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Opinion

Thinking like a raven: restoring integrity, stability, and beauty to western ecosystems

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Abstract: Common ravens (*Corvus corax;* ravens) are generalist predators that pose a threat to several rare wildlife species in the western United States. Recent increases in raven populations, which are fueled by increased human subsidies—notably food, water, and nest sites—are concerning to those seeking to conserve rare species. Due to the challenges and inefficiencies of reducing or eliminating subsidies, managers increasingly rely on lethal removal of ravens. Over 125,000 ravens were killed by the U.S. Government from 1996 to 2019, and annual removals have increased 4-fold from the 1990s to mid-2010s. We contend that lethal removal of ravens, while capable of improving the reproduction of rare species, is at best a short-term and ethically untenable solution to a problem that will continue to grow until subsidies are meaningfully reduced or made inaccessible to ravens. In part because of ravens' abilities to track natural and anthropogenic resources across unfamiliar and expansive areas, the removal of subsidies can lead to sustained shifts in raven abundance, which can have long-lasting benefits for sensitive species. In the Greater Yellowstone Ecosystem, USA, for example, we documented extensive use of human subsidies during fall/winter, daily 1-way commutes regularly in excess of 50 km by territorial birds to such subsidies, and dispersals of >700 km by nonbreeders that exploited food and roost subsidies. We call for managers to embrace new approaches to subsidy reduction including: increased involvement of conservation social scientists; increased enforcement of local, state, and federal laws; and increased deployment of a diversity of new technologies to haze and aversively condition ravens. Tackling the hard job of reducing subsidies over the expansive area exploited by ravens is right because it will increase the integrity, stability, and beauty of western ecosystems.

Key words: anthropogenic subsidy, common raven, conservation social science, *Corvus corax*, endangered species act, lethal control, predation

That the number of common ravens (*Corvus corax*; ravens) in North America is increasing in response to human modification of the land—notably through increases in food, water, roost site, and nest site resources—has been quantitatively known for over a quarter of a century (Houston 1977, Boarman 1993, Marzluff et al. 1994; Figure 1). During this same period, other less adaptable species have decreased in response to human domination of Earth (Jetz et al. 2014, Pimm et al. 2014, Rosenberg et al. 2019). Because the diet of generalist predators, such as ravens, includes the eggs, nestlings, and juveniles of rare species that are in decline (e.g., desert tortoise, *Gopherus agassizii* [Kristan and Boarman 2003], greater sage-grouse, *Centrocercus urophasianus* [Coates and Delehanty 2010]; snowy plover, *Charadrius nivosus* [Hardy and Colwell 2012; Figure 2], Steller's eider, *Polysticta stelleri* [U.S. Fish and Wildlife Service (USFWS) 2003]), conservationists have attempted to understand the degree to which ravens limit rare

Figure 1. Examples of human subsidies exploited by common ravens (*Corvus corax*). (A) Begging from tourist at gathering point in a recreation site; (B) scavenging from rural waste transfer site; (C) fishing grease out of a municipal water treatment facility (*photos courtesy of J. Marzluff*).

species and to reduce any such limitation.

There is evidence that raven predation reduces breeding success of rare species, especially where human activity degrades the rare species' nesting habitat and disturbs nesting behavior, both of which increase conspicuousness of prey to sharp-eyed ravens (Boarman and Berry 1995, Colwell et al. 2005, Coates and Delehanty 2010). This finding is unsurprising. Across a wide variety of bird species, nest failure from predation befalls a third to a half of nests (Lack 1954, Nice 1957, Ricklefs 1969, Martin 1995).

It is less certain and more difficult to conclusively prove that ravens limit the growth of rare species populations (Côté and Sutherland 1997, Dinsmore et al. 2014). This difficulty arises in part because of the compensatory effects of other predators (Dion et al. 1999, Mezquida et al. 2006, Madden et al. 2015), the unreliable association of raven and related corvid numbers with predation rate (Gooch et al. 1991, Luginbuhl et al. 2001), and the confounding effects of abiotic factors on prey populations (Conover and Roberts 2017). In addition, populations of long-lived vertebrates are often most sensitive to changes in breeder lifespan rather than changes in annual reproductive output (Sæther et al. 2005). For these reasons and more, Madden et al. (2015) concluded that the vast majority (81%) of the 42 studies they reviewed did not demonstrate a negative effect of corvids on productivity or abundance of prey and that while effects on productivity were 5 times greater than effects on abundance, in most

Figure 2. The western snowy plover (*Charadrius nivosus nivosus*; plover) is a rare species threatened in part by predation on its eggs and nestlings by common ravens (*Corvus corax*). This plover was photographed in 2019 at Centerville Beach, Humboldt County, California, USA (*photo courtesy of N. Sojka*).

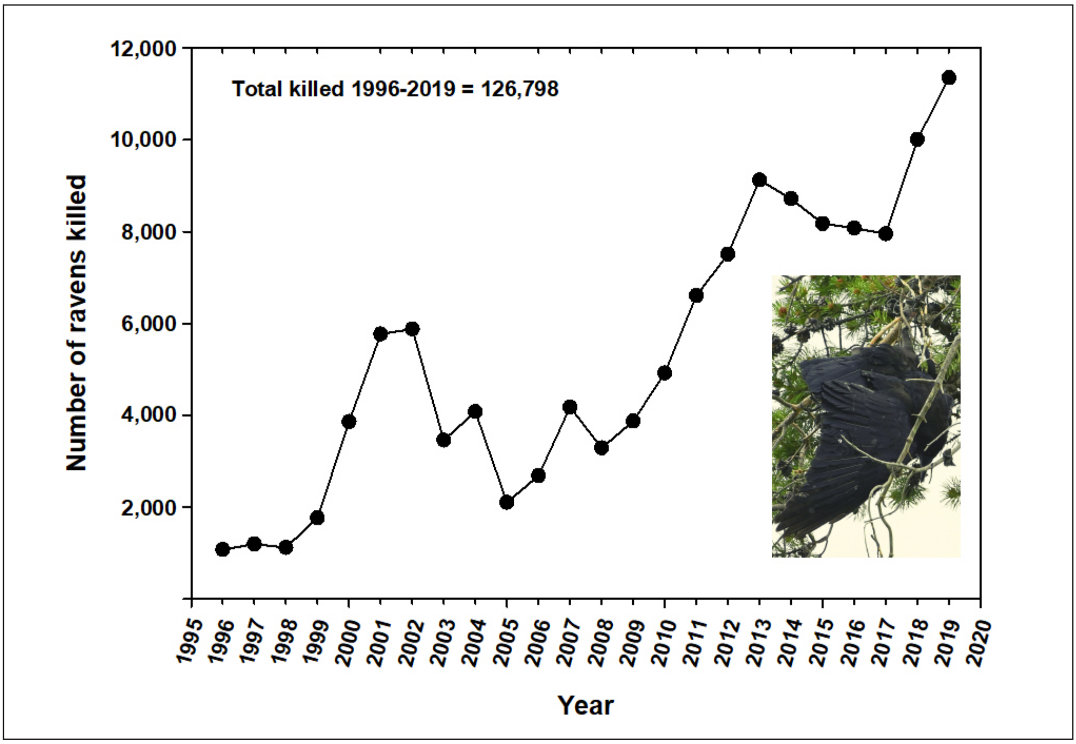

Figure 3. Annual numbers of common ravens (*Corvus corax*) estimated killed by the U.S. Department of Agriculture (USDA) Wildlife Services in the United States (USDA 2019).

cases bird populations are not limited by corvid predation "and that conservation measures may generally be better targeted at other limiting factors" (Madden et al. 2015, 1).

In the western United States, where raven numbers have increased recently, native breeding habitat for several rare species has declined precipitously, and human activity threatens rare species directly and indirectly, it is possible that raven predation on eggs and young limits rare species. This may be especially true for rarities that breed in open habitats, such as beaches, deserts, and shrublands. In response to such possibility, ravens have been excluded, dispersed, killed, and had their nests destroyed and eggs oiled (Dinsmore et al. 2014, Dinkins et al. 2016, Conover and Roberts 2017, Shields et al. 2019). However, while raven control may be needed in these dire situations, the efficacy of it depends on improvements in prey habitat and reductions in the anthropogenic resources used by ravens. For example, in an experimental assessment of the breeding success of snowy plovers in response to predator removal, nest protection, and habitat improvement over a 20-year period, removal of predators only increased nest success at sites that did not provide nest protection (wire cages that prevented ravens and other avian and mammalian predators from accessing plover nests; Dinsmore et al. 2014). The authors cautioned that the long-term cost of predator removal, which must continue in perpetuity, should be weighed against the cost of habitat restoration, which provides long-term benefits and was associated with increased nesting success. In a similar vein, although raven removals have produced some short-term increases in sage-grouse productivity and populations (Dinkins et al. 2016, Peebles et al. 2017), researchers stressed that managers should focus long-term efforts on maintaining native habitats (e.g., sagebrush [*Artemisia* spp.] cover, forb abundance) and modifying or eliminating anthropogenic features promoting and supporting raven population growth (e.g., stock tanks, power lines; Webb et al. 2004, Boarman et al. 2006, Bui et al. 2010, Taylor et al. 2012, Baltensperger et al. 2013, Lockyer et al. 2013, Dinkins et al. 2016, Foster et al. 2019). It makes sense that efforts to improve habitat for the prey will reduce their risk to ravens and other corvids, which are opportunistic, area-restricted, visual hunters (Marzluff 1988, Marzluff and Balda 1992, Vigallon and Marzluff 2005). Increasing cover and habitat continuity has long been known to reduce corvid predation (Sugden and Beyersbergen 1987, Andren 1992).

The ineffectual nature of raven control is underscored because within the western United States, where the federal government now kills 10,000 ravens per year and has killed >125,000 ravens during the past quarter century (U.S. Department of Agriculture 2019; Figure 3), raven numbers continue to increase and rare species remain at risk of extinction. Killing ravens and other predators without appreciable reduction in the risk of extinction to rare species (i.e., an increase in lambda) is in direct opposition to the tenets of environmental ethics, which affords value to all species and processes in the natural world (Leopold 1949, Rolston 1988). Justifying raven control for the sake of other species is increasingly questionable on ethical grounds as new research reveals the early development of corvids' advanced cognitive abilities (Pika et al. 2020) and sentience (Nieder et al. 2020). Considering the shared neurological circuits that are thought to underly consciousness (Butler and Cotterill 2006), the high-amplitude, slow-wave sleep that aids memory (Rattenborg et al. 2009), and their ability to imagine, causally reason, and adjust action to changing current and future situations (Emery and Clayton 2004, Marzluff and Angell 2012), killing ravens is akin to killing great apes (Emery and Clayton 2004, Marzluff and Angell 2012), and to many it is just as untenable.

Mutualists, people that see wildlife as part of their own social networks and worthy of care and compassion (Manfredo et al. 2020), are especially unlikely to accept lethal management of ravens on behalf of rare species (Clucas 2021). People with mutualist values are increasing throughout the western United States (Manfredo et al. 2020) and comprise a majority of the public in some areas with raven-rare species conflict (Clucas 2021). Indigenous peoples, important stakeholders throughout the western United States, also may espouse mutualist values and emphasize habitat improvements (e.g., fence removal, native plant restoration, and rotational-rest grazing regimes) rather than predator removal for rare species, such as sage-grouse (https://www.sagegrouseinitiative.com/sagebrush-community/the-people/).

Killing, translocation, and occasional hazing of ravens is inefficient when not paired with subsidy reduction because it does not address the underlying causes driving raven populations upward. As Aldo Leopold opined in 1937: "To hold a species down or to build it up requires the same research. Both operations require the same detailed knowledge of life history and relation to environment" (Leopold 1937, 30). In recovering rare species, we seek the detailed knowledge to build up a species while rarely seeking or employing the existing detailed knowledge required to hold its predators down. It is time to move beyond reflexive trigger-itch to kill ravens and instead think like a raven. Powerful flight, rapid associative learning, and spatially explicit memories guide ravens to seasonally reliable foods. Thinking in these terms, one immediately realizes the critical importance of reducing anthropogenic subsidies if the goal is to limit raven abundance. And, we have known this for some time. Boarman (2003) tied increases in waste present at sanitary landfills, surface water, foods in open dumpsters, spilled grain, agricultural activities, pet food, and road-killed animals to raven increases in the Mojave where they prey on desert tortoises. Marzluff and Neatherlin (2006) extended this to the coastal forests of Washington, USA, where a suite of corvids, including ravens, were presumed predators on the eggs and chicks of threatened marbled murrelets (*Brachyramphus marmoratus*). They concluded that food was also a key to raven numbers, survival, and reproductive output. And controlling it would be a challenge, stating "…not only do food sources in areas of management concern need to be controlled, but those at substantial distances from such areas also need to be controlled. Animal-proof garbage cans and camping regulations will not be enough to control predators. Dump closures, restrictions on agricultural activities, and increased control of garbage, animal husbandry practices, and bird feeding around residences will likely be needed" (Marzluff and Neatherlin 2006, 312). Marchand et al. (2018) demonstrated the re-

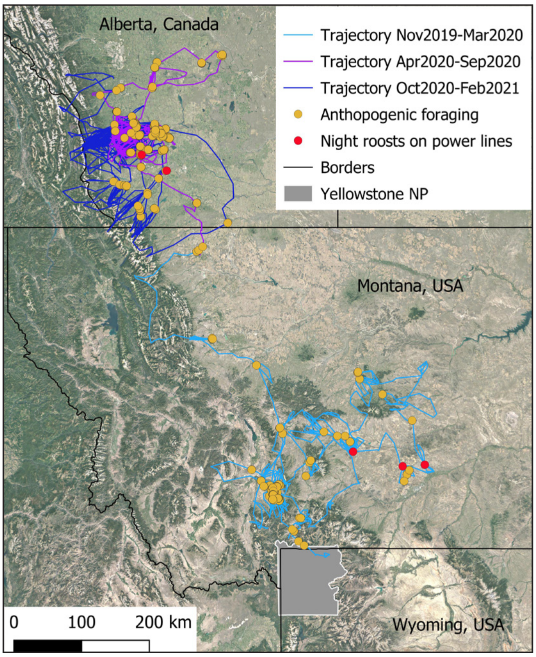

Figure 4. Example movements of a juvenile male common raven (*Corvus corax*) from its trapping site in Yellowstone National Park (NP, grey area), USA, to Alberta, Canada, November 2019 to February 2021. Movement trajectories (lines) are color-coded by season and year (light blue: autumn-winter 2019–2020; purple: spring-summer 2020; dark blue: autumn-winter 2020–2021). Orange points indicate global positioning system locations of the raven that could be related to an anthropogenic food sources; red points indicate its use of power lines as night roost.

siliency of ravens to translocation and hazing when subsidies remained in the landscape. New technologies are sharpening our ability to see the world from a raven's perspective and directly reduce the subsidies that buoy their populations.

In this opinion article, we draw on our ongoing study of raven movements within the Greater Yellowstone Ecosystem, USA, to demonstrate the reliance of ravens on anthropogenic subsidies and the geographic extent over which they move to exploit such subsidies. Our experience emphasizes the need to reduce subsidies that draw ravens to lands inhabited by rare species, and our review of efforts to conserve rare species suggests the need for increased effectiveness in doing so. Therefore, we consider a variety of subsidy-reduction strategies and suggest how they may be used to lessen the effect of ravens on rare species in the western United States.

Clarifying our view of the raven's world

Miniaturization of tracking devices with global positioning system (GPS) locators is revealing the raven's world in fine detail (Harju et al. 2018). This technology had already uncovered surprisingly large home ranges and travel distances of ravens in Central Europe, an area that is greatly modified by humans and provides a high density of subsidies (Loretto et al. 2016, Marchand et al. 2018). Since 2019, we employed such devices on ravens in the Greater Yellowstone Ecosystem. In so doing, we are currently learning the specific resources managers must reduce and the geographic extent over which this must be done to affect local raven numbers. Here we report results from a sample of 61 ravens trapped with a netlauncher (CODA Enterprises, Mesa, Arizona, USA) and equipped with GPS tags (Bird Solar UMTS 25 g, e-obs GmbH, Bavaria, Germany) within or close to Yellowstone National Park between October 22, 2019 and March 14, 2020. These solar-powered GPS tags weigh <3% of the birds' body weight and are attached with a backpack harness. We collected GPS positions of the ravens from approximately sunrise to sunset every 30 minutes or when batteries were low due to unfavorable light conditions every 60 minutes or fewer leading to 387,353 GPS locations as of February 10, 2021. To illustrate the size of the areas ravens potentially roamed, we first calculated the 100% minimum convex polygon of nomadic non-breeders and territorial breeders. Since most GPS locations are clustered in areas close to food sources, we additionally estimated the size of their 95% utilization distributions using dynamic Brownian bridge movement models (dbbmm) to better illustrate the area ravens spent most of their time (Kranstauber et al. 2012). The analysis was done with the statistical software R, version 4.0.3 (R Development Core Team 2020) using the package "adehabitatHR" (Calenge 2006) and for the dbbmm the package "move" (Kranstauber et al. 2020). We created maps in QGIS 3.12.1 (QGIS.org 2020) with a basemap from Google Satellite (Figure 4). We identified anthropogenic and natural resources at locations with extended (>1 hour) use by single ravens or where multiple ravens gathered away from nests and roost sites by visual inspection of GPS points superimposed on

Table 1. Mean, minimum (min), and maximum (max) area (km^2) of 100% minimum convex polygon (MCP) and 95% utilization distribution from a dynamic Brownian bridge movement model (UD dbbmm; Kranstauber et al. 2012) for territorial breeding and nomadic non-breeding common ravens (*Corvus corax*), Greater Yellowstone Ecosystem, USA, October 2019 to February 2021. Calculations employed techniques from Calenge (2006) and Kranstauber et al. (2020).

	Territorial breeders mean (min–max) km^2	Nomadic non-breeders mean (min–max) km^2
100% MCP	3,805.7 (195.4–32,082.5)	27,209.8 (229.1–204,596.0)
95% UD dbbmm	562.1 (35.5–2,256.3)	2,786.68 (67.8–16,564.3)

Table 2. Proportion of global positioning system (GPS) locations of all tagged common ravens (*Corvus corax*) that could be associated with different food sources, Greater Yellowstone Ecosystem, USA, October 2019 to February 2020 (n = 6,769) and April to September 2020 (n = 5,212). Resource types include gutpiles (including carcasses from hunting and livestock), agriculture (food resources associated with crops or livestock), garbage dumps, compost stations, water treatment centers (debris that gathers on the surface of water treatment ponds), roadkills, urban dispersed (food sources that are present in urban environments), recreation site (begging for handouts and scrounging from picnic areas and bird feeders) and natural (food sources that are not provided or generated by humans such as predator killed carcasses, natural deaths, and invertebrates).

Resource type	% of GPS positions at different subsidies, October to March	% of GPS positions at different subsidies, April to September
Gutpile	26.09	6.33
Agriculture	16.77	9.06
Garbage dump	6.87	3.72
Compost	14.51	6.52
Water treatment	7.65	1.01
Roadkill	0.41	0.02
Urban dispersed	11.83	7.46
Recreation site	2.20	6.35
Natural	12.96	59.48

Google Earth satellite images of landcover, to which we added known locations of National Park Service carcass dumps, carnivore kill sites, and other foods observed by field crews.

In the Greater Yellowstone Ecosystem, where ravens are able to access natural and anthropogenic resources, they make extensive use of those provided by humans. Nomadic non-breeders as well as territorial breeders range over larger areas (Table 1) than described in other studies (Loretto et al. 2017, Harju et al. 2018, Marchand et al. 2018), and exploit a large number of anthropogenic food sources that are often widely dispersed. Two non-breeders even moved from Yellowstone National Park to Canada, which resulted in the longest recorded dispersal distances for ravens (757 km and 745 km). Even during such long-range movements, presumably through unknown areas, ravens rely mostly on anthropogenic resources for feeding and powerlines for roosting (Restani and Lueck 2020; Figure 4). Although seasonal variations in food availability (e.g., hunting gut piles, natural food such as insects) lead to variation in the use of anthropogenic food sources, ravens use human subsidies year-round (Table 2). Ravens with territories in central Yellowstone National Park move in winter almost daily to anthropogenic food sources 50–100 km outside the national park (Figure 5). When food at 1 place is removed or consumed, be it a wolf (*Canis lupus*) kill or a garbage source, ravens abandon the site. For example, on March 15, 2021, a solid waste collection site, in operation since the beginning of our study, was closed. In the 6 weeks prior to removal of the garbage

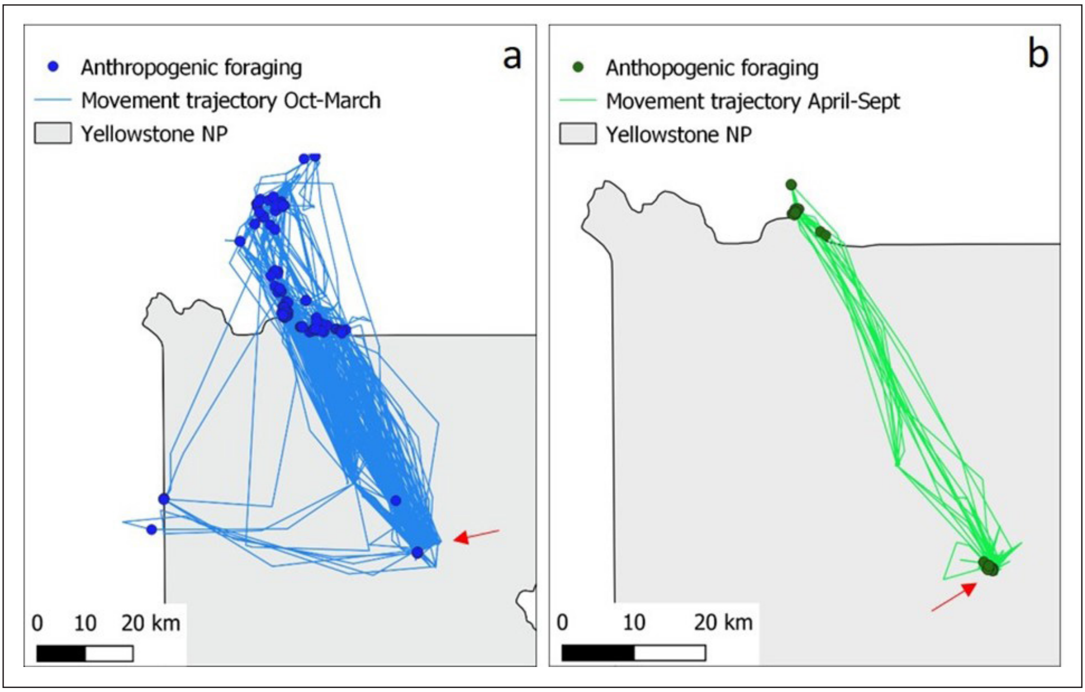

Figure 5. Global positioning system (GPS) trajectories of a male breeding common raven (*Corvus corax*; raven) in Yellowstone National Park (NP), USA, during (A) October 2019 to March 2020 (blue lines) and (B) April to September 2020 (green lines). Dark blue and dark green points represent raven GPS locations that could be related to anthropogenic food sources. The red arrow indicates the location of the raven's territory and nesting site south of Hayden Valley in Yellowstone National Park.

collection bin, 10 of our tagged ravens were regular visitors to the site. Concentrated and reliable use of the subsidized area ended with the removal of the dumpster (Figure 6). In contrast, at the same time during the previous year, use remained steady (Figure 6). Our initial results clearly demonstrate that individual ravens in the Greater Yellowstone Ecosystem use a large number of anthropogenic food sources across hundreds to thousands of km^2 and frequently cover the large distances to these resources within just a day. They are quick to adjust their use of the landscape to changes in the occurrence of food.

The need to revise priorities

Resource managers increasingly recognize the importance of a phased or tiered approach to raven management. The USFWS (2008) plan to limit raven increases in the Mojave to benefit desert tortoises, for example, includes a host of measures: developing educational outreach, denying raven access to human subsidies, removing nests and oiling of eggs, killing offending ravens, and killing ravens at large. Similarly, sage-grouse conservation plans combine habitat enhancements for the species with reductions in human subsidies to ravens, oiling of raven eggs, and lethal control of free-flying ravens (Howe et al. 2020). While these plans are comprehensive and would certainly decrease raven numbers in areas inhabited by sensitive species, efforts to reduce subsidies are challenging, inefficient, and frustrating for managers. The vexing nature of subsidy reduction can lead to prioritization of lethal raven control over redoubled focus on subsidy reduction. For example, from 2013 to 2018, the USFWS spent $2.6 million primarily to reduce anthropogenic food subsidies on behalf of the desert tortoise (K. Holcomb, USFWS, personal communication). However, this was only half of the funding made available for the effort. Over $2 million USD was unspent because many land and business owners as well as city and county agencies were reluctant to cooperate, and area managers concluded that reducing raven access to thousands of dumpsters and road-killed carcasses along miles of roads was impractical and ineffective (K. Holcomb, USF-

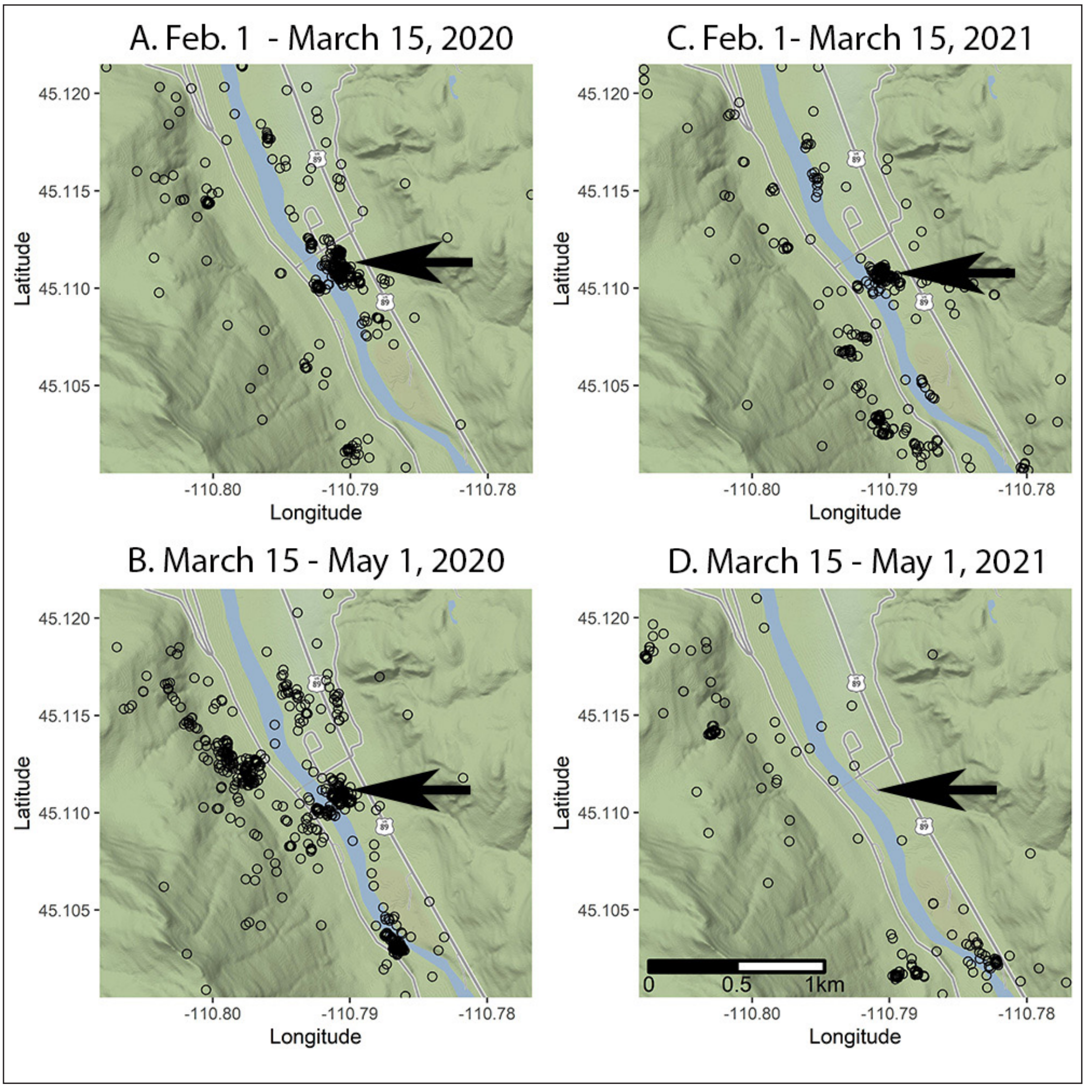

Figure 6. Global positioning system locations of common ravens (*Corvus corax*; ravens) at and around a solid waste collection site (bold black arrow) at Corwin Springs, Montana, USA. Raven locations (open black circles) were frequent and concentrated at the site before (A) and after (B) March 15, 2020, when a large dumpster was present for trash collection. Raven use remained frequent and concentrated until March 15, 2021 (C), when, according to W. Newhouse, Park County solid waste foreman, the dumpster was removed. After removal of the dumpster, which provided a food subsidy, ravens abandoned the site (D).

WS, personal communication). As a result of an inability to sufficiently reduce subsidies (only ~45% of landfills employed raven deterring soil caps; K. Holcomb, USFWS, personal communication), spending in 2019 increasingly focused on raven reductions, first by targeting raven productivity and food requirements through oiling of nesting pairs' eggs and then by widespread killing of breeding and nonbreeding ravens (e.g., in 2020, $600,000 USD was spent on raven removal, $100,000 USD on raven monitoring, and $0 USD on subsidy reduction; K. Holcomb, USFWS, personal communication).

Removing ravens before the resources subsidizing their populations are reduced or eliminated is biologically unsound. Raven populations include substantial numbers of non-breeders (Ratcliffe 1997, Loretto et al. 2016), who quickly fill territories vacated by natural events or lethal control efforts (Webb et al. 2012). The homing and ranging behavior of non-breeders enables them to quickly return to subsidies even after translocation and disturbance (Marchand et al. 2018). Abundant resources attract ravens from an immense area (Restani et al. 2001, Wright et al. 2003, Preston 2005, Baltensperger et al. 2013, Loretto et al. 2017; Figures 4 and 5), sustaining numerical responses to rich and predictable foods. Projections of local raven population dynamics used to estimate the scale of lethal control do not sufficiently account for the productivity of distant raven populations or the size and mobility of non-breeder populations (Kristan et al. 2005, Fleischer et al. 2007) and therefore likely underestimate the amount of raven removal that will be needed to alleviate local predation. As a result, raven control will remain an annual effort (USFWS 2008) that fails to address the root cause of the problem rather like placing one's finger in a dike to stop a flood.

Strategies to reduce subsidies

Reducing subsidies addresses the root cause of raven population increases and therefore can have immediate and lasting effects. Ravens quickly leave rich food sources when the attractive resources are removed. This is an integral part of their natural history evidenced by seasonal shifts away from hunting grounds in spring/summer (Restani et al. 2001, Wright et al. 2003, Preston 2005, Baltensperger et al. 2013, Loretto et al. 2016; Table 1), avoidance of dumpsters when they are shut or moved (Ocañas et al. 2020; Figure 6), and abandonment of recently closed recreational areas (Marzluff and Neatherlin 2006). Decreasing subsidies is costly and will eventually be needed throughout the western United States given the extent of human modification of the land (Leu et al. 2008). Private ownership (Berry et al. 2020) and multiple jurisdictions complicate top-down efforts, but these are not insurmountable. Interventions designed to promote behavioral change in trash management, for example, increase voluntary efforts by business owners to limit garbage availability to ravens (Ocañas et al. 2020). Celebrating such efforts with local gatherings, social media campaigns, or recognition signage visible to customers and the general public can build community support for compliance, reward practitioners, and spread the message about what needs to be done (Jones and Niemiec 2020, Niemiec et al. 2021). Enforcing existing ordinances and establishing fines or incentives for the public that limit resource provisions are also possible.

For example, to reduce availability of lead-contaminated hunter offal to California condors (*Gymnogyps californianus*), and incidentally to ravens, the Arizona Game and Fish Department rewarded complying hunters with chances to win unique hunts, experiences, and other prizes. This program achieved nearly 90% participation (Parker Pioneer 2018). In Montana, USA, free and easily downloaded vehicle-killed wildlife salvage permits encourage motorists to remove road-killed ungulates that otherwise would be available to ravens. From 2013 to 2019, nearly 7,000 carcasses have been voluntarily removed under this program (C. Fetherston, Montana Fish, Wildlife and Parks, personal communication).

The inability to effectively and efficiently limit subsidies that influence native species is a socioecological problem. It is a classic form of human–wildlife conflict characterized by tension between subsidy producers and resource managers (Dickman 2010). The resolution of such conflict requires the knowledge of ecologists and applied social scientists and their respectful engagement with stakeholders, policymakers, and practitioners (Bennett et al. 2017*a*, Clucas 2021). To date, the methods of social conservation science (Bennett et al. 2017*b*) have rarely been tapped to understand the values, motivations, concerns, beliefs, attitudes, and perceptions of the people and agencies managing subsidies. Yet, such understanding is fundamental to limiting subsidies favorable to raven populations. Conservation psychologists, for example, could devise productive interactions between agency representatives that manage solid waste or water treatment facilities and federal or state land managers seeking to reduce raven access to these subsidies to forge effective cooperative agreements (Sorice and Donlan 2015). Applied geographers could query agriculturalists and decision makers within transportation departments to define areas of "anthropogenic resistance" to conservation measures (Manfredo et al. 2020), which would identify where stakeholder workshops may be needed to build trust between wildlife managers and those owning or managing private and non-federal lands (McInturff et al. 2020).

Conservation sociologists and marketing

specialists could help develop effective tools, including rewards and social incentives, for adjusting norms and behaviors of business owners, hunters, farmers, ranchers, refuse managers, outdoor recreationists, and road crews that reduce anthropogenic foods (Ocañas et al. 2020). Full engagement of the conservation social sciences could help reduce subsidies by revealing the diversity of thought on the problem, highlighting imaginative and innovative solutions, improving governance processes, devising socially acceptable initiatives, normalizing conservation actions, increasing acceptance of management actions, and facilitating more socially equitable and just conservation processes (Bennett et al. 2017*b*).

When stakeholders, scientists, and practitioners are unable to resolve the subsidy problem, the policymakers responsible for protecting rare species must have the political will to enforce state and federal law. While the U.S. Supreme Court's interpretation of the Eleventh Amendment as a means to limit federalism may dissuade federal agencies from enforcing laws such as the Endangered Species Act (ESA) on states, this reaction is unjustified. For example, permitting open landfills, water treatment facilities, recreational areas, businesses, and agricultural operations to subsidize predators of an endangered species can be viewed as "take" under Section 9 of the ESA because these actions reduce the suitability of the habitat to support a listed species. A recent review of case law on this topic concluded that "state programs as well as state licensing programs that specifically allow activities that 'take' species, could lead to liability under Section 9" (Melious 2001, 620). Enforcement of federal law against cities, counties, and individuals is not viewed as an infringement on state's rights (Melious 2001). In fact, "the spectre of enforcement against local agencies may encourage states to act as brokers between the federal government and local governments, establishing innovative programs and approaches to help local governments comply with the ESA under the regulatory control and supervision of the federal agencies" (Melious 2001, 673).

The complex job of reducing anthropogenic subsides at a continental scale can be made practical by prioritizing reduction of resources that are available during critical seasons near or within the habitat of rare species of concern. Managers reducing raven use of sage-grouse nesting habitats might prioritize subsidies for reduction by developing spatially explicit overlays that indicate where humans are likely to provide supplemental foods and nesting sites to ravens during the lekking and nesting season (O'Neil et al. 2018). Our research in Yellowstone suggests that such considerations should involve a variety of subsidies and account for seasonal variability in occurrence of ravens and rare species. For example, managers wanting to reduce spring/summer vulnerability to raven predation—as experienced by desert tortoises, sage-grouse, plovers, and terns—should reduce raven access to water treatment facilities, solid waste collection sites (e.g., transfer stations, dumps, and compost facilities), carcasses, and other concentrated food sources associated with agriculture (Table 2).

Moreover, raven nesting sites on anthropogenic structures near sensitive species nesting grounds would need to be managed. However, while such actions may reduce annual predation by reducing the concentration of ravens in sensitive areas, they are not expected to lower raven populations at larger geographic extents. The willingness of ravens to exploit distant (up to 70 km in the Greater Yellowstone Ecosystem; Figure 5), rich subsides on a daily basis suggests that widespread subsidy reduction will be needed to lower regional raven carrying capacity, which limits raven population size (Ratcliffe 1997). However, the minimal spatial extent over which subsidies must be reduced to sufficiently lower threats to rare species and reduce raven populations is not currently known and could best be understood by monitoring prey and adaptively managing subsidies.

Subsidy management may be made more affordable by embracing emerging technologies and encouraging those who work with subsidies to reduce their use by ravens. Emerging laser technology shows promise. Shooting high-power laser dazzlers (e.g., TALI TR3 2.5-Watt green laser, Xtreme Alternative Defense Systems, Anderson, Indiana) near roosting and feeding ravens is effective at dispersing birds from industrial scale composting facilities, agricultural settings, and a variety of human infrastructure used by ravens (T. Shields and A. de Martini, Hardshell Labs, unpublished report; T. Shields, Hardshell Labs, and W. Boarman, Conservation Science Research & Consulting, unpublished report). In their current configuration, lasers require manual operation, but ongoing development of precise, automated target-recognition controllers will allow these devices to operate remotely and continuously (T. Shields, Hardshell Labs, personal communication). Devices could be developed to effectively and safely harass ravens at stationary food subsidies such as those associated with water treatment, solid waste processing, and agricultural areas for as little as $20,000 USD per site (T. Shields, Hardshell Labs, personal communication).

Lasers might also be used to deter nesting on difficult to retrofit anthropogenic structures such as utility towers. Continuous harassment would reduce the chances of ravens sneaking subsidies when they are left unguarded; however, if subsidies are not entirely removed from a raven's sight, then it will be important to employ a diversity of hazing techniques in unpredictable sequences at critical times of the year (e.g., lasers, aerial and terrestrial drones, concussive cannons, sonic nets (Mahjoub et al. 2015), pyrotechnics, effigies, chasing by attendant workers or dogs [*C. l. familiaris*]) to reduce habituation. Ravens so far do not seem to habituate to lasers of adequate power (W. Boarman, Conservation Science Research & Consulting, personal communication).

As ravens decrease their use of human subsidies, they could also be educated to directly avoid rare species, yet this possibility is rarely embraced. Some managers striving to increase desert tortoise populations, for example, have off-handedly rejected calls (USFWS 2008) to employ conditioned taste aversion (e.g., Nicolaus et al. 1983 as demonstrated on *Corvus brachyrhynchos*) as a means to teach ravens not to prey on rare species. Emerging technologies such as 3D-printed juvenile tortoises are now readily available and their use as aversive training tools is under development (T. Shields, Hardshell Labs, and W. Boarman, Conservation Science Research & Consulting, personal communications). These could serve as powerful teaching devices by weaponizing them with bird-specific irritants, such as methyl anthranilate. The use of unmanned rovers and aquatic surface vehicles to haze ravens at concentrated subsidy sites such as landfills and sewage ponds is also under development (T. Shields, Hardshell Labs, and W. Boarman, Conservation Science Research & Consulting, personal communications). Combining hazing at food subsidies with aversive training of ravens actively pursuing rare prey could be an effective, socially acceptable, nonlethal safeguard for rare species.

Reallocating most management resources away from monitoring and lethal control of ravens into efforts to reduce subsidies and employ nonlethal hazing could be cost effective. Continued research beyond the response of ravens to subsidy reduction and hazing is unlikely to advance knowledge relevant to managers, and therefore funding would be better used to actively reduce what we already know are critical subsidies and determine how these reductions affect the productivity of rare species (McGowan et al. 2017). As an example, consider the $700,000 USD per year the USFWS spends on lethal removal of ravens on behalf of desert tortoises (USFWS 2008; K. Holcomb, USFWS, personal communication). Over the coming decade, this ~$7,000,000 USD could fund social scientists to engage, understand, and build trust among stakeholders and managers ($200,000 USD per year) and implementation teams ($200,000 USD per year) that monitor effectiveness and aversively condition the most offensive territorial ravens while installing automated laser deterrence systems at concentrated subsidies.

Laser systems, which are expected to cost <$20,000 USD and eventually $5,000–10,000 USD (T. Shields, Hardshell Labs, personal communication), could be installed at >100 sites (15 per year at $20,000 USD per site). In the first year of such a project, the teams could build cooperation among landowners and waste managers, while also installing systems that haze ravens away from the most sensitive locations. These immediate reductions in raven presence would benefit tortoises, and these effects would persist because the habitat suitability to ravens is reduced. During their on-the-ground work, these teams might incidentally identify previously unknown raven concentration sites and would be in a perfect position to reach out to land owners and municipalities to coproduce educational materials and jointly develop additional subsidy reduction programs.

Doing what is right

Wildlife scientists and managers seek to do the right thing for the ecosystems we enjoy and depend upon. Controlling predators and creating edge habitats favored by game species were once considered "right." Today, few professionals would question the importance of conserving all native biodiversity including predators and the habitats needed to sustain them. Most of us would agree with Leopold (1949), who noted that "a thing is right when it tends to preserve the integrity, stability, and beauty of the biotic community. It is wrong when it tends otherwise" (224–225). Leopold's (1949) dictum calls into question our rush to lethally control ravens rather than subsidies and blame the bird for the demise of tortoises, plovers, grouse, and other species.

Placing blame on the raven, rather than on the myriad human actions that have fueled its increase is wrong because it unnecessarily stigmatizes a native species that has inspired humanity for millennia. Inappropriate ridicule of native predators by the scientific community colors public perception and may result in bounties, persecution, and hatred that run counter to holistic appreciation and preservation of the biotic community. We see such vilification creeping into the way managers speak about ravens. For example, in response to The Wildlife Society's (TWS; 2016) remarks that "some indigenous species can be perceived as invasive when population increase or range expansion beyond historical levels disrupt ecosystem processes, resulting in economic or environmental harm" (Final Position Statement, Invasive and Feral Species [TWS 2016, 1]), ravens have been labeled as "invasive species" (e.g., Coates et al. 2020; see also Fleischer et al. 2008). Such disparagement is inappropriate for 2 reasons. First, the traditional and widely accepted definition of invasive species in the ecological and conservation literature applies only to non-native species whose introduction is or is likely to cause economic, environmental, or human health harm (National Invasive Species Council). The USFWS (2012), National Oceanographic and Atmospheric Administration (2020), and U.S. Geological Survey (2021) follow this definition. Modifying language to loosen traditional definitions reduces standardization and clear communication in science. Second, labeling common ravens as invasive lumps the species into groups that receive widespread and negative media attention and coverage (e.g., Burmese python [*Python bivittatus*], Asian carp [*Cyprinus carpio*]). Without a doubt, the public views pythons and carp as deserving of dedicated lethal population control. Should a native species experience similarly? In addition to calling ravens invasive, some literature also refers to their predation on desert tortoises and greater sage-grouse as "hyperpredation" (e.g., Kristan and Boarman 2003, Berry et al. 2020, Coates et al. 2020). Such hyperbole only serves to denigrate the predator in the public's eye. Relating the level of predation to well understood scientific processes such as numerical and functional responses or the formation of a search image would increase accuracy and remove the bias in our communication.

Doing what is right also means we must question our assumptions and shift course when new insights are revealed. Thinking critically about current raven populations may be a case in point. While there is no doubt that common raven abundance has increased significantly in the past 50–70 years (Marzluff et al. 1994, Boarman et al. 2006, Pardieck et al. 2019), there is considerable uncertainty about how today's populations compare with those centuries ago. Because few nesting substrates are available in the arid deserts and shrublands of the western United States, breeding ravens were likely historically rare. However, foraging ravens, both territorial and especially non-territorial birds, may have regularly used areas where breeding was rare if food was abundant. Their exploitation today of ephemeral resources provided by carnivores and humans over wide areas speaks to this regular feature of the species' biology (Figures 4 and 5).

Historical observations during the early to mid-1800s summarized by Houston (1977) indicate that ravens were common throughout the northern Great Plains. Lewis and Clark commented on the high abundance of ravens nesting in the cliffs along the Columbia River (Cutright 1969). Raven numbers declined after widespread persecution of predators through poisoning and the near simultaneous disappearance of bison (*Bison bison*) from overharvest. Their numbers may have also been reduced by widespread use of organochloride pesticides that took a heavy toll on other predatory birds (Wurster 2015). These uncertainties should make us cautious in assuming that ravens are more common and widely distributed today than they were hundreds of years ago before Europeans greatly altered North American ecosystems, suppressing the populations of many native species. Therefore, starting population levels of common ravens documented by the Breeding Bird Survey and Christmas Bird Count should not be assumed to represent baseline levels.

Conclusion

Leopold (1949) urged wildlife managers to consider the long-term and unintended consequences to the ecosystem of predator removal by thinking like a mountain. This represented an about-face of the pioneering scientist's views as reflected in comparison of statements such as "the advisability of controlling vermin is plain common sense, which nobody will seriously question," from Leopold (1919, 6), with "how long shall we apply the name 'conservation' to a system which attempts to replenish game and fish by stripping the landscape of owls, hawks, kingfishers, and herons?" from Leopold (1941, 42).

We suggest a similar change of attitude would help the conservation of rare species currently threatened by raven predation. We do not disagree that some form of predator removal may be needed, but we urge managers to see the raven as a symptom rather than the cause of the real, underlying problem and to act on the cause to effect sustainable change. The raven is a messenger heralding the need to reduce our abuse of the land. As such, it continues its longstanding role in the ecology and aesthetics of western ecosystems and, if we act appropriately, in the evolution of human culture (Marzluff and Angell 2005).

Unfettered growth of raven populations shows us the need to reduce supplemental foods, to limit the provision of new nesting and roosting locations, and to restore cover to prey habitat. Accomplishing this will take the collective and sustained efforts of individuals, corporations, municipalities, and governments. If we do these first, then pulling the trigger on offending ravens, if even necessary, will have lasting effect. If we shoot first and put off repairing the land, then we will fail to fully restore integrity, stability, and beauty to western ecosystems and gain little of lasting value for rare species and human residents of this land.

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John M. Marzluff (shown left) is James W. Ridgeway Professor of Wildlife Science at the University of Washington. His graduate (Northern Arizona University) and initial post-doctoral (University of Vermont) research focused on the social behavior and ecology of jays and ravens. He continues this theme investigating the intriguing behavior of crows, ravens, and jays. His current research focuses on the interactions of ravens and wolves in Yellowstone. He teaches ornithology, governance and conservation of rare species, field research in Yellowstone, and natural and cultural history of Costa Rica. He has written 6 books and edited several others. His Welcome to Subirdia (2014, Yale) discovers that moderately settled lands host a splendid array of biological diversity and suggests ways in which people can steward these riches to benefit birds and themselves. His most recent In Search of Meadowlarks (2020, Yale) connects our agriculture and diets to the conservation of birds and other wildlife. He has mentored >40 graduate students and authored >140 scientific papers on various aspects of bird behavior and wildlife management. He is a member of the U.S. Fish and Wildlife Service's Recovery Team for the critically endangered Mariana Crow, a former member of the Washington Biodiversity Council, a Fellow of the American Ornithologist's Union, and a National Geographic Explorer. Photo with the Royal Ravenmaster, Chris Skaife (*photo by L. Pendergraft*).

Matthias-Claudio Loretto is a research scientist in the group Ecosystem Dynamics and Forest Management in Mountain Landscapes at the Technical University of Munich, Germany. He studies movement ecology and animal behavior with a particular interest in scavenging ecology and inter- and intraspecific interactions. He received his Ph.D. degree at the University of Vienna studying movement ecology of ravens, followed by a postdoc position in the same project. In 2019, he moved for another postdoc position to the Max Planck Institute of Animal Behavior, where he started a project studying whether ravens follow large carnivores like wolves and mountain lions to exploit their kills in Yellowstone National Park during winter. For >10 years, his main study species has been the common raven, but he also worked with other bird species, mammals, and amphibians. In 2020, he founded with 2 colleagues the COVID-19 bio-logging initiative investigating how animals are responding to reduced levels of human activity during the COVID-19 pandemic.

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