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Managing a Subsidized Predator Population: Reducing Common Raven Predation on Desert Tortoises

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ABSTRACT / Human communities often are an inadvertent source of food, water, and other resources to native species of wildlife. Because these resources are more stable and predictable than those in a natural environment, animals that subsist on them are able to increase in numbers and expand their range, much to the detriment of their competitors and species they prey upon. In the Mojave Desert, common ravens (*Corvus corax*) have benefited from human-provided resources to increase in population size precipitously in recent years. This trend has caused concern because ravens prey on juvenile desert tortoises (*Gopherus agassizii*), a federally threatened species. In this paper, I discuss management strategies to reduce raven predation on desert tortoises. The recommendations fall into three categories: (1) managing raven populations by reducing access to anthropogenic resources; (2) removing offending ravens or other birds in specially targeted tortoise management zones; and (3) continuing research on raven ecology, raven behavior, and methods of reducing raven predation on tortoises. I also recommend approaching the problem within an adaptive management framework: management efforts should first be employed as scientific experiments—with replicates and controls—to yield an unbiased assessment of their effectiveness. Furthermore, these strategies should be implemented in concert with actions that reduce other causes of desert tortoise mortality to aid the long-term recovery of their populations. Overall, the approaches outlined in this paper are widely applicable to the management of subsidized predators, particularly where they present a threat to a declining species of prey.

Humans have the unique ability to modify landscapes and alter the distribution of habitats and resources. The effects of landscape changes become more widespread and pronounced as humans increasingly populate natural areas. Such changes often are detrimental to native species, but can be beneficial to generalists that not only make use of disturbed habitats but also may subsist on anthropogenic resources. Such species—termed "abundant vertebrates" by Goodrich and Buskirk (1995)—can create problems for habitat specialists through predation, competition, disease transmission, and hybridization. The effect is not limited to the disturbed areas. "Spillover predation" (Schneider 2001, Kristan and Boarman 2003) occurs when vertebrate predators (i.e., subsidized predators) (Soule 1988), subsisting on human-provided food bonanzas, move into adjacent native habitats and prey on species that may already be rare. Furthermore,"hyperpredation" (Smith and Quin 1996) occurs when predator populations are maintained by some abundant, often introduced, prey, but depredate rare native prey when they come across them in the same habitat. In many cases, active management is necessary to overcome the imbalance that favors subsidized species.

KEY WORDS: Subsidized predators; Vertebrate pests; Endangered species management

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In the Mojave and Colorado deserts of California, USA, common ravens (*Corvus corax*) are a classic subsidized predator. They have a varied diet, including grains and scavenged carcasses, as well as live prey—a versatility that allows them to benefit from garbage at landfills and dumpsters. They are able to travel long distances to take advantage of anthropogenic food and water sources, and they make use of power towers, billboards, and other structures as nest substrate (Boarman 1993a). Their reproductive success and fledging survival are enhanced by proximity to resources (Kristan and Boarman 2001, Webb 2001). As a result, their local populations have increased by more than 1000% during a recent 25-year period (Boarman and Berry 1995). Raven abundance is a concern to resource managers because they are known to prey on juvenile desert tortoises (*Gopherus agassizii*), a federally and state-listed threatened species (Boarman 1993a). In this paper, I detail a comprehensive, long-term program recommended to reduce the effect raven predation has on desert tortoise populations by (1) managing raven

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populations and their habitats, and (2) conducting research to improve our understanding of the ecology and behavior of ravens, especially with regard to their predation on tortoises. In addition, I make a case for using an adaptive management approach in which the effectiveness of management efforts is assessed through experiments that have proper controls and replicates. In other words, I advocate that developing an effective management plan for ravens and tortoises be viewed as a science-based, evolutionary process. The specific recommendations in this paper are applicable to the management of subsidized predators, particularly where they present a threat to a declining species of prey, while the adaptive approach described may be of broader utility in conservation-oriented land management.

Other than ravens, factors contributing to declines in many tortoise populations include disease, habitat loss and fragmentation, and highway mortality. The long-term consequence of the loss of juveniles is lowered recruitment of new individuals into the breeding population, which likely significantly affects the stability and recovery of some tortoise populations (Fish and Wildlife Service 1994). While many other human activities result in adverse impacts on adult components of tortoise populations, efforts to reduce these impacts will be fruitless unless tortoise populations can recruit young (Fish and Wildlife Service 1994, Congdon and others 1993). Conversely, if little or nothing is done to reduce adult mortality, improve reproduction, and reverse the declining health of adult tortoises, raven management will have little impact on long-term tortoise recovery (Frazer 1993, Doak and others 1994).

Background

Predatory Behavior of Ravens on Tortoises

In the Mojave Desert, ravens are known to capture or scavenge many food items including lizards, rodents, invertebrates, grains, seeds, birds, snakes, and tortoises (Camp and others 1993, Sherman 1993, Kristan and others in preparation). Evidence that ravens prey on juvenile desert tortoises (< 100-mm midline carapace length MCL) comes from a handful of direct observations and strong circumstantial evidence (US BLM 1990a, Boarman 1993a, Morafka and others 1997, Boarman and Hamilton in preparation). Circumstantial evidence is mostly in the form of tortoise shells found beneath active raven nests and shells that bear evidence of raven predation found lying on the desert floor often beneath likely perch sites (Campbell 1983, Berry 1985, Rado 1990, US BLM 1990a, Boarman and Hamilton in preparation).

Tortoise shells eaten by ravens usually contain characteristic holes pecked in the carapace or plastron (63%), although many do not (37%), Boarman and Hamilton in preparation). Such remains have been found beneath raven nests throughout the California deserts (Boarman and Hamilton in preparation) and in the Eldorado and Piute Valleys, Nevada (McCullough 1995, personal observation). Exceptionally high concentrations of tortoise shells were found beneath several raven nests in the Mojave Desert. Several collections of 50–250 shells were found at several sites in the 1980s (John Wear cited in Berry 1985, Woodman and Juarez 1988, cited in US BLM 1990a, b, Boarman unpublished data). These numbers are potentially significant given that estimates for tortoise < 140 mm MCL ranged from 2 to 63 per 0.5 km^2 (from tables presented in Berry 1990). Smaller collections of tortoise shells were found in the 1990s (Boarman and Hamilton in preparation), which corresponded to a period when tortoise populations were reportedly showing precipitous declines (Berry 1997).

As ravens are well known scavengers (Boarman and Heinrich 1999), it is likely that some of the shells reported above were scavenged rather than depredated. However, four lines of evidence suggest that predation is the main source of mortality for these shells (Boarman 1993a). First, many of the shells found beneath raven nests and at other locations show evidence of being pried open while the shell was still very soft (Boarman and Hamilton in preparation). The shells of live tortoises younger than approximately 7 years of age are soft, but they harden rapidly after death (Morafka personal communication). If a shell is pecked or pried open after hardening, it would crack, but most shells found are bent, not cracked. Second, during the thousands of person hours spent surveying for tortoises each year since the mid-1970s, observations are rarely made of ill, moribund, or recently dead juveniles (Berry personal communication). Observations of ill, moribund, and recently dead adults are relatively common in some areas. If juvenile tortoises are dying at rates high enough to be found in such large numbers beneath raven nests and perch sites, we would expect to find more ill, moribund, or recently dead ones on tortoise surveys. However, live juvenile tortoises are notoriously difficult to find, but that is largely because of their cryptic behavior (Berry and Turner 1986, Shields 1994). Although harder than adults, they should be easier to find when dead on thorough surveys. Additionally, until 1988, very few sick or disabled tortoises were observed on 16 US BLM study plots in the California deserts (Berry 1997). Over the past 14 years, three diseases appear to be decimating some tortoise populations (Jacobson and others 1991, 1994, Berry 1997, Homer and others 1998). However, large numbers of dead juvenile desert tortoises were found under raven perching and nesting sites in areas where incidence of diseased tortoises had not yet been documented (Berry 1985, Boarman in preparation). Third, there are at least two instances of live, apparently healthy juveniles that were being marked as part of separate studies and then found dead one or two months later and showing typical signs of raven predation (Woodman and Juarez 1988, Boarman unpublished results). Finally, ravens are opportunistic feeders and are unlikely to pass up a relatively defenseless food item when found.

However likely predation on juvenile tortoises is, there is no way of knowing for certain what proportion of tortoise shells found beneath raven nests were actually scavenged versus depredated. When managing a threatened or endangered species, we must rely on the best available data and, when little or no data are available, it may be best to err on the side of the threatened or endangered species rather than risk greater population declines due to inaction. Most management decisions can be reversed or relaxed as new information is obtained, but a slip to extinction or critical endangerment may be irreversible.

Other potential avian predators on juvenile desert tortoises in California include golden eagles (*Aquila chrysaetos*), greater roadrunners (*Geococcyx californianus*), and red-tailed hawks (*Buteo jamaicensis*). However, there is little reason to suspect that other predators are responsible for killing the large number of tortoises found. Berry (1985) reported finding tortoise shells beneath 12 out of 34 golden eagle nests in tortoise habitat, but the shells were all larger (129–263 mm MCL) than those found beneath raven nests. Berry (1985) also reports one freshly killed tortoise (50 mm MCL) found with roadrunner tracks around it. However, roadrunners shake, bash, and then swallow their prey, they do not peck at them (Hughes 1996). Tortoise shells have occasionally been found beneath red-tailed hawk nests (Fusari 1982, Camp personal communication). Contrarily, Boarman and Hamilton (in preparation) found no tortoise shells beneath 54 red-tailed hawk nests. Although hypothetically possible, there is no direct evidence that burrowing owls (*Athene cunicularia*) or loggerhead shrikes (*Lanius ludovicianus*) prey on tortoises. Thus, whereas other avian species may occasionally prey on tortoises, only ravens eat juvenile tortoises (< 100 mm MCL) in any great quantity.

Impacts of Raven Predation on Desert Tortoise Populations

Because raven populations are supported by abundant anthropogenic resources, they are able to decimate tortoise populations without being affected by the loss of tortoises as food, a decoupling of predator from prey population dynamics known as hyperpredation (Smith and Quin 1996). Raven predation may result in reduced numbers of juvenile tortoises in the hatchling to 8-year-old classes, and reduced recruitment of tortoises into the larger and older size-age classes (e.g., tortoises from 9 to 20 years of age) (US BLM 1990a). The best way to determine the effect raven predation has on tortoise populations is to evaluate data from actual tortoise populations. However, these data have limitations because juvenile tortoises are often difficult to detect and are consequently underrepresented in samples. Also important, the method employed for determining tortoise density is imprecise (Corn 1994), yielding very weak estimates of age class structure, so little inference can be made from the data. Nonetheless, they are the only data available to determine long-term trends in tortoise demography.

Data from permanent tortoise study plots provide a glimpse at the levels of raven predation likely occurring on juvenile desert tortoises in the California deserts (Berry 1990, US BLM 1990a) and how those levels affect tortoise populations. They show apparent gaps in representation among juvenile and immature size classes in some populations, particularly in those where predation pressure from ravens is presumably high (e.g., West Mojave). However, the gaps may also be from reduced natality or increased mortality from other causes.

The next best way to evaluate the likely impact ravens have on tortoise populations is through modeling. Three such models have been discussed in the literature. One model uses extensive sensitivity analysis on various life history traits to explore the relative contributions of the different parameters. When juveniles of long-lived animals such as tortoises, with delayed maturation approaching 20 years, experience heavy mortality, the population becomes unstable (Dunham and others 1989, Congdon and others 1993). The problem is greatly exacerbated when mortality among adults is increased, as evidenced in populations of Blanding's turtles (*Emydoidea blandingii*) (Congdon and others 1993) and snapping turtles (*Chelydra serpentina*) (Brooks and others 1991). To remain stable, a desert tortoise population may require juvenile survivorship of approximately 75% per year. However, in populations where adult survival is depressed and the population is declining, juvenile survivorship must be about 95%–97% for the population to recover (from figures in Congdon and others 1993). In populations where raven predation is high, a sufficient number of juvenile tortoises is probably not surviving to reach the larger size and older age categories.

Ray and others (1993) presented a demographic model based on an increasing population ($r = 1.02$) of tortoises at Goffs, California. Their stage-structured, space-structured model predicted that juvenile mortality in excess of 25% per year is required before the modeled population experiences a decline ($r < 1.00$). If the modeled population was stable ($r = 1.00$), juvenile mortality in excess of 15% would cause instability. Ray and others (1993) concluded that ravens are not likely to be a major problem for tortoise populations. Their model as presented has limited applicability because most desert tortoise populations addressed by these recommendations are experiencing overall population declines (Berry 1990, Corn 1994), increased adult mortality from several sources, and juvenile mortality from causes other than just raven predation (Fish and Wildlife Service 1994).

Finally, Doak and others (1994) also modeled desert tortoise populations using a size-structured demographic model and incorporating important variability in demographic parameters and correlations among vital demographic rates. One of their conclusions was that conservation actions should focus on adult females rather than just juvenile tortoises. They questioned the value of raven control, but stated that "programs to reduce raven predation of small tortoises...are unlikely to significantly change current population trends unless combined with other, more effective, measures" (Doak and others 1994 p. 458). Therefore, there is little actual conflict between the models by Congdon and others (1993) and Doak and others (1994).

These three demographic models make somewhat conflicting conclusions regarding the relative importance of reducing juvenile mortality. A critical evaluation of the three competing models using current data is needed. However, it is clear that reduction of raven predation will probably not work if efforts to increase adult survival are not also implemented successfully.

Reducing Raven Predation on Desert Tortoises

The primary purpose of a raven management program is to enhance juvenile tortoise survival, thereby facilitating recruitment of young tortoises into the reproductive population. For the long term, I recommend habitat alterations coupled with research in order to develop management strategies based on a better understanding of the ecology of ravens with regard to raven predation. For the short-term, I recommend limited lethal removal of ravens as a means of lowering the predation pressure of ravens on desert tortoises. This includes removing known offenders, ravens that are almost certainly killing tortoises, as well as reducing the overall raven population in certain areas with the assumption that doing so will reduce the number of birds potentially depredating tortoises. The long-term actions should be implemented at the same time as the short-term ones, but must be continued until tortoise populations recover. In the sections below, these recommendations are discussed in detail, with the hope that this document may guide land managers and researchers in their immediate and long-term efforts to reduce raven predation on desert tortoises.

Actions to Alter Raven Habitat

Reduce raven access to anthropogenic food and water resources. Given the rapid growth in desert raven populations around cities and towns, the immediate concern of land managers should be to reduce raven numbers by limiting access to anthropogenic resources. Of these resources, solid wastes at sanitary landfills should be a primary focus, as they provide an important source of food year round for ravens (Engel and Young 1992, Boarman and others 1995, Kristan and Boarman 2003). This food subsidy is particularly important during times of normally low natural food availability and helps to increase survivorship of ravens resulting in an increased population. Landfills provide food for nestlings and breeding adults in the spring, thereby facilitating greater survival and reproductive success (Kristan and Boarman 2001, Webb 2001). Ravens are known to fly up to 65 km in a day (Engel and Young 1992, Boarman unpublished data) and range over several hundred kilometers throughout the year (Stiehl 1978, Heinrich and others 1994). Hence, any given landfill could influence raven populations over a broad area. Because ravens move about seasonally, and individuals eat a varied diet, birds from landfills may forage in tortoise habitat many kilometers away and may feed on juvenile tortoises. Furthermore, water is a critical resource for ravens in the desert. Any water source close to a landfill will be heavily used by ravens and make that landfill highly attractive to them ravens. (Boarman and others 1995, unpublished data). Because of the heavy use of landfills by ravens, intense efforts must be placed on reducing raven access to organic wastes and standing water at landfills. This can best be accomplished by (1) ensuring effective cover of waste (either ≥15 cm cover or complete cover of garbage with tarps temporarily) multiple times each day, (2) erecting coyote-proof fencing to keep coyotes from exposing garbage for ravens to access, (3) eliminating or raven proofing all sources of standing water at the landfill, and (4) keeping truck cleaning areas and temporary storage facilities clean and free from organic wastes and standing water. A combination of transfer stations, regional landfills, trash compaction, and alternative temporary covers (e.g., canvas tarps) may be an efficient way to manage landfills.

These recommended measures are not entirely foreign to the California deserts. The California Integrated Waste Management Board and county departments of health are more strongly enforcing regulations requiring effective end-of-day coverage at some landfills (personal observation). Some counties (e.g., San Bernardino) and landfill operators (e.g., Edwards Air Force Base, EAFB) are compacting garbage into blocks before depositing in the landfill and using alternative covers (i.e., tarps) to temporarily cover garbage until dirt can be used. This latter practice can significantly increase a landfill's waste capacity. Some landfills appear to be greatly reducing the number of ravens present by employing these methods (personal observation), but no scientific data have been collected except at EAFB (Boarman unpublished data). An additional advance currently being employed in San Bernardino County is to reduce the number of landfills by collecting garbage in well-maintained trash bins at community transfer stations. The garbage is then transported to one of three regional landfills where it is permanently deposited.

In addition to landfills, ravens obtain food from dumpsters, open garbage drums and bags placed at the curb for pickup, grain dropped from trains, and livestock carcasses at dairies (personal observation). Additionally, some ravens subsist on food left out for pets or intentionally left out for ravens (Goodlett personal communication, Webb personal communication). It is not known what proportion of raven forage is received from these sources nor what effect their reduction would have on raven populations; however, reproductive success is higher nearer to residential areas (Kristan and Boarman 2001, Webb 2001, Marzluff and Neatherlin in preparation).

A number of measures can be taken to reduce raven access to such food sources. Businesses and residents should be encouraged or required to use self-closing trash bins at transfer stations and roadside rest stops and behind restaurants, gas stations, and grocery stores; use raven-proof garbage drums at houses and other facilities; and avoid use of plastic bags for curbside pick up in residential areas. In addition, livestock operators should be encouraged to reduce availability of cattle feed, carcasses, afterbirths, and insects at feedlots and dairy farms. Public education can also help to reduce food subsidies, as citizens who purposely feed ravens or who inadvertently do so by leaving pet food out, may not realize the effect of their actions. Lastly, US BLM and county governments should attempt to clean up illegal dumpsites that contain organic wastes and impose harsh penalties for people caught illegally dumping organic wastes.

A third source of food for ravens that is associated with humans is the carcasses of road-killed animals along highways (Boarman and Heinrich 1999). Road kills are an abundant resource along highways in the desert (Rosen and Lowe 1994, Boarman and Sazaki 1996) and are likely to make up a substantial proportion of the diet of birds nesting near highways. Road kills may help increase nesting success where there otherwise would not be adequate food to support a raven family (Knight and Kawashima 1993, Kristan and Boarman 2001). In addition, tortoise shells bearing evidence of being depredated by ravens have been found beneath raven nests along highways (Boarman and Hamilton in preparation). Reducing the incidence of road kills using barrier fences (3- to 6-mm-mesh hardware cloth) (Boarman and Sazaki 1996) along major roads and highways would remove a steady source of food for ravens. Several highways in the southwest have already been equipped with fences to reduce tortoise mortality along roads, but in many cases, the mesh size is inadequate to prevent most smaller reptiles and rodents from attempting to cross. Boarman and Sazaki (1996) found that 13-mm-mesh barrier fence reduced vertebrate mortality by 90%; they recommended fences be used in concert with culverts to allow animal movement and prevent fragmentation of tortoise and other animal populations.

Sources of free or standing water are yet another resource—the importance of which must not be underestimated in an arid environment—that must be controlled to reduce raven populations. In the eastern Mojave Desert, Sherman (1993) found that breeding ravens left their territories every day to drink water several kilometers away. Sources of standing water such as sewage containment sites, irrigation ponds, stock tanks, golf course ponds, and puddles beneath leaking faucets provide ravens with year-round water (personal observation). Knight and others (1998) recorded that ravens made use of stock tanks but not naturally occurring springs. The presence of these unnatural sources of water may facilitate a higher raven population by providing water during periods of low availability, while allowing ravens to expand their range into parts of the desert isolated from natural sources of water. In addition, because ravens are able to travel long distances on both a daily and a seasonal basis, human-provided water sources may affect raven populations over a broad area. Reducing availability to ravens of anthropogenic sources of water could be accomplished by modifying sewage and septage containment practices in four possible ways: (1) covering the water, (2) altering the edge of the pond with vertical walls, (3) placing monofilament line or screening over the entire pond, or (4) adding methyl anthranilate or other harmless taste aversive chemicals to standing water sources. Availability of other sources of water (e.g., stock tanks, dripping water faucets, golf course ponds, tamarisk irrigation lines, etc.) could also be reduced. Emphasis should be placed on reducing availability of water during the spring, when ravens are nesting, and summer, when water demands for ravens are high but natural sources are low. The need to reduce raven populations must be balanced against the need to provide water for other forms of wildlife that depend on anthropogenic sources of water (e.g., migratory birds), so a multispecies evaluation should be made before implementing this action (e.g., Knight and others 1998).

Agricultural practices also make food and water available to ravens (Engel and Young 1992, personal observation). Grains at cattle feed lots and dairies, rodents and insects in alfalfa fields, and nuts and fruits in orchards and row crop fields all are eaten by ravens (Boarman and Heinrich 1999). Water is accessible on farms and dairies at irrigation ditches, ponds, puddles, and sprinklers (G. C. Goodlett, personal communication, W. Webb personal communication, personal observation). The majority of approximately 80 ravens radio tracked at EAFB spent some portion of their time at a agricultural sites, which were a minimum of 20 km from where the birds were initially trapped (unpublished data). Knight and others (1993) found significantly more ravens in agricultural areas than in rangelands and desert controls in the Mojave Desert. Controlling raven access to subsidies in an agricultural setting presents a challenge, as food and water are ubiquitous; however, doing so is an important step in reducing the abundance of ravens. Education will play a critical role, as extension agents can encourage agricultural professionals to cover unused grain containers, bury or render carcasses immediately, and dispose of other wastes and byproducts in secure containers.

Discourage nesting behavior. Efforts to discourage ravens from nesting also will help reduce raven populations and local raven predation on tortoises. The majority of raven predation on tortoises probably occurs in the spring (April and May) when tortoises are most active and ravens are feeding young (Boarman and Heinrich 1999, Boarman and Hamilton in preparation). Parent ravens spend most of their time foraging within approximately 0.4 km of their nest (Sherman 1993); hence this is probably the zone of greatest impact on the tortoise population (Kristan and Boarman 2003). Removing raven nests with eggs in them would probably have the greatest benefit because they are not likely to renest, and if they do, they are less likely to be successful (Kristan and Boarman 2001, Webb 2001, cf. Marzluff and others 1995). In addition, it is best to remove nests before chicks have hatched, when the pressure to feed 3–7 juveniles may increase the frequency of tortoise predation. Dipping bird eggs into corn oil prevents hatching and causes the parents to continue incubating rather than renesting that year (Wildlife Services 2001). Although labor intensive, this is an alternative way to reduce reproduction and brood-related foraging. Recent evidence from EAFB indicates that fledging success is significantly reduced in late broods. Thus, if destroying nests or oiling eggs causes initiation clutches to be delayed sufficiently, then these reproduction efforts would probably fail.

Removing nests outside of the breeding season probably would have less effect on the raven populations or their predation on tortoises since they may readily rebuild at the beginning of the next nesting season. However, recent evidence from EAFB showed that birds with no nest in their territory at the beginning of the breeding season were less likely to commence nesting than those that already had an intact nest (Kristan and Boarman 2001). Hence, if experiments show that removing nests outside of the breeding season does reduce the probability of nest initiation in the next year, then nests should also be removed then. Other species of raptors nest in raven nests (and vice versa) and raven nests often resemble other raptor nests, so caution should be taken not to greatly impact these other bird populations (e.g., great horned owls and red-tailed hawks).

In addition, the construction of new nesting structures (e.g., power towers, telephone poles, billboards, etc) should be avoided in tortoise habitat, and, if possible, existing nesting structures should be removed in areas where natural substrates are lacking. Structures that facilitate nesting in areas ravens otherwise could not nest in may pose a danger to nearby tortoise populations, particularly if they are well away from other anthropogenic attractants. At EAFB, a significant number of ravens nested on myriad anthropogenic structures (e.g., radar towers, high-tension power poles, telephone poles, buildings, etc.) (Webb 2001, Boarman personal observation). Many of these structures can be modified to prevent raven nesting, but some cannot. Telephone and power towers of solid construction rather than lattice and with diagonal crossbars instead of horizontal ones are harder for ravens to nest on (Boarman personal observation). Additional reductions in tortoise losses to ravens can be accomplished by removing unnecessary towers, abandoned buildings, vehicles, etc., that may serve as nesting substrates within tortoise management areas unless natural structures are in abundance. Because ravens hunt primarily from the wing and will readily perch on small shrubs and the ground, there is little value in modifying structures to prevent perching.

Lethal actions against individual ravens. There is no evidence that lethal removal will have a long-lasting effect on raven population levels, raven foraging behavior, or survival of juvenile tortoises. In Iceland, a large-scale raven removal program found that there was no measurable reduction in numbers of breeding pairs following nine years of removal (Skarphedinsson and others 1990). Still, a relaxation from predation pressure in specific areas for several years may help tortoise recruitment. The BLM conducted two short-term, multiagency projects that involved lethal removal of ravens for the benefit of tortoise populations. In 1989, a pilot program poisoned and shot 106–120 birds at the Desert Tortoise Natural Area (DTNA) (Kern County, California) and the landfill at the US Marine Corps Air Ground Combat Center at Twentynine Palms (San Bernardino County) (Rado 1993). No effort was made to monitor the effectiveness of this aborted program on tortoise populations (Boarman 1993b). Some success at taking this approach was demonstrated in 1993 and 1994 in an experimental program in which 49 ravens were shot (Boarman unpublished data). Unfortunately, no effort was made to monitor the effect this limited program had on either tortoise populations or territorial replacement by other ravens. I recommend that lethal actions should only be implemented as a short-term solution in an effort to give the local tortoise population a small window of time with minimal predation. The nonlethal raven management measures proposed above must also be implemented for there to be a reasonable probability of success at reducing raven predation (Schneider 2001).

One case in which lethal removal may be particularly effective is for ravens that are known to prey on tortoise. Evidence suggests that some ravens may be responsible for taking relatively large numbers of tortoises (US BLM 1990a, Boarman and Hamilton in preparation). These individuals can be identified by the presence of juvenile tortoise shells beneath their nests, which are generally used year after year by the same individual breeding ravens (Boarman and Heinrich 1999). By removing those birds known to prey on tortoises, survival of juvenile tortoises may increase locally. However, it is very difficult to identify an offending bird with absolute certainty. Furthermore, it is even harder to find tortoises killed by a raven, because the shells may be spread over a broad area. Territorial ravens should be selectively shot in areas of high tortoise predation if they are found with at least one tortoise shell bearing evidence of raven predation within 1.6 km of their nest, a reasonable estimate of the radius of their territories in the California desert (based on Sherman 1993). Under this recommendation, targeted ravens would be shot by rifle or shotgun or trapped and humanely killed where shooting is not possible (e.g., on power lines or in residential areas) or successful. Young ravens found in nests of removed adults should be killed euthanized humanely if they can be captured. Poisoning with DRC-1339, or other appropriate agents, could be used against targeted birds in these limited areas if it is shown to be safe for other animals. Poisoned carcasses should be removed when feasible.

Lethal removal of ravens also may be a useful tool in situations where critical tortoise populations face threats from several sources, including raven predation. In this case, ravens would be removed from specific areas (e.g., limited portions of Desert Wildlife Management Areas, experimental captive release and translocation areas, DTNA, etc.) with historically high tortoise mortality and raven predation, particularly where demographic analyses indicate that juvenile survivorship has been unusually low. Areas near anthropogenic resources (e.g., landfills and towns) that meet these criteria could be targeted because they probably facilitate a high level of predation pressure through spillover predation (Kristan and Boarman 2003) . None of these actions should be implemented without being accompanied by nonlethal, long-term actions.

Research and Monitoring

It is recommended that a program including the above actions also contain a strong research component because there are many uncertainties about how to reduce raven predation on tortoises. The research actions are designed to yield information necessary to develop future phases of a comprehensive raven management program.

The first objective of research efforts should be to determine the behavior and ecology of ravens as they pertain to predation on tortoises. Information on the ecology and behavior of ravens in the California deserts is necessary to design and modify effective long-term management actions. Over the past eight years, data have been collected in the western Mojave Desert, mostly at EAFB, on several aspects of raven ecology.

Most of that research was focused on populations in moderately to heavily human-dominated landscapes, so information is spotty on raven ecology and behavior in more natural settings. To provide a clearer picture of raven ecology in the deserts, some future research needs to focus on birds in more natural landscapes (e.g., Joshua Tree National Park and Mojave National Preserve), particularly where predation on tortoises is occurring, as well as in areas dominated by agriculture. Other research is necessary to better understand raven demography and life history to identify where the population is most vulnerable and what factors facilitate its great increase.

There are several specific objectives that still need to be met to fully understand and manage raven predation on desert tortoises: (1) discover how and where ravens forage on tortoises by studying individuals or pairs that are known to prey on tortoises; (2) identify the preferred food items and foraging methods employed by ravens in different parts of the desert and determine if forage choice is learned in the nest, developed after fledging, or is simply an opportunistic behavior; (3) identify the important sources of water for ravens in the Mojave; (4) determine the extent of predation by ravens on tortoises and other animals and its effect on prey populations; (5) investigate how raven territoriality affects raven populations and predation losses from tortoise populations; (6) evaluate how concentrated anthropogenic food and water sources influence raven populations and behavior in tortoise habitat; (7) characterize the nesting and foraging ecology of ravens living near highways to determine the relative importance of road kills to those birds; (8) determine if alterations to the habitat (e.g., from livestock grazing) change tortoise vulnerability to raven predation; and (9) model age-specific mortality and reproduction in raven populations to better predict the effect various management options may have on raven populations.

The US Geological Survey, in cooperation with the US Air Force (EAFB) and US Army (Fort Irwin), studied raven movements and nesting ecology for six years in an effort to better understand their population dynamics (Boarman and others 1995, Kristin and Boarman 2001, Kristan and Boarman 2003, Webb 2001). Studies concentrated on the use of anthropogenic habitats and resources, nestling and fledgling survival relative to proximity to anthropogenic resources, natal dispersal, adult movements, and spatial aspects of predation risk posed by ravens. For six years, Boarman and Hamilton (in preparation) collected data from 304 raven nests throughout the California deserts to determine the geographic extent of raven predation.

In addition, regional surveys should be conducted of the California deserts to locate and map ravens and their nests and communal roosts. Information on the densities and distributions of ravens and their nest, perch, and roost sites are necessary to understand the causes of their increases, to direct and modify management efforts, and to monitor the effectiveness of management efforts. These can all serve as baselines, but continuous information is necessary to monitor raven activities. Objectives of this effort would be to characterize distribution, behavior, and ecology of raven populations in the California deserts; monitor changes in population levels and distribution of ravens as a result of management changes; and identify potential causative factors for changes in raven population levels and distribution. Inventories should include private and public lands. Project proponents and other interested parties could contribute funds to a coordinated surveying program that would concentrate both on specific sites and broad regional patterns.

Surveys were conducted between 1994 and 2000 in and around EAFB with the primary goals being to monitor changes in raven numbers as landfill management changed and to determine which resource sites were used most by ravens (Boarman and others 1995). These and the other less extensive surveys throughout the Mojave Desert, California (Fauna West Wildlife Consultants 1990), Amboy, California (Knight and others 1999), Primm, Nevada, Mesquite, California (McKernan, personal communication), Fort Irwin, California (Boarman and others in preparation), Joshua Tree National Monument, California (Boarman and Coe 2002), EAFB (Boarman and others 1995), and Marine Corps Air Ground Combat Center, California (Chamblin and Boarman, unpublished data) could be used to develop a broad-based statistically sound survey protocol. GIS maps of over 400 nest sites in the California deserts have been prepared, but nest surveys were ad hoc, the effort was disproportional in some areas, and funding was very limited (Boarman and Hamilton in preparation).

An effort should also be made to develop, test, and implement methods for monitoring juvenile tortoises to determine effectiveness of and need for raven management efforts. The ultimate measure of success of reduction efforts is increased survival of juvenile tortoises and recruitment into the adult population. Because of their size and cryptic behavior, juvenile tortoises are difficult to find on standard surveys of tortoise populations, making estimates tenuous at best (Berry and Turner 1986, Shields 1994). Although such surveys may be useful for tracking overall trends in populations, surveys must be developed and conducted that concentrate on monitoring the juvenile component of the populations. The methods must yield statistically valid results and use sufficient sample sizes to make valid inferences about population trends. Data on tortoise populations have been collected at 16 permanent study sites throughout California deserts (Berry 1997). Although the method is biased towards larger size classes and generally provides weak estimates of density, the data need to be evaluated to determine if their continued use can yield the data required to monitor the juvenile component of tortoise populations. Alternative methods using distance sampling (Buckland and others 1993) or removal rate of tortoise models (Kristan and Boarman 2003) could perhaps be used.

Another important goal is to develop a demographic model of raven populations to predict the effect various management alternatives might have on raven populations. It is difficult to be certain what long-term effect any management action will have on raven populations or their predation on tortoises. Modeling, when accompanied by statistically sound data, can provide valid predictions. Such a model can be used to predict the outcomes of alternative management strategies giving us a glimpse into the probable future. A study is needed to develop and validate a computer model of the dynamics of raven populations, incorporating age-specific mortality, natality, and dispersal and to apply the model to alternative management scenarios (e.g., removal of nests, selected shooting of breeding birds, broad scale removal of birds at landfills) to determine the effect the actions would have on raven populations and their overall impact on tortoise populations. No demographic modeling has been accomplished to date, but data on clutch size and nestling and fledgling survivorship that has been collected at EAFB can be used in the models (Kristan and Boarman 2001, Webb 2001).

A fifth research objective is to develop and test specific methods to directly manage raven populations and behavior. Several possibilities exist to reduce raven impact on tortoise populations, but few have been tested. Aversive chemicals, antiperch devices, and noisemakers can keep birds away from specific resource sites that may facilitate increasing raven populations (e.g., landfills). Poisons, shooting, and relocating following live trapping are all possible ways of removing ravens from specific areas. Removal of nests both during and outside the nesting season may reduce future nesting behavior. Tests are needed to determine the effectiveness of these and other measures with ravens in the Mojave Desert.

Several aversive chemicals have been used to keep various species of birds from eating economically important crops [e.g., methyl anthranilate (Avery and others 1995), methio-carb (Conover 1984), carbachol (Avery and Decker 1994, Nicolaus and others 1989)]. However, they do have limitations. Methyl anthranilate is highly volatile and breaks down readily under exposure to ultraviolet light; it has limited utility in natural settings. Perhaps it could be sprayed over garbage to repel ravens for a few hours until the garbage can be covered. Methio-carb has been used to condition ravens against eating bird eggs (Avery and others 1993). Maybe it could be applied to model tortoises and deployed at sites where nursery-bred juvenile tortoises are to be bred and released (Morafka and others 1997). Studies need to be conducted on captive and wild ravens to determine their utility for achieving the goals set out herein. Preliminary trials conducted in spring 2001 with three captive ravens indicated that ravens find methyl anthranilate to be distasteful, but showed no conditioned taste aversion under the conditions used in the trials (Boarman and others 2002).

Human-provided nest and perch sites in areas where tall natural substrates are lacking may facilitate hunting, roosting, and nesting in areas where tortoises may otherwise have been immune to raven predation. If the nest and perch sites are removed or made unattractive to or unusable by the ravens, then ravens may be less apt to use or benefit by the resource or prey on nearby tortoises. However, as ravens likely do the vast majority of their hunting while in flight and will often perch and eat on low bushes or the ground, modifying human-provided perches probably will not greatly reduce raven predation on tortoises. If, however, new nesting substrates are introduced to an area previously devoid of adequate nesting sites, then foraging on tortoises may be facilitated. A study should be conducted to determine definitively if: (1) raven dependence on human-provided perches and nest sites aids hunting, nesting, and overall survival; (2) modifying raven perches, roost sites, and nest sites on a localized basis is an effective way of reducing raven predation on tortoises; (3) removal of raven nests early in the breeding cycle will prevent ravens from renesting in that season; and (4) oiling of eggs inhibits egg hatching while discouraging parents from laying another clutch (Wildlife Services 2001).

One of the most effective ways of killing ravens is with the avicide DRC-1339 (Seamans and Belant 1999). The task is effected by injecting hard-boiled eggs with the poison. The measure potentially poses an adverse impact to nontarget species that may also eat the avicide-laced eggs. To determine conclusively whether DRC-1339 has an impact on nontarget species, an experiment should be designed and conducted to determine what other species of animals in the California