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*Opinion*

# Raven control from a conservation biology perspective

**David J. Delehanty**, Idaho State University, Department of Biological Sciences, Pocatello, ID 83209, USA *daviddelehanty@isu.edu*

***Abstract:*** The common raven (*Corvus corax*; raven) is a large, highly intelligent passerine songbird with a Holarctic distribution attributable to a high degree of plasticity in its foraging and nesting behavior. Historically, ravens have received special attention in human culture, being either respected or vilified. In the western United States, ravens are exploiting the expanding human enterprise, which provides them with unintended subsidies of food, water, and breeding locations, allowing ravens to expand their range and increase in population density and resulting in raven depredation threatening species of conservation concern. From a conservation biology perspective, increased raven populations present a difficult challenge in managing human–wildlife conflict. Some raven control measures are effective empirically but present ethical dilemmas, are economically expensive, or are socially divisive. Current studies seek to better understand raven population dynamics in relation to human land use and to identify socially acceptable ways to ameliorate raven impacts on biodiversity in the American West. The purpose of this paper is to provide readers with summaries of important constraints in the search for how to address deleterious effects of an expanding raven population. Specifically, I describe ethical, legal, social, and biological constraints in relation to calls for lethal control of ravens. Despite these constraints, a conservation strategy may emerge through modeling the relationship between raven presence and reproduction of sensitive prey species, and developing a clearer understanding of raven ecology. Papers in this special issue explore raven population dynamics, conservation consequences, and conservation solutions in detail and reveal innovative ways to address the complex human–wildlife conflict presented by ravens.

***Key words:*** animal control, anthropogenic subsidies, common raven, *Corvus corax*, ethical dilemma, generalist predator, human–wildlife conflicts, invasive species, management, North America

Conservation biology is the science of conserving biodiversity through biologically defensible pathways that also account for human sociological factors. Conservation biology recognizes that societal values ranging from economic outcomes to aesthetic preferences can influence social acceptance or rejection of biologically effective conservation actions. For example, what may work biologically is not necessarily supported socially as is seen in negative attitudes toward bats (Chiroptera), which hamper the conservation of imperiled species despite their ecological significance (Boso et al. 2021). The inverse relationship also may develop such that social preferences may not be effective biologically. For example, social preference for avoiding lethal control or barrier fencing in the management of deer (Cervidae) in Europe and North America hinders population management considered by wildlife managers to be beneficial (Dandy et al. 2012).

This complex milieu of forces is the context for common raven (*Corvus corax*; raven) management in western North America, and it applies acutely when wildlife managers propose that raven populations be suppressed or eliminated through direct management such a shooting or the use of toxicants (Sillero-Zubiri et al. 2007). Unsurprisingly, the prospect of lethal suppression of a culturally prominent bird raises difficult questions and elicits strong views within the wildlife management arena. Unfortunately, the search for resolution is hampered when management discussions conflate science, ethics, economics, and politics in the evaluation of options. For example, the scientific question of whether or not ravens can be controlled using toxicants is distinct from whether or not management agencies ought to do so, whether it is cost effective, and whether it is socially acceptable. The purpose of this paper is to assist stakeholders in recognizing and separating distinct arguments surrounding raven control and in doing so provide stakeholders with important information on issues constraining the search for effective management action. By separately considering scientific and social constraints, it becomes clear that simple management solutions to raven impacts on sensitive species currently are unlikely. Rather, this paper seeks to communicate why management actions intended to ameliorate raven effects necessarily are likely to be nuanced and conditional, and likely to evolve as much needed data progressively emerge.

## Evolutionary complexity

Ravens are sentient, intelligent passerines within Corvidae, an avian family comprised of species known for their complex sociality, behavioral innovation, and communication through nuanced vocal repertoires (Enggist-Dueblin and Pfister 2002, Heinrich 2011, Jelbert et al. 2018). Ravens employ problem solving and variable behavior to occupy wide-ranging forest, desert, and arctic habitats across the Northern Hemisphere (Boarman and Heinrich 2020). Ravens long have drawn special attention from humans who frequently have assigned either positive or negative attributes to ravens, resulting in ravens being either culturally valued or culturally vilified within human society (Clifford 2021), perhaps due to their intelligence and ability to overcome environmental challenges or, alternatively, as a result of a hypothesized cultural coevolution between ravens and humans (Marzluff and Angell 2005).

Although non-migratory, ravens are strong flyers, able to travel 160 km/day, with measured dispersal distances of up to 11,000 km in Old World populations (Loretto et al. 2016). Given this high capacity for range expansion (Pruett et al. 2018), ravens are among the most widely distributed passerine birds of the world.

Ravens appear to have colonized North America twice (Omland et al. 2000, Webb et al. 2011, Kearns et al. 2018, Boarman and Heinrich 2020), and raven occupation of North America predates the arrival of humans by approximately 2 million years. North American ravens of the so-called California clade, which includes the ravens of the Great Basin, are thought to descend from a colonization occurring approximately 2 million years ago and perhaps were isolated in a southern refugium during the last North American glacial maximum when North America was colonized by ravens a second time, probably across Beringia or from an Aleutian refugium (Pruett et al. 2018) and probably occurring during the late Pleistocene (Boarman and Heinrich 2020).

Raven capacity to learn and transmit behavior culturally (Heinrich 2011, Jelbert et al. 2018) enables them to take advantage of unintended human subsidies resulting from human activities. Ravens seek and readily consume roadkill and other carrion, small vertebrates, insects, eggs, cereal grains, and human garbage, and they use human buildings, towers, and other constructions as secure nesting substrates. Upon colonizing a new area, ravens can learn to exploit local species that have not previously been exposed to high raven density, and if these prey species are inflexible in their behavior, ravens are able to exploit them continuously.

Concomitantly, ravens can learn to avoid, resist, or otherwise circumvent management actions designed to limit ravens (Crabb et al. 1986). Since 1970, the overall population of arid land birds in the American West has declined by nearly 20% (Rosenberg et al. 2019), but during this time, raven population size, density, and range of occupation have increased substantially within these arid lands (Fleischer et al. 2007, Coates et al. 2016, Sauer et al. 2017, Coates et al. 2020). This is a direct result of ravens exploiting unintended human subsidies of food, water in arid regions, and nesting substrate (Boarman 2003; Coates et al. 2014*a*, *b*; Howe et al. 2014; O'Neil et al. 2018).

## Policy considerations

Like other native songbirds, ravens are protected throughout North America through treaty agreements and conventions between the United States, Canada, Mexico, and Japan. The Migratory Bird Treaty Act (MBTA) of 1918 (16 U.S.C. 703–712, MBTA) created federal protection for ravens in the United States because, under the treaty, ravens are recognized as migratory native birds, a status that expressly qualifies them for protection (Rozan 2014). The MBTA implemented a 1916 treaty agreement between the United States and Great Britain (namely, the *Convention with Great Britain [on behalf of Canada] for the Protection of Migratory Birds*, art. I, 39 Stat. 1702, T.S. No. 628 [1916]; Rozan 2014). Later, through amendment, the MBTA also implemented a 1936 treaty between the United States and Mexico, which created a *Convention for the Protection of Migratory Birds and Game Mammals*. The MBTA has continued to protect ravens following subsequent treaty modifications between the United States and Mexico in 1976 and the United States and Canada in 1995 (U.S. Fish and Wildlife Service [USFWS] 2020).

The MBTA prohibits the capture and handling of ravens as well as killing without prior authorization by the U.S. Department of the Interior's USFWS. This means that all raven control actions in the United States are subject to approval by the USFWS. The MBTA does include provisions for intentional or unintended killing of individuals of otherwise protected species of nongame migratory birds under certain circumstances that reflect degrees of utility to humans.

Special exceptions to take individuals of species otherwise protected under the MBTA are made for birds posing a threat to humans, birds that become agricultural pests, and birds subject to traditional and sustainable hunting for subsistence or for sport (Rozan 2014). Importantly, a "ravens as agricultural pests" perspective does not apply directly to conservation circumstances prevailing in the American West at this time. Raven impacts are not on agriculture but rather on other native species of conservation concern like greater sage-grouse (*Centrocercus urophasianus*; sage-grouse; Coates et al. 2008, Coates and Delehanty 2010, Lockyer et al. 2013, Coates et al. 2020).

Besides the legal restrictions of international agreement, lethal raven control has the potential to factionalize the public politically and emotionally. Some portion of the public sees lethal control as unethical or as a false panacea that allows local, state, and federal agencies to resist alternative management actions that address underlying causes of raven population growth. For example, reducing food subsidies through intensified management of road-killed animals, agricultural carrion, and municipal dumps may be meaningful alternatives to toxicant programs but also are difficult or expensive to implement. Lethal control of ravens also may factionalize support for wildlife management within the conservation community. Birding groups and bird conservation organizations, for example, may oppose raven control actions that are acceptable to state wildlife management agencies. These potential social conflicts are real, but finding mutually agreed upon solutions is difficult. One key to finding functional solutions is to identify the basis for underlying objections to proposed actions by distinguishing between objections that are due to disagreement over ethical versus conservation or economic factors (Hewitt and Messmer 1997, Messmer et al. 1999).

## Contemporary management

From a biological perspective, ravens physiologically are highly susceptible to toxicants. At the population level, local populations can be suppressed temporarily through the use of toxicants (Coates and Delehanty 2007). At the community level, emerging evidence, including in this special topic issue, indicates that raven population suppression can reverberate through ecological communities insofar as prey species can exhibit increased reproduction following raven population suppression (Dinkins et al. 2016, O'Neil et al. 2018).

When field application is carefully designed, ravens will consume food baits laced with the compound CPTH: 3-chloro-p-toluidine hydrochloride, sometimes referred to as "DRC 1339," "Starlicide," or "Corvicide." The compound works by preventing uric acid, the primary form of nitrogenous waste excreted by birds, from being cleared by the avian kidney. This results in systemic nitrogen toxicity and death approximately 0.5–3 days following ingestion as a result of progressive and generalized organ failure (Johnston et al. 1999). Mammals, which clear less nitrogenous waste via uric acid than birds, are not regarded to be at great risk from CPTH food baits deployed for birds insofar as estimated risk quotients for mammals exposed to CPTH are an order of magnitude lower than for birds and far below prevailing standards for acceptable risk to non-target species (Johnston et al. 1999).

For CPTH delivery to ravens, managers may employ a form of appetitive operant conditioning (Skinner 1938, Park et al. 1985, Avery et al. 1995) causing ravens to learn to consume baits. This is accomplished by placing non-treated, boiled domestic chicken (*Gallus gallus domesticus*) eggs in conspicuous locations within the raven control area for several days (Coates and Delehanty 2007). During this time, ravens learn to recognize the eggs as food and are rewarded by a surfeit of egg baits. Once ravens have learned to consume chicken eggs, additional CPTH-treated chicken egg baits are placed in the environment.

This process takes advantage of ravens' ability to exploit newly available food and ravens' propensity to be an egg predator. Ravens that consume 1 or more poisoned eggs die. Local raven populations can be reduced through intensive application of CPTH egg baits, but the effect may be temporary because ravens quickly re-occupy vacant habitat following the cessation of the egg bait treatment (Coates and Delehanty 2007).

The CPTH-treated bait also would be lethal to birds other than ravens that consume the poisoned egg baits (Coates and Delehanty 2010). One technique to minimize risk of secondary mortality is to place egg baits where they will be discovered by aerially foraging ravens but be less conspicuous to birds foraging on the ground (e.g., by placing CPTH egg baits on fence posts). The effectiveness of this approach has not been reported in the scientific literature.

Also absent from the literature are cases of mortality due to secondary consumption of CPTH as might happen when a predatory bird catches and consumes a raven that recently ingested CPTH. Concentrations of CPTH in tissues of experimentally poisoned boat-tailed grackles (*Quiscalus major*) were sufficiently low in CTPH to assign a "negligible risk" to any bird and mammal scavengers of carcasses (Johnston et al. 1999). Anecdotally, death of great-horned owls (*Bubo virginianus)* preying on roosting ravens previously exposed to CPTH has been observed on rare occasions. Unfortunately, at this time the literature does not provide guidance on whether the absence of reported secondary effects is a result of sub-lethal dosing, a result of the infrequency of such events, or a result of the difficulty of making sufficient observations in the field.

Shooting ravens to provide meaningful population control through some form of public hunting has not been addressed quantitatively scientifically, but indirect lines of evidence suggest it is not feasible. Scientifically, the lethality of using firearms is obvious, and firearms are regularly employed to kill birds for scientific investigation and for recreational hunting. At this time, raven hunting in the United States is prohibited by international agreement. Importantly, the geographic breadth of raven distribution, the remote habitat ravens often occupy, the speed at which ravens recognize and avoid threats, the lack of cultural tradition for hunting ravens, and the undesirability of hunting activities in close proximity to human infrastructure combine to make public hunting an unlikely solution for broad-scale raven control (Hewitt and Messmer 1997). Agricultural pistachio (*Pistacia vera*) growers in California, USA reported that employing roving shooters to move among orchards to be of "little value" in suppressing avian crop predators because birds, including ravens, quickly learned to avoid shooters, then resume foraging upon departure of shooters (Crabb et al. 1986).

## Ethical considerations

Ethical considerations surrounding raven control, especially lethal control, are complex. Substantial philosophical literature exists regarding the degree to which humans have a right to exploit or sacrifice animals and the degree to which animals themselves have autonomous rights (Regan 1983, Messmer et al. 1999, Stucki 2020). These fundamental issues also surface in public discussions of raven control.

However, a narrower and essentially utilitarian assessment takes place in wildlife management and especially in research settings where detailed control actions are proposed and vetted. In these settings, actions that cause stress, pain, or death to animals are judged relative to prevailing public standards for the humane use of animals (Committee for the Update of the Guide for the Care and Use of Laboratory Animals 2010). Proposed actions must comply with public standards but are weighed for their utility by Institutional Animal Care and Use Committees (IACUCs) rather than against fundamental philosophical questions regarding animal rights.

The legal basis for ethical oversight of animals in research is complex and byzantine, but 2 principle federal actions regulating animal use are especially relevant to research on raven control. The U.S. Animal Welfare Act of 1966 (AWA; Public Law 89-544, 7 U.S.C. § 2131 et seq.) protects all warm-blooded animals used in research except rats (*Rattus* spp.), mice (*Mus* spp.), and birds bred for research. The U.S. Department of Agriculture implements the AWA and requires research institutions to establish IACUCs. These committees not only oversee compliance with federal policies, but also are charged with compliance to prevailing veterinary, scientific society, and public standards. Importantly, IACUC membership must include an attending veterinarian, an active scientist, a non-scientist, and a member of the public who represents community interests in proper care and use of animals (Committee for the Update of the Guide for the Care and Use of Laboratory Animals 2010). Secondly, U.S. Public Health Service (PHS) policy protects all vertebrate animals, including fish, reptiles, rats, mice, and birds used in research funded by the PHS, though it is common for American universities to expect all research within their institution to comply with PHS regulations. Such compliance generally is accomplished by having an IACUC in good standing (Public Health Service 2015).

It is at the level of IACUCs that research utility and ethics are weighed. Fundamental evaluations regularly made by these committees unavoidably include some subjective judgments and utilitarian perspectives as individual members weigh research benefits, scientific and community standards, and veterinary understanding. Committees weigh the perceived benefit to humans versus perceived suffering by animals. Actions that harm animals can be approved when the benefits of the proposed actions outweigh the suffering experienced by the animals that are subject to the actions. In this process, an aspect of evaluating the magnitude of suffering depends on the perceived capacity of subject animals to suffer. This approach is reflected by the careful consideration of use of vertebrate animals with known cognitive function in research versus the absence of such regulation for most invertebrate animals (Committee for the Update of the Guide for the Care and Use of Laboratory Animals 2010).

A common perception is that animals that are less evolutionarily derived generally have less intricately developed central nervous systems and thus lower cognitive function and lower capacity to suffer than animals that are evolutionarily highly derived (Sherwin 2001, Linzey 2013). For example, sponges as members of phylum Porifera, basal within kingdom Animalia, lack a central nervous system and are regarded as less capable of suffering than birds, members of phylum Chordata and in possession of a sophisticated central nervous system including pallial layers in the forebrain that support higher cognitive function. In this formulation, utility derived from actions harming birds would need to be greater than similar actions harming sponges because bird suffering would be greater than sponge suffering. Applying this reasoning to ravens, lethal CPTH control of ravens generally would require very high utility for humans because raven control involves large numbers of sentient birds experiencing a slow death through progressive organ failure.

Whether or not such a high standard is met can be an important source of disagreement among stakeholders when considering raven control measures. Evaluating the merits of raven control action also invokes an overt or implied rank of the forms of utility that might accrue to humans from the control action. For example, perceived utility may follow a linear rank hierarchy such as: Human well-being > Human livelihood > Human cultural practice > Ecosystem health. Understandably, humans find great utility in human health and also place high value on human economic well-being and human culture. However, raven control does not provide these kinds of utility to humans. The basis for raven control action typically is ecosystem health and, especially, the protection of rare or endangered species that are subject to raven depredation.

## Conservation biology considerations

There is an additional difficult ethical judgment that must be made when considering lethal control of ravens for conservation purposes, one that may not have received adequate consideration to date. Expanding human enterprise in the American West simultaneously is subsidizing ravens while suppressing populations of other species, such as the western snowy plover (Charadrius nivosus nivosus) and greater sage-grouse. This puts the public and management agencies in the difficult position of weighing the implications of not intervening to save threatened native species in order to avoid the ethical implications of lethal intervention to suppress a different native species (Hewitt and Messmer 1997). Ultimately, raven control may be viewed as necessary when it serves to protect highly valued threatened or endangered species (Boarman 1992) such as the desert tortoise (*Gopherus agassizii*; Boarman 2003) or the western snowy plover (Burrell and Colwell 2012) but may be unacceptable for general population suppression.

Within conservation biology, higher value often (Selge et al. 2011), though not always (Messmer et al. 1999), is placed on the conservation and protection of native species over non-native species. This is understandable considering that a fundamental goal of conservation biology is to protect not just biodiversity but also intact ecosystems. Although protecting native species yields higher utility than protecting non-native species from a conservation biology perspective, it leads to inconsistent application of ethical standards from an animal-suffering perspective as applied to lethal control of birds.

For example, European starlings (*Sturnus vulgaris*) were introduced into the United States in 1890–1891, rapidly becoming an invasive, non-native pest species (Cabe 2020). Starlings do not receive federal legal protection in the United States and, as agricultural pests, regularly are subject to lethal control through CPTH and other eradication programs. Simultaneously, in Britain, where they are native, starlings are red-listed as a bird of "high conservation concern" following decades of population decline (Eaton et al. 2015) and are protected. Native birds in the United States that become agricultural pests, such as the yellow-headed blackbird (*Xanthocephalus xanthocephalus*), retain federal protection by default, and control actions are subject to federal permitting. This intrinsic valuation of native status also is embedded in international agreements such as the *Convention with Great Britain [on behalf of Canada] for the Protection of Migratory Birds* and the *Convention for the Protection of Migratory Birds and Game Mammals* (Rozan 2014) and applies to ravens when developing management policies.

The concept of "conservation-reliant species" is well established in conservation biology (Scott et al. 2005, 2010). These are species that require permanent human conservation intervention for their continued existence in the wild. Conservation actions often include lethal predator control. Hawaiian waterbirds offer a good example of lethal control to protect conservation-reliant species. The eggs and young of 5 endangered Hawaiian waterbirds are depredated by house cats (*Felis catus*), Norway rats (*Rattus norvegicus*), mongooses (*Herpestes javanicus*), dogs (*Canis familiaris*), wild pigs (*Sus scrofa*), barn owls (*Tyto alba*), cattle egrets (*Bubulcus ibis*), predatory fish, and bullfrogs (*Lithobates catesbeianus*), and these predators regularly are subject to a range of control actions including lethal control (Underwood et al. 2013). In the Hawaiian example, all predators are non-native. Nevertheless, it may be that endangered species or critical subpopulations in the American West increasingly are conservation-reliant, with the threat emanating from a burgeoning native predator. The Hawaiian waterbirds example suggests that there may be circumstances in the American West where lethal control of ravens will be judged to be acceptable to protect small populations of animals.

### Economic considerations

Raven control through using toxicants is expensive in terms of human capital for ongoing assessment and monitoring. Furthermore, the results of control actions within an otherwise large and robust raven population may only achieve local and temporary suppression (Coates and Delehanty 2007). These aspects may make lethal raven control economically unfeasible at statewide or region-wide scales, especially across long time periods. However, the need for immediate local population suppression for conservation reasons such as protecting a remnant population of sage-grouse is often used to justify lethal control under federal permits (Peebles and Spencer 2020).

## Conclusions

From a conservation biology perspective, common ravens in the American West present a conundrum for wildlife managers and a true challenge in managing human–wildlife conflict. Ravens are exploiting human enterprise to such an extent that they are threatening naïve native species of great conservation concern. But simply labeling ravens as a "pest" is to ignore the attributes generally admired by humans, such as ability to learn and solve problems, use of language, and behavioral adaptability. Raven control using toxicants stretches ethical boundaries, is expensive, is temporary, and is not practical across large spatial scales. Shooting of ravens by the public or by management personnel is not realistic range-wide, especially near human infrastructure, and likely would face rapidly diminishing returns as ravens learned and adjusted their behavioral responses. Thus, range-wide suppression to numbers found 50 years ago probably is economically too expensive and too divisive.

That is not to say there is no hope of conserving western biodiversity in the presence of abundant ravens. A range of potential options exists. Though not the direct topic of this paper, habitat restoration could substantially mitigate threats currently confronting vulnerable species. Perhaps sufficient population increases of currently vulnerable species would adequately alleviate the need for raven control in some situations. Similarly, management actions that alleviate threats to vulnerable species other than the threats posed by ravens could reduce the urgency for raven suppression. Where ravens and vulnerable species necessarily interact, non-lethal suppression of raven population size is a sensible first course of action except in those cases where ravens imminently threaten population extirpation. Taking steps to reduce raven subsidies through roadkill and livestock carcass removal and disposal as well as landfill management, for example, deserve greater attention.

One new approach to suppressing local raven populations is receiving important scientific investigation at this time, namely oiling eggs within raven nests (Brussee and Coates 2018, Shields et al. 2019). Egg-oiling suppresses reproduction by causing egg failure, a technique that generally is ethically acceptable to the public and one that has been used successfully to suppress other bird populations (e.g., Johnson et al. 2001, Engeman et al. 2012, Fernandez-Duque et al. 2019).

Despite advances towards nonlethal suppression, lethal control may be judged to be appropriate when small populations of sensitive prey species are in urgent need of relief from raven depredation (Messmer et al. 1999). An extremely useful contribution would be studies measuring raven predation rate in relation to prey population change, especially where direct causality could be established. Such linkages would open the way for detailed models of the relationship between raven densities and the reproductive success of critical prey species and perhaps simultaneously provide empirical numeric and temporal estimates of the effects of lethal raven removal.

For example, knowing the relationship between raven density and raven depredation rate, raven monitoring might indicate that raven densities have reached a critical threshold such that a sensitive population likely will experience reproductive failure. Such a scenario would provide an empirical basis for managers to evaluate the need for temporary lethal suppression of ravens, even as nonlethal measures for long-term reduction in raven density are being implemented. These scenarios call for detailed understanding of raven population dynamics and the relationship between raven presence and the conservation of biodiversity. The papers of this special topic issue are a strong and important first step toward that goal.

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*Associate Editor: Terry A. Messmer*

**David J. Delehanty** is a professor of biology at Idaho State University, where he has completed 21 years of teaching, research, and service. He studies the breeding biology and conservation of North American birds. He teaches ornithology, animal behavior, mammalogy, and conservation biology to graduate and undergraduate students, and together they have produced numerous scientific papers, book chapters, dissertations, and theses on the breeding behavior, reproductive biology, and restoration of birds of the American West. He received his Ph.D. degree in ecology, evolution, and conservation biology from the University of Nevada, Reno, following an M.S. degree in North Dakota and a B.S. degree in his home state of Minnesota.