesting area. Although toxic baiting had been carried out to a degree around parrot nest sites, an extraordinary trap success for black rats at all sites in the parrot nesting area (42% all sites combined) demonstrated that the rat control strategy was insufficient to be effective for protecting parrot nests. Despite the existence of some control, the trapping index for rat abundance was among the highest reported in the literature anywhere in the world using live or snap traps (Engeman et al. 2006). Similarly, rat response to the nontoxic bait blocks for population monitoring purposes was universally high, regardless of ground or tree placement. Black rats appeared exceptionally abundant in the forest where the parrots nest. Most studies report <10% trap success for black rats (e.g., Dunlevy et al., 2000; Robinet et al., 1998; Tamarin and Malecha, 1972), but even those lower rat densities are well documented as causing insular avian extinctions or declines (e.g., Atkinson, 1985).

Wild parrot breeding success fluctuates considerably. A rat-induced nest failure was particularly unacceptable in a year (2002) when there were only three active nests, only one of which was successful and produced two fledglings. Nest success improved substantially in 2003 when rat control was intensified, with four of five active nests successful and eight fledglings produced (Engeman et al. 2006). Various factors may have influenced nesting success including weather conditions, natural fluctuations in breeding success, and enhanced rat control. Rat control is the only one of these factors that could be managed, and is highly cost-effective to apply (Engeman et al., 2003b).

As an illustration of control cost-efficacy, management of all predators as a general species enhancement method for the Puerto Rican parrot was analyzed from an economic perspective. A benefit-cost analysis was used to examine the potential improvements from predator management for protecting Puerto Rican parrots. Using median parrot values across five years from two captive breeding facilities demonstrated that saving only one parrot from predation every 2.6 years allows the combined predator management for all predator species to be cost-effective. Use of the maximal empirical per-parrot value during the same time period showed the combined application of all forms of predator management as cost-effective if only one parrot was saved from predation every 11.8 years.

The Puerto Rican parrot is another example of extreme cost-effectiveness for conserving an endangered species through predator management. The example of rats as nest predators is a demonstration that application of some level of predator control can lead to the belief that the predator species is being effectively managed when, in fact, that was not the case. Similar to the sea turtle situation at HSNWR, a better understanding and consequent management of the predator situation for the Puerto Rican parrot led to enhanced reproduction of the endangered species.

Steller's Eiders: The Simple Solution

Sometimes predation turns out to be the simplistic explanation for reproductive failure in a listed species and defies predictions from complex explanations of system dynamics pointing to a variety of other factors as playing more major roles in breeding success. The Alaska breeding population of Steller's eiders (*Polysticta stelleri*) is federally listed as threatened and state-listed as a species of concern. Steller's eiders are highly susceptible to predation during nesting season in late spring and early summer. Control of arctic fox (*Alopex lagopus*) on the Barrow Steller's Eider Conservation Planning Area (BSECPA) began in 2005 to protect the threatened Alaska-breeding population of Steller's eider, as well as other indigenous birds.

The nesting success of Steller's eiders at BSECPA has fluctuated greatly since 1991. Nest success averaged 16% from 1991-2004, prior to fox control. Since fox control from 2005-2007 nest success averaged 52% (Gilsdorf and Rossi 2008). Nest success for shorebirds at BSECPA also had a simultaneous dramatic increase, averaging about 29% for the years monitored pre-control (2003-2004), and averaging about 83% during the years with control (Gilsdorf and Rossi 2008). Prior to fox control, the eiders only nested successfully in less than half of the years where observations took place. During that time, they only nested successfully in two consecutive years twice, and they never successfully nested in three consecutive years. However, they successfully nested in all three consecutive years where fox control was applied. The positive influence from fox control on reproductive success for the Steller's eiders and the other shorebirds nesting in BSECPA has been dramatic and immediate (Gilsdorf and Rossi 2008).

Breeding by Steller's eiders and their consequent breeding success were considered dependent on a variety of factors, including predation. Predictions based on past breeding patterns in connection with other predator and prey species abundances and interactions suggested to some that the eiders would not breed in the third year that predator control was applied (Gilsdorf and Rossi 2008). If true, this would imply that application of predator control to protect breeding in a non-breeding year would be unproductive (and uneconomical). Fortunately, empirical evidence was sought, control was applied, and the eiders bred successfully contrary to predictions based on complex dynamics (Gilsdorf and Rossi 2008). Moreover, at this writing, preliminary results from 2008 indicate that this fourth year of predator management will be the fourth consecutive, and most outstanding, year of successful breeding by the Steller's eiders in BSECPA.

The average cost per year to apply the control has been less than $29,000. Detailed economic analyses of these results have been initiated at this writing, but it is clear from even a cursory scan of these results coupled with even minimum valuations for the Steller's eiders and shorebirds, that the monetarily valued returns in production (benefits) will be orders of magnitude greater than the costs. These returns, both biologically and economically, have the potential to be increased in the future. Arctic fox, while most harmful, are not the only eider predator on BSECPA. Red fox (*Vulpes vulpes*) was added to the predators managed in the 2008 breeding season. Jaegers (*Stercorarius groenlandicus*), snowy owls (*Nyctea scandiaca*), weasels (*Mustela* spp.), ravens (*Corvus corax*), and glaucous gulls (*Larus hyperboreus*) are also abundant and also prey on eiders, their eggs or young. Judicious management of these species may further enhance the returns from predator management for conserving Steller's eiders.

As demonstrated in other aspects of the examples presented earlier, hypothetical approaches for predator management should be tested by obtaining empirical results. Otherwise, the predator control would not have been applied for the third consecutive year, and breeding success for the eiders would likely have been lost for that year at BSECPA. This parallels the situation at HSNWR where predator control would have been expended prior to nest predators accumulating at the beach had not empirical information been obtained, and also the situation with the Puerto Rican parrot where population monitoring contradicted the belief that the originally applied level of rat control was sufficient to protect parrot nests.

Endangered Salmonids of the Columbia River Basin

A number of salmonid (*Onchyrhyncus spp*) Evolutionary Significant Units (ESUs), representing demographically independent groups of fish, within the Columbia River Basin in the northwestern U.S. have been designated as endangered (e.g., McClure et al. 2003). Salmon (*Onchyrhyncus spp*) and steelhead (*Onchyrhyncus mkkiss*) populations in the upper Columbia River cannot replace themselves due to the extensive series of hydroelectric dams and reservoirs, a problem which can only be resolved by reducing the mortalities caused by dams (USDA 2003, WDFW 1997). Therefore, hatchery-raised juvenile smolt are used to strengthen recovery efforts and supplement recreational and commercial harvest.

The dams pose several interrelated hazards for the migrating fish. The physiological condition of migrating juvenile salmonids may be altered by dam passage or transportation, increasing their vulnerability to predators (see USDA 2003 for citations and summary). Juvenile salmonids may be injured and also can experience various levels of gas bubble trauma in tailraces due to supersaturated water caused by air dissolved in water at pressures exceeding one atmosphere. The hydroelectric dams act as bottlenecks for juvenile salmonid migration, and the tailrace immediately below hydroelectric dams (approximately 300 m) is where smolt, especially the injured and disoriented, are most vulnerable to avian and piscine predators (Beamesderfer et al. 1996, USDA 2003). Reducing predation in the tailrace of each dam can allow smolt time to recover from the physiological effects of hydroelectric dam passage and to continue on their journey.

The challenge to protecting the smolt is that both avian and piscine predators accumulate at the tailraces of the dams to feed on the smolt. Not only do the piscivorous birds often feed in areas of high fish density, but their presence also attracts additional birds to feeding areas (see USDA 2003 for citations and summary). Juvenile salmonids are a major food source for avian predators on the Columbia River, and basin-wide losses to avian predators constitute a substantial proportion of the juvenile salmonid out-migration (Ruggerone 1986, USDA 2003). Because human-caused changes in the Columbia River Basin created situations with an excess of predators, these healthy predator populations may be controlled when the action is (1) part of a comprehensive recovery plan addressing all aspects of salmonid survival; and (2) as long as the predator population remains abundant (WDFW 1997).

An integrated management approach is used to thwart predation at dam tailraces. Northern pikeminnows (*Pytchocheilus oregonensis*), the primary piscine threat to the smolt, are captured and removed from the tailraces. Predation by piscivorous birds is reduced primarily by deterring birds from congregating and feeding at the tailraces where smolt are unnaturally exposed and susceptible to predation. Methods for reducing bird usage of these areas include overhead wiring systems to inhibit flight into the tailrace areas. Mylar tape, propane cannons, pyrotechnics, effigies and other harassment methods are also used to deter birds from the area (USDA 2003). While > 97% of the protective actions are nonlethal, some lethal removal is necessary for individual birds evading the nonlethal methods (R. Woodruff, USDA/WS, pers. comm.).

Despite reducing predation in discrete river segments of high smolt susceptibility (300 m of tailraces), it is difficult to directly observe the efficacy of predator management on the smolt population. The competing sources of mortality and an underwater population moving through an area make direct population impacts difficult to observe. Many studies have indicated tremendous smolt losses to predators (see Beamesderfer et al. 1996, USDA 2003). An application of bioenergetic modeling attempted to evaluate some aspects of predator management efficacy for protecting smolt (Weise et al. 2008). Recommendations based on the modeling results showed the key components for smolt protection were already in place (for a number of years) (Weise et al. 2008). However, there were also some recommendations contrary to practical management approaches in the wild. For example, the study recognized that the current low take of smolt by birds at tailraces is likely a result of the predator management programs in place for over a decade. Not surprisingly then, current smolt losses to birds in the reaches between the dams were indicated to be greater than at the tailraces, prompting the suggestion that bird management in these river segments that can be over 50 km-long would be an effective means to reduce smolt losses (Weise et al. 2008). This, of course, would be impractical due to the extreme costs that would be incurred for effective implementation. Similarly, it was suggested that lethal removal of birds actually results in greater smolt losses because those same birds would no longer also consume pikeminnow juveniles, thereby increasing predation by pikeminnows through larger populations (even though pikeminnows are also removed at tailraces) (Weise et al. 2008). While this makes for an interesting hypothesis, the number of birds lethally removed 2001 - 2007 has been insignificant. For example, during that time period < 6 birds/yr on average were removed from the dams in the Chelan Public Utility District (USDA/WS unpublished data). Lethal removals of birds across all dams in recent years have been too trivial to have such an impact to influence future adult pikeminnow populations, and the current removal numbers are also trivial in comparison to the (high-variance) mean figure of 3360 from 1997 to 2001 presented in Weise et al. (2008), the period when smolt protection from predators was in its initial phases and bird congregations at the dams were orders of magnitude higher than now (R. Woodruff, USDA/WS, pers. comm.). Moreover, the current low lethal take is highly necessary to handle some birds unaffected by the other deterrent methods. Those birds otherwise would not only consume smolt at will, but they would also serve as decoys for ever-increasing numbers of birds to also evade the deterrents, ultimately defeating or diminishing efficacy of the nonlethal measures in place (R. Woodruff, USDA/WS, pers. comm.). Thus, relative application of smolt protection methods has followed an adaptive management approach responding to induced and natural changes in populations and behaviors of the species preying on smolt.

Spotted Owls: The Brewing Concern

The northern spotted owl (*Strix occidentalis caurina*) was listed as federally endangered in Canada in 1986 (Campbell and Campbell 1984, Government of Canada 2002) and as federally threatened in the United States under the Endangered Species Act in 1990 (USFWS 1990). A land-based conservation strategy was devised for northern spotted owl recovery, with 3.01 million ha designated as Late-Successional Reserves to protect forests used by northern spotted owls, and another 1.06 million ha designated as riparian reserves, in large part to allow dispersal of northern spotted owls among Late-Successional Reserves, all in addition to existing protected areas such as national parks (USDA and USDI 1994; Marcot and Thomas 1997). Overall, "the federal forests in the Pacific Northwest underwent the largest shift in management focus since their creation" (Thomas et al. 2006), from timber production to protection of late-successional forests used by northern spotted owls and other species. As the basis of the Northwest Forest Plan, "no species in the United States has had a greater impact on land-use planning at the landscape scale" than the northern spotted owl (Noon and Blakesley 2006), resulting in significantly decreased timber harvest on federal lands within the range of the northern spotted owls (Charnley 2006, Thomas et al. 2006). Based on the value of the timber now unavailable for harvest and the numbers of owls potentially occupying the protected areas, an empirical valuation of northern spotted owls would probably show it to have one of the highest monetary values in the world.

This land-based conservation strategy is now being confounded by a species invasive to western North America. Barred owls (*Strix varia*) have invaded from eastern North America into the range of the northern spotted owl, where they are negatively affecting site occupancy, reproduction, and survival of northern spotted owls. Barred owls are larger than northern spotted owls, are physically aggressive toward them, can kill them, and use the same habitats and prey as they do. Moreover, barred owls negatively affect calling behavior, site occupancy, fecundity, and survival of northern spotted owls (see Livezey et al. 2007 for a summary of negative impacts). Therefore, the 2007 Draft Northern Spotted Owl Recovery Plan (USFWS 2007) identified Barred Owls as a very important threat to northern spotted owls.

As barred owls continue to expand their range and saturate the range of northern spotted owls, habitat preservation by itself will likely be insufficient to conserve northern spotted owls. Furthermore, barred owls are beginning to also invade the range of the California spotted owl (*Strix occidentalis occidentalis*). While not currently listed, subjecting California spotted owls to the same pressures that northern spotted owls are receiving from barred owls might well lead to their listing (Livezey et al. 2007). Thus, the threat posed by barred owls also may well lead to having to make a difficult choice: wide scale removal of barred owls or permit spotted owl populations to dwindle, possibly to extinction (Gutiérrez et al. 2004, Livezey et al. 2007). Such management of barred owls may eventually be required to save both northern spotted owls and California spotted owls. Even though the barred owl is an invasive species to the western U.S, and poses a substantial threat to a listed species, control of owls would still be an objectionable management choice to many wildlife professionals. Although raptor control is sometimes applied on a spot basis to protect endangered species such as black-footed ferrets or endangered ground squirrels, it has rarely been applied in the U.S. on a large scale to protect endangered species. The red-tailed hawk control to protect critically endangered Puerto Rican parrots would not compare in scale to what potentially would be needed to conserve northern spotted owls. More than likely, the difficult choice will need to be made if populations of northern spotted owls (and California spotted owls) are to remain viable.

Aleutian Cackling Goose: The Ultimate Success Story

The definitive assessment for predator management as a conservation tool would be delisting a species based primarily on this management approach. Such was the case for the Aleutian Cackling goose (*Branta canadensis leucopareia*), until recently known as the Aleutian Canada goose.

Over the course of nearly 200 years, arctic fox and red fox (*Vulpes vulpes*) were introduced for fur production to islands throughout the breeding range of the Aleutian Cackling goose. Aleutian Cackling geese were particularly easy targets for predators as they are ground nesters and flightless during molting in the summer, and only escaped extinction by persisting on three islands where foxes had not been established (Ebbert 2000), and the species became the third species overall to be listed under the U.S. Endangered Species Act.

Beginning in1949 and continuing into this century, foxes were targeted for elimination from the islands within the breeding range of the Aleutian Cackling goose by the U.S. Fish and Wildlife Service (USFWS), and in collaboration with USDA/WS. The island eradications involved a variety of methods and were highly successful. Coupled with natural and human translocations of geese to islands cleared of foxes, the removal of predators led to greatly improved breeding and rapid population increases (USFWS 2001). By 1999 the Aleutian Cackling goose population (~ 37,000) had reached nearly five times the population objective for delisting (USFWS 2001). The Aleutian Cackling goose was officially delisted in 2001 (USFWS 2001), and today's population exceeds 120,000. Thus, the Aleutian Cackling goose represents a significant conservation accomplishment for the recovery of an endangered species, and its recovery is largely a result of successful predator management.

DISCUSSION

Through the use of a variety of example situations, the utility of predator management as a conservation tool for endangered species was demonstrated in the preceding section. However, most examples also demonstrated clear caveats concerning the application, or non-application, of predator management. We easily could have shown examples where applications of predator management did not appear to benefit the species intended to be protected. In fact, some of our examples showed predator management to be unsuccessful, or only marginally successful at assisting endangered species until it was applied in a fashion that allowed it to be successful. Predator management must be applied in an informed and skilled manner. The examples presented also illustrated a variety of application concepts enhancing the prospects for benefiting the species to be protected. Thus, key aspects for predator management to produce tangible benefits for protecting endangered species include:

- Application by skilled/trained personnel able to focus on the task.
- Timing of management efforts so the most favorable impact can be achieved.
- Applying the effort with sufficient intensity that the desired effect can be achieved.
- Use of predator population information for optimizing the timing, distribution and intensity of management efforts.
- Adapting management strategies to changing circumstances through time.

These concepts seem obvious, but they do not always seem to be recognized in practice. They are also interrelated. A specialist in the area is more likely to recognize the appropriate timing, intensity, and placement needed to achieve a desired outcome. Even so, empirical information can be invaluable for even an expert to carry out predator management most effectively. Placement of traps, baits or any management tools in the field might provide a sense that predator management is being carried out. However, just because tools are being applied in the field does not mean they are being applied effectively. If the methods are not being applied effectively, then predator management is not taking place. We saw this in the case of protecting sea turtle nests where predator management was originally assigned not to a specialist, but as an additional duty for refuge staff. Even when specialists were called in, efficacy was not maximized until empirical population observations were obtained and incorporated into method application strategies. The same was clearly true for protecting Puerto Rican parrot nests from rats. Rat baits were applied by staff without expertise in rat control, and as an adjunct to the other conservation activities for the parrot. Rat population information demonstrated the insufficient intensity in application and experts in rat control were able to apply control tools efficiently and effectively, and pass the information along (Engeman and Whisson 2004). It would be a disservice to the species in need of protection to discount predator management as useful because it was ineffectively applied. Fortunately, this was averted with the Puerto Rican parrot through empirical demonstration.

Sometimes empirical demonstrations serve to supersede a theoretical situation. Such was the case with the Steller's eiders where the hypothesized species interrelationships would have suggested the third consecutive year of predator control was unnecessary, because the eiders were unlikely to breed in that year. To the credit of all parties concerned with eider conservation, that hypothesis was evaluated through applying a third year of predator control, resulting in successful breeding. Similar empirical demonstrations likely may fortify strategies for protecting juvenile salmonids in the Columbia River Basin, and test cases may prove the advantage to northern spotted owls from managing barred owls.

There are rarely objections raised to managing rats for endangered species protection, or reclaiming land for endangered bird reintroduction by applying the highly effective control methods for brown treesnakes (*Boiga irregularis*) on Guam (e.g., Engeman and Vice 1999). However, when more popular species are targeted for management, we have seen important conservation aspects stymied. For example in Florida, objections frequently are raised to managing populations of highly abundant raccoons and feral cats for the protection of endangered prey species such as Key Largo woodrats (*Neotoma floridana smalli*), Lower Keys marsh rabbits (*Sylvilagus palustris hefneri*), or beach mice. Public buy-in is often difficult, but when permitted, monitored and appropriately applied, the positive impacts from predator management are usually incontrovertible. Initially, there was considerable resistance to managing red-tailed hawks to protect Puerto Rican parrots, but the necessity and logic were inescapable, and the approach has received acceptance. The spotted owl situation in all likelihood will draw a tight focus on having to make tough choices between managing a predator species and letting a listed species eventually disappear from the wild.

Monitoring populations, at least on the local management scale, has been a theme discussed in various contexts here. It has been our experience that monitoring populations greatly assists their successful management. We have discussed how monitoring predators can greatly aid in the optimal application of management techniques in terms of timing and placement. Efficacy in management also is indicated, but the true measure is in the benefits to the protected species. Thus, there also is a need to monitor the species requiring protection to demonstrate, or identify, efficacy of management methods. As espoused early on, the ability to monetarily value the protected species allows the returns on conservation expenditures to be evaluated, and compared in some circumstances. This also is highly beneficial to species conservation, as it provides a direct means to justify continued conservation expenditures.

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