March 1992

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ABSTRACT: Common ravens (*Corvus corax*) are a major predator on the threatened desert tortoise (*Gopherus* [= *Xerobates*] *agassizii*). Large numbers of juvenile tortoise shells have been found beneath known raven nests and perches; many shells that show evidence consistent with raven predation have been found sporadically throughout the range of the tortoise; significant proportional decreases in juvenile size/age class distributions have been identified; and people have observed ravens killing, carrying, and consuming juveniles. In 1988 the U. S. Bureau of Land Management initiated a process to evaluate, design, and implement a program to reduce raven predation on desert tortoises. A pilot program was temporarily halted by a law suit filed by the Humane Society of the United States, and a draft long-term plan and Draft Environmental Impact Statement were subsequently issued and are now being modified.

Several complex issues have arisen in attempting to design and implement control of ravens including: pitting one native species against another, making management decisions in light of data of varying scientific validity and depth, targeting individuals versus populations, and managing a predation problem over a broad geographic range. Addressing each of the concerns is highly problematic and the solutions are not always satisfying.

Proc. 15th Vertebrate Pest Conf. (J. E. Borrecco & R. E. Marsh, Editors) Published at University of Calif., Davis. 1992

INTRODUCTION

Predator control usually involves removal of predators that are causing an economic impact and are often exotic pest species. Recently, predator control efforts are increasingly focused on native predators on threatened or endangered species (e.g., raven and least tern, brown-headed cowbird and Kirtland's warbler, coyote and San Joaquin Valley kit fox, etc.). Such situations involve several issues due to ethical, social, or political concerns with managing native species for non-economic reasons. The United States Bureau of Land Management's (BLM) program to reduce common raven (*Corvus corax*) predation on the threatened desert tortoise (*Gopherus* [= *Xerobates*] *agassizii*) has encountered several such issues.

The objectives of this paper are to: a) define the problem as it exists today by providing some background to the issue of raven predation on tortoises; b) characterize the nature of the interaction between tortoises and ravens; c) present some of the solutions that have been considered for solving the predation problem; and d) briefly discuss two of the more difficult issues that the BLM has had to face.

BACKGROUND

History

In 1989 and 1990, state and federal governments listed the western Mojave population of the desert tortoise as a threatened species (Hohman et al. 1990). Several factors were responsible for the drastic population declines that resulted in the listings. Tortoise numbers were rapidly declining due to: upper respiratory tract disease, vandalism, illegal collecting, and habitat destruction (Berry 1986, 1989, Hohman 1990). The problem was exacerbated by a precipitous decline in the numbers of juvenile tortoises available for recruitment into the breeding population. One of the primary causes for the loss of juveniles was considered to be excessive predation by common ravens (Berry 1985). All of these problems are still considered to exist today.

Raven populations are rapidly increasing in the Mojave desert. Based on Breeding Bird Surveys (Robbins 1986) conducted by the United States Fish and Wildlife Service (FWS) between 1968 and 1988, the number of ravens in the Mojave desert increased by over 1,500% (BLM 1990a); and this increase is likely much higher in the western Mojave desert. The primary reason for the overwhelming population boom is probably the increased presence of concentrated anthropogenic food and water sources: landfills, sewage ponds, roadside rest areas, agricultural fields, and urban/suburban centers. The presence of such food and water provides year-round sustenance for ravens and likely facilitates survival of adult and hatchling ravens when natural supplies of food and water are generally low (e.g., summer and winter). The result is a larger population of ravens, thus more individuals to potentially find and attack juvenile tortoises.

In 1989, a pilot control program was initiated by the BLM in cooperation with the FWS, California Department of Fish and Game, and the United States Department of Defense (BLM 1989). The purpose of the pilot program was to reduce raven predation on juvenile tortoises and gain valuable information necessary to design a long-term raven control program. The pilot program primarily consisted of poisoning ravens with hard-boiled eggs laced with the avicide DRC-1339 (Rado 1990). The pilot program was stopped by a temporary restraining order filed by the Humane Society of the United States (HSUS vs Manuel Lujan et al. 1989). The lawsuit was subsequently settled out of court, but the pilot program was not re-initiated.

In 1990, the BLM drafted and issued a Raven Management Plan (BLM 1990a) and an associated Draft Environmental Impact Statement (BLM 1990b) that proposed a long term strategy for reducing the threat raven predation poses to desert tortoise recovery in California. The plan included lethal control by poison and shooting; non-lethal control such as nest destruction, sterilization, and removal of roadkills; habitat management such as changing landfill operation methods and altering perch sites; and research into pertinent aspects of raven behavior and ecology. As part of the public input process, the BLM convened a Technical Review Team composed of professional biologists and conservation policy specialists. The Raven Management Plan and Environmental Impact Statement are presently being reviewed and rewritten by the BLM and are expected to be completed and implemented sometime in 1993.

Tortoise Biology

The desert tortoise, a member of the Testudinidae, is a long-lived reptile that occurs in the deserts of southern California and Nevada, Arizona, extreme southwest corner of Utah, and in portions of northwest Mexico. The Mojave population primary occurs in open plains and valleys and is associated with creosote bush (*Larrea tridentata*), burrowbush (*Ambrosia dumosa*), saltbush (*Atriplex* sp.), and Joshua trees (*Yucca brevifolia*). Their activity periods primarily correspond to periods of water and food availability, and are mediated by temperature. Inactive periods are spent in subterranean burrows. Desert tortoises can live for over 100 years and they reach sexual maturity at 15 to 20 years of age (Woodbury and Hardy 1948). The midline carapace length (MCL) of hatchling tortoises is approximately 35 mm, of 20 year olds is 180 mm, and of the largest adults can be over 320 mm. Females lay an average of 4.5 eggs per year (Turner et al. 1987), but there is significant variability within and among individuals due in part to changing weather and habitat conditions.

Subsidized Predators

Subsidized predators are populations of predatory animals that survive and perhaps grow in part due to food, water, or other limiting resources provided by or associated with human activities. As a result of their association with humans, the populations are allowed to grow well beyond the natural carrying capacity of the habitat. The subsidies may be particularly crucial in facilitating large populations by reducing mortality during only a short period of time when limiting resources are normally in particularly low supply (e.g., winter).

Ravens provide an excellent example of a subsidized predator. For instance, they often make heavy use of landfills and roadkills for food (Knight and Call 1980). They also obtain food subsidies at sewage ponds, open dumpsters, agricultural fields, parks, and picnic areas, (FaunaWest 1989). Ravens obtain water subsidies in agricultural fields, cattle troughs, sewage ponds, reservoirs, and gutters (FaunaWest 1989). In the deserts of California, food and water subsidies likely facilitate excessive raven populations by allowing survival during the summer and winter when prey species are particularly inactive and water is scarce. Two other forms of resource subsidies are artificial perch and nest sites. Ravens often nest or perch on power towers, telephone poles, buildings, billboards, fences, abandoned cars, freeway or railroad overpasses, and light posts (Knight and Call 1980). In some localities, these artificial perch sites may allow ravens to nest or perch in broad areas previously inaccessible to them except for during short forays. It is also possible that high perches allow ravens to hunt and scavenge more effectively or with less energy expenditure than required by flight or a low perch. Raven numbers were likely much lower in the first half of this century when fewer subsidies were made available (BLM 1990a) Furthermore, during surveys conducted throughout tortoise habitat in California, raven sightings were far more numerous in regions of relatively high human presence (e.g., western Mojave desert) than those of relatively low human presence (FaunaWest 1989).

INTERACTIONS BETWEEN RAVENS AND TORTOISES

Ravens obtain their food in three ways: scavenging, predating, and pirating from other animals (Knight and Call 1980). The former two are the primary forms used by ravens in the deserts of California (M. Sherman, unpubl. data). Ravens are known to kill many types of animals for food: ground squirrels, weasels, invertebrates, chickens, mice, and lambs (Knight and Call 1980). Ravens are also known to eat juvenile desert tortoises (Berry 1985). There have been several direct observations of ravens attacking and eating tortoises (see references cited in BLM 1990a). A juvenile tortoise was found in 1991 by R. Knight (pers. comm.) beneath a raven nest. Its carapace was pecked open and it was partially eviscerated, but the tortoise was still moving.

Other pieces of evidence are more circumstantial and are based on a combination of associative and physical characteristics that are consistent with being predated on by ravens. In an analysis of shells found beneath a raven nest, Berry (1985) identified several characteristics of the carcasses that she used as a standard to determine that raven predation was the probable cause of death for other carcasses found. For instance, she found many of the shells to have holes pried or torn into the carapace or plastron. Some of the shells showed small holes or scratches of similar diameter to the tip of the ravens bill. Often only one or two of the appendages were missing, which suggested that the bird pulled the leg or head out with muscles and other organs attached, then discarded the carcass.

Since ravens are known to obtain a significant amount of food from scavenging it is reasonable to expect that some of the tortoises were scavenged. Four lines of evidence support the hypothesis that ravens do predate on tortoises, perhaps in large quantities. First, young tortoises (< 7 years) have rather soft shells, only shortly after death does the shell harden. If the shell is hard when it is forced open, the shell is likely to crack and fracture. If the shell is still soft and pliable when it is forced open, the shell will tear and fold in, hardening in that position later. Many shells found associated with raven nests and perches show this latter pattern. Second, if all or most shells attributed to raven predation were actually scavenged by ravens after a natural death, we would expect to occasionally find recently dead or moribund juvenile tortoises. However, this has very rarely happened. The BLM generally has had field workers spend a minimum of 2,400 hours per year since the mid 1970s, during prime tortoise activity season, intensively searching for live and dead tortoises. Whereas several ill, moribund, or dead adults have been found, on only one occasion that I know of, has a moribund juvenile tortoise been found (G. Goodlett, pers. comm.). Additionally, large numbers of adult tortoises are currently dying from a respiratory disease that often exhibits several external symptoms and is probably the major source of non-traumatic mortality. No juveniles have yet been found with the disease, so there is currently no reason to expect large numbers of juveniles to be dying and becoming available for raven scavenging. Third, ravens are very opportunistic and are likely to predate any still or slow moving, relatively defenseless food item when they come across it. Finally, as noted above, there are several anecdotal accounts of ravens actually eating tortoises, small and large.

In her survey of 1,898 juvenile tortoises carcasses, Berry (1985) found that those associated with raven nests and perches were all less than 105 mm MCL in size. The numbers of juveniles found becomes a particular problem for tortoise recovery when we consider its effect on population demography. BLM (1990a) presents data from the tortoise population at the Desert Tortoise Natural Area that shows the possible effect raven predation has had on the age/size class structure of the population. These data support the hypothesis that raven predation significantly reduced the numbers of juveniles represented in the population, hence reducing the number of animals eventually available for recruitment into the population of breeding adults (which generally occurs when an animal reaches 180 mm MCL). Preliminary analysis indicates that trends are similar in other populations with high raven densities (Berry 1990).

Raven predation on tortoises may be quite extensive in California; it occurs over a broad geographic area and the numbers of animals may be quite large (Berry 1985, BLM 1990a, Boarman and Berry in prep.). Ravens and tortoises co-occur over approximately 40,000,000 acres of desert in California with shells showing signs consistent with raven predation being found throughout this range. The largest numbers of shells have been found in the western Mojave, followed by the eastern Mojave, with the fewest being found in the Southern Colorado desert. This pattern parallels the relative distribution of ravens (FaunaWest 1989). However, the numbers of shells being found recently is lower than in the 1980s. It is more likely that this reduction is due to far fewer juvenile tortoises being represented in tortoise populations, rather than to a fundamental change in raven behavior, ecology, or distribution.

POSSIBLE SOLUTIONS

The BLM's draft Raven Management Plan (BLM 1990a) proposed several actions to increase juvenile survival and aid tortoise recovery by reducing raven predation on tortoises. The BLM is currently revising the plan and is presently considering a subset of the originally proposed actions, which are considered to be the most viable and effective methods. Which actions the final plan composes has not been decided on by the BLM. I briefly discuss here the actions I consider at this time to be among the most reasonable. These actions can be loosely categorized into short-term or local, and long-term solutions.

The short-term, or local, solutions may be most effective for immediate reductions in population levels on either a broadscale or localized basis. These include alteration of perches, taste aversion agents (e.g., methyl anthranilate), nest destruction, hazing, and lethal removal by shooting or poisoning. I believe that lethal removal will be most effective for broad-scale, short-term population reduction and localized removal on a more permanent basis. The specialized locations for lethal removal may include specific locations of food subsidies (e.g., landfills) and known problem birds (e.g., where juvenile shells are found that show signs consistent with raven predation). Methyl anthranilate (Mason et al. 1985) could be used if it is found to be effective at preventing raven use of food and water subsidies, such as landfill garbage. Nest destruction and hazing may be employed at some areas where raven occurrence is undesirable. Perch site alteration, using currently available technology, is likely to be effective on only a very localized basis (L. Young, pers. comm.). This is because ravens use a broad variety of potential human and natural perches. If a given perch is altered, and ravens are strongly attracted to the area, they will most likely switch to an alternative perch type nearby. Thus, broad application of anti-perch devices may not keep birds out of a general area, it may only keep them from an immediate site (e.g., building, radio tower, or water tower).

All of the above listed local or short-term actions are either only effective locally or require repeated applications throughout the period of control (which may be for 500 years or longer in the case of desert tortoise recovery; FWS 1992). I believe that the most effective control for the long-term must address the sources of food subsidies and must be relatively low maintenance. The best methods will involve reducing the resource subsidies thereby lowering the overall carrying capacity of the desert. This approach requires the removal or alteration of primary food subsidies such as landfills, sewage ponds, garbage dumpsters, and agricultural fields. The alternative may be a program using costly methods on a continuous or frequent basis for perhaps the next 500 yrs.

DIFFICULT ISSUES

In developing the raven control program, the BLM has been confronted by several difficult issues. The solutions to the issues are not always obvious and they rarely satisfy all interested parties. A brief discussion follows of two of these issues.

Priorities for Species Recovery

Predator control is sometimes an easier way of solving a problem than attacking the root causes for the problem. This may be for political, economical, social, or technological reasons. The initiation of BLM's raven control activities in 1989 closely paralleled actions to list the tortoise at state and federal levels, and was the first highly visible action the government took to help recover tortoise populations. These points led to the perception by many that the BLM's only effort to help save the tortoise was going to be predator control rather than addressing other politically or economically more sensitive activities such as off-highway activities, grazing, mining, energy generation, and other commercial developments. There are currently opposing pressures by some to more aggressively pursue raven control and by others to drop raven control and address other issues affecting tortoise survival.

The solution to the controversy is to define clearly the relative importance of various factors affecting long-term tortoise survival and recovery, and to invest resources into studying and effecting change in those factors that are under our control. Population models are one way of evaluating the relative importance of raven predation, however contradictory models exist (C. Ray and M. Gilpin unpubl., J. Congdon unpubl.). The BLM has committed substantial funds to studying the impacts of grazing, disease, and nutrition on tortoise populations, and has devoted relatively little to raven control. The BLM has implemented actions to: a) reduce off-highway vehicle activity in tortoise habitat; b) develop habitat and other management plans, which will direct activities that may affect tortoise populations; c) implement several mitigation measures to reduce impacts to tortoises; d) acquire lands that will be managed for tortoise recovery; and e) conduct research on disease transmission and epidemiology, nutrition, thermal ecology, and impacts of grazing. The relative importance of raven predation and the final level of funding for raven control by the BLM are yet to be determined.

Weighing Scientific Accuracy vs. Practical Management Needs

Science requires rigorous hypothesis testing with clearly identified assumptions and predictions. Popperian philosophers of science profess that hypotheses can never be proved, they can only be disproved. In practice, one of the primary ways of drawing conclusions is through statistical inference whereby data is collected in well designed and properly controlled experiments and hypotheses are accepted or rejected based on some *a priori* but arbitrary level of significance (i.e., alpha). The statistical methods used to test the statistical hypotheses all have conditional assumptions which must be met. Rigorous adherence to all of these principles, as advocated by many scientists, may often lead to few unambiguous conclusions from which resource managers can make sound decisions. Violation or ignorance of the assumptions, as committed by many resource managers, may lead to inappropriate actions based on faulty conclusions.

Scientists and resource managers often disagree on actions to take because of differing appreciation for each others' perspectives: the scientist requires strict adherence to scientific hypothesis testing while the manager is often required to make decisions based on existing knowledge. The scientist often criticizes the manager for making decisions based on poorly collected, analyzed, or interpreted data, while the manager often criticizes and ignores the scientist for insisting on stringent conditions for making judgements. For true progress towards wise management of our resources, it is necessary for scientists to recognize the limitations managers are under when management decisions must be made well before sufficient data are available, or when data cannot be collected in tightly controlled situations. On the other hand, managers must recognize that too often, poorly designed or analyzed experiments may result in incorrect management actions which may waste enormous amounts of time and effort.

These problems directly affect the management of ravens in many ways. The justification for raven control comes in large part from several observations: a) large numbers of shells showing signs consistent with presumed raven predation have been found beneath some raven nests and perches, b) individual or small groups of shells have been found beneath many additional nests and perches or sporadically on the desert floor, c) several well studied populations of tortoises have recently become depauperate of juvenile tortoises of the size usually taken by ravens, and d) a few sightings of ravens actively predating on tortoises. In the sense of hard science, these observations do not consist of proof that ravens are causing significant harm to tortoise populations, but they do support the hypothesis. On the other hand, direct observation is very difficult to observe, and managers must depend on the strength of circumstantial evidence to make a decision.

The nature of control is also subject to differences in perspectives of managers and scientists. Of particular concern is the fact that little is known about effective methods of control of ravens on a large scale (perhaps well over 10,000 birds occupying 40,000,000 acres of tortoise habitat, plus many more within 50 or more miles of tortoise habitat). The primary source of food subsidy in the desert is likely to be landfills, however, we are uncertain of what measures can be employed to effectively prevent raven populations from benefitting from landfills. The scientist might argue that well controlled experiments must be conducted at various landfills to measure the relative effectiveness of different methods. But, with the multitude of factors affecting raven populations existing in the region, it would be very difficult to conduct a properly controlled experiment on mitigations against raven use of landfills. Furthermore, the focus on tortoise populations is relatively recent, so there has been little work on testing mitigations.

In spite of the paucity of data, resource managers are being forced by the Endangered Species Act, National Environmental Protection Act, and other laws to implement changes now. In addition, there is the contention by some scientists that ravens occupying landfills are not the ones predating tortoises, but no data on desert ravens currently exists to test this hypothesis. The BLM must weigh the costs of waiting for the information against the costs of not implementing interim control in the mean time.

In the final analysis I believe it is essential for management agencies to strive for high scientific standards in conducting studies, interpreting data, and implementing management actions. Internal and external peer review should occur at all stages of the project and results should be published in peer reviewed scientific publications. This approach will help to ensure that scientifically supported actions are taken that will reduce the likelihood that costly incorrect decisions are made. On the other hand, scientists must recognize that oftentimes, for political, legal, or practical reasons, resource managers are required to make decisions before sufficient data are available. Sometimes the actions may involve management problems that are not easily amenable to well controlled, rigorous experimentation. Managers do not always have the luxury of waiting until all of the data are available, but nonetheless, their decisions may be costly or irreversible and should be based on sound scientific data.

ACKNOWLEDGEMENTS

The BLM's raven control work was initiated by Dr. Kristin Berry and Ted Rado. My comments have benefitted by stimulating discussions with many people including: Harold Avery, Dr. Kristin H. Berry, John Borneman, Pete Butchko, Faith Campbell, Tom Dodson, Maureen Gardner, Dr. John Grandy, Steve Johnson, Dr. Rick Knight, Ed Kniltle, Dr. Jeff Lovich, Dr. David Ou's, Daniel Pearson, Jim St. Amant, Mike Sherman, and Lenny Young. The views expressed herein do not represent the official views of the Bureau of Land Management.

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