Evaluation of Evidence Supporting the Effectiveness of Desert Tortoise Recovery Actions

Scientific Investigations Report 2006–5143

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Evaluation of Evidence Supporting the Effectiveness of Desert Tortoise Recovery Actions

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Abbreviations

BLM, U.S. Bureau of Land Management
BO, biological opinions
CMBC, Circle Mountain Biological Consultants
DMG, Desert Managers Group
DTNA, Desert Tortoise Natural Area
DTRPAC, Desert Tortoise Recovery Plan Assessment Committee
EAFB, Edwards Air Force Base
ESA, Endangered Species Act
Exper, Experimental
GAO, General Accounting Office
NA, not available
NPS, National Park Service
Observ, Observation
OHV, off-highway vehicles
RMP, resource management plan
USFWS, U.S. Fish and Wildlife Service

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1. Introduction

1.1. Statement of problem

As a federally threatened species, the desert tortoise's (*Gopherus agassizii*) recovery is required under the Endangered Species Act (ESA). According to the criteria established by the Desert Tortoise Recovery Plan (U.S. Fish and Wildlife Service 1994) for delisting the tortoise from ESA protection, the species as a whole will be considered recovered when tortoises have exhibited a statistically significant upward trend for at least one tortoise generation (25 years), enough habitat is protected to allow persistence, provisions are in place to maintain discrete population growth rates at or above 1.0, regulatory measures are in place to ensure continued management of tortoise habitat, and there is no longer reason to believe that the species will require ESA protection in the future. Just as species extinction can be thought of as the cumulative extinction of all populations, species recovery can be thought of as recovery of constituent populations; management efforts for recovery generally are implemented and assessed at the population level. A recent review of the Desert Tortoise Recovery Plan, including an exhaustive literature search, has been compiled by the Desert Tortoise Recovery Plan Assessment Committee (Tracy et al. 2004).

An important step in recovery planning is to identify known causes of mortality or reductions in fecundity, and to propose actions that will reduce or eliminate these threats to population persistence. Because populations change in size as individuals are added (through births or immigration into a population) or subtracted (through deaths or emigration out of a population), threats are identified by establishing that they cause reductions in births, increases in deaths, or changes in movements into or out of a population. However, once a threat has been identified there are several sources of uncertainty in formulating recovery actions. First, the severity of a threat may not be well established. For example, roads can be identified as a threat to tortoises by observing road-killed tortoises on highways, but the amount of road mortality observed may or may not be sufficient to reduce populations. If road mortality is not sufficient to cause a population decline, then reducing road mortality may have no effect on population recovery. Second, even if a threat is known to be sufficiently severe to cause tortoise population declines, there may be more than one possible approach to reducing the threat. For example, if road mortality is shown to be associated with reduced population size, building tortoise-proof fencing along highways is one possible (and commonly used) approach to reducing this threat. Other approaches are also possible, however. Roads could be closed, speed limits could be reduced, tortoise monitors could be employed to safely move tortoises across roads, or underpasses could be constructed to allow safe crossing. Each approach involves some investment of resources, and some may be more effective than others. Additionally, some approaches, such as speed limits and road closures, involve imposing changes on human behavior that may not be welcomed by the public.

Because of the diversity of possible approaches to desert tortoise recovery, it is important to assess whether the effectiveness of recovery actions is well supported. Additionally, because every recovery action entails costs (in dollars, time, resources, or public goodwill), it is important to evaluate whether actions are achieving the intended benefit. It also is important to evaluate how well managers' needs for scientific support are being met by the current state of knowledge. These issues were identified by a General Accounting Office (GAO) report in 2002, and remain issues today.

This current (2006) report was commissioned by the Desert Managers Group (DMG) to evaluate the state of knowledge about the effectiveness of desert tortoise recovery actions. To do this, we gathered and then critically examined the best available evidence of the effectiveness of recovery actions related to major threats to desert tortoises. This document can be viewed as an extension of Boarman's (2002) report in which the major threats to desert tortoise populations were described based on a thorough review of the literature.

1.2. Need for scientific basis for management actions

Population-level responses to recovery actions are intrinsically difficult to study in desert tortoises owing to their long generation time and low detectability (Tracy et al. 2004). However, recovery actions are likely to be most effective when they are based on scientific principles and reliable data. There are two typical situations in which knowledge about the effectiveness of recovery actions would be beneficial to resource managers. The first situation is that in which a manager must decide among several possible recovery actions. If studies of the effectiveness of various management options had been conducted, they would provide invaluable information in making such decisions, as well as in explaining and justifying the management action to line employees and the public. The second situation is one in which a recovery action has already been implemented, but the expected recovery has not occurred. Lacking reliable information about the effectiveness of the action, the manager cannot tell whether the action does not work in general, or has failed in the particular context because of other problems, such as additional threats that have not been addressed. However, if the effectiveness of the action has been conclusively documented, then the lack of recovery can be treated as de facto evidence that other threats are present, and the manager can immediately direct attention to identifying and reducing them. For example, if fencing along a road does not help in increasing tortoise populations (studies have shown that fencing reduces the incidence of road kills), then it becomes clear that other factors, such as disease, predation, or collecting, may be derailing the recovery. To have this level of confidence in a recovery action, however, ample supporting evidence must exist.

The GAO drew the distinction between demonstration of threat and demonstration of effectiveness of recovery (General Accounting Office 2002), and pointed out that the effectiveness of recovery actions already implemented was not known. In the absence of this knowledge, it was not possible to know if the limited resources were being wisely spent (General Accounting Office 2002). The effectiveness of particular recovery actions should be tested scientifically whenever possible. Pullin and Knight (2001) describe the "effectiveness revolution" in the British health-care system in which analysis of the effectiveness of different treatment courses is advocated to improve future decision-making. The authors point out a parallel to conservation biology, in which science and statistical analysis of the effectiveness of historic practices should serve as a guide for future efforts. The parallels they cite between medical and conservation practitioners are strong and bear repeating. Doctors treat their patients' critical health conditions under time pressure with limited information. Treatment decisions are based on an understanding of the relevant science (such as human anatomy and physiology), but prior to the effectiveness revolution there often was little basis for choosing the best treatment from among a range of possibilities. Personal experience was an important driver of treatment choices under these circumstances. However, personal experience may be of little use in detecting treatments that are ineffective because a patient's health can spontaneously improve, even in the absence of treatment; conversely, treatments effective in a majority of cases may fail to work for a given patient. Additionally, personal memory can subjectively review only a limited number of cases, which are probably an inadequate number of cases on which to draw conclusions, especially without filtering the data through statistical methods that eliminate biases. Similarly, resource managers must decide which recovery actions to implement from a range of possibilities and how to implement them, in spite of uncertainty. Basing management decisions on sound ecological principles is helpful, but more than one possible approach may be defensible.

1.3. Specific questions addressed

1.3.a. How much information is available to support recovery actions, and what kind of information is it?

One measure of whether resource managers are receiving adequate guidance from scientists in their management decisions is the number and type of studies that address the effectiveness of recovery actions. We searched available literature to determine whether studies of effectiveness were being conducted and to assess whether the information available to managers is based on scientific evidence. In the process, we attempted to gauge whether effectiveness evaluation and monitoring efforts taking place at local levels could be performed in a manner more conducive to scientific interpretation.

1.3.b. Is the effectiveness of recovery actions well supported by scientific evidence?

The results of well-planned scientific studies ultimately will be more useful in guiding management actions than will reports of an observational or anecdotal nature. Therefore, we rated the supporting evidence for the effectiveness of recovery actions and the reliability of the evidence relative to the scientific principles outlined in sections 2.1.a–d.

2. Conceptual approaches

2.1. Variables examined

Evaluating the effectiveness of management actions is a complicated process, with two important issues for managers to consider. The first issue to consider is the reliability of studies used to demonstrate effectiveness, which depends on the experimental methods employed. Before implementing an action based on previous studies, a manager should decide if the conclusions of the studies are justified based on the methods used to collect and analyze the data. The second issue is can effectiveness be evaluated at different levels? On the basis of the measures of impact that an investigator chooses, a study can document effects at the individual level or at the population level. The generality of the results can also be evaluated: results can be reliable at the level of a particular project ("project level") and at the level of the action in general ("action level"). If studies are to meet the needs of managers, the difference between action and project levels should be carefully considered at the experimental design stage, as demonstrating effectiveness at one level does not imply effectiveness at another (see section 2.1.c, below). In other words, a management action may reduce impacts to tortoises at a particular project site, but one cannot assume that the action will be effective for the entire population of tortoises that may be subject to that action.

2.1.a. Classification of kinds of information

Managers have a wide range of information available to employ in their decision-making. Boarman (2002) classified this information by type and by source as a guide to judging its scientific validity and reliability. Data types, described below, include experiments, correlations, descriptions or observations, anecdotes, and speculations.

Experiments: Experiments involve changing one or more variables and observing the result on one or more other variables. Experiments are widely considered to be the most reliable form of scientific information because direct manipulation gives the investigator greater certainty that the results are due to the manipulation, and not to some other unknown factor. Though experiments are the most reliable form of study, they are often impractical or impossible at the spatial and temporal scales required for population-level assessments and may be considered unethical or illegal for endangered species. For example, studying mortality factors on desert tortoises experimentally could require exposing tortoises to predators, a practice that would be at odds with recovery goals. Furthermore, experiments are often open to the criticism that their manipulations are not sufficiently similar to naturally-occurring situations to allow their conclusions to be readily applied to real populations.

Correlations: Correlational studies make observations of sets of variables that are not under the investigator's control, and infer the relationships among the variables based on patterns observed. Because the investigator does not make direct manipulations of variables, it is logically impossible to determine which variables are causing changes in others. For example, if A and B are correlated, it is possible that A causes change in B, that B causes change in A, or that changes in both A and B are caused by changes in another unmeasured variable, but have no causal relationship with one another. In practice this limitation is dealt with by applying additional biological knowledge to the system (for example, it is logical to hypothesize that raven predation could cause a decline in tortoise population sizes, but it is not logical to hypothesize that tortoise population declines are causing raven predation), and by studying problems from multiple perspectives with multiple independent data sets. A great advantage of correlational studies is that they capture and reflect natural variation, so that their applicability to real populations is easy to justify. Generally, it is considered best to conduct experiments when they are possible, to use correlational studies when experiments are not feasible, and ideally to use each to complement the other.

Description/observation: Observations are fundamental to science, but isolated observations made outside of a designed study are of limited value. Observations play a prominent role in developing scientific theories and testable hypotheses, and good, objective, detailed observations can make unique contributions to the descriptive scientific knowledge base (for example the first description of a new species). However, tests of hypotheses require designed studies.

Anecdotes and speculation: Anecdotes are stories, usually including both observations and conclusions about the meaning of the observations. Anecdotes are intrinsically less reliable than designed studies. Speculation is an unsupported, untested assertion, and clearly cannot substitute for designed studies as the basis for reliable management.

2.1.b. Tenets of reliable study design

Whether scientific studies are experimental or correlational, their reliability increases when they follow certain tenets of study design. These include control of extraneous variables, use of control groups, isolation of effects, and replication. Each of these practices addresses particular problems.

Controlling extraneous variables: From a purely theoretical perspective, the ideal experimental subjects are completely homogeneous and have identical reactions to experimental manipulation. However, real experimental subjects differ for a variety of reasons. At best, differences among experimental subjects make results less clear (and require statistics to detect experimental effects), and at worst, differences among subjects can be inadvertently confounded with an experimental treatment so that the apparent effect of the treatment is actually due to unrelated differences among subjects. Scientists deal with this problem by holding as many variables constant as possible, randomly assigning subjects to experimental groups, and by measuring variables that cannot be controlled so that their effects can be accounted for statistically. Field studies of wild populations must compromise on several of these guidelines; environmental variables cannot be held constant, but major sources of variation can be controlled by the experimental design. For example, the potentially confounding effects of habitat differences among sites can be minimized by careful site selection; likewise, temporal effects can be controlled by making observations of different treatments over an identical time frame. Environmental variation that cannot be eliminated through design choices can often be measured and removed statistically as "covariates" or "block effects."

Controls: In ecological studies "control" is used interchangeably with the term "comparison group," and is generally meant to signify the group that is not subjected to an experimental treatment. For example, in a study of the effects of fencing on road mortality, areas with fences would be designated "treatment" areas, and areas without fences would be the controls. Though this classic experimental concept of a control can be found in some scientific studies, there are also many variations. Sometimes it is logical to substitute "before and after" for "control and treatment," that is, to use the conditions before a treatment is applied as the control. However, this design does not control for changes over time, which in a temporally highly-variable environment such as the Mojave Desert, can cause problems of interpretation. Some studies have more than one type of control; for example, making comparisons between treated and untreated sites before and after a treatment is applied provides a control both for spatial and temporal differences among subjects. Finally, it is also valid to compare subjects that have received different levels of a treatment without a true untreated control.

Isolation of effects: Just as it is necessary to control extraneous variables, multiple variables of interest can interfere with one another and make results difficult to interpret. For example, a fence that simultaneously reduces road mortality, removes off-highway vehicles (OHVs), and removes livestock may increase tortoise population size, but it will not be possible to tell whether the improvement is due to the removal of one single threat or due to some combination of the three; only a general treatment effect can be claimed. If the desired effect is achieved in a management context, this problem may not be viewed as important; for example, if fencing always reduces the same set of threats, and desert tortoises always respond positively, then the details of how the effect was achieved may be uninteresting. However, studies that fail to isolate effects can provide little guidance if the action is applied and a recovery does not occur. Additionally, when effects are not isolated, studies provide little basis for resolving disputes among stakeholders who may only be responsible for an unknown proportion of the overall problem.

Replication: Different experimental subjects may respond differently to treatments. The best way to ensure that observed results are reliable is to apply the treatment to a number of different subjects, in other words to "replicate" the experiment. Although this is conceptually straightforward, what constitutes replication changes depending on the question being asked or the population about which conclusions are to be drawn. This problem was highlighted by Hurlburt (1984), who coined the term "pseudoreplication" to describe replication at the wrong level. For example, repeated observations (e.g., multiple transects, multiple individual tortoise home ranges, etc.) of the effects of a single project on a population can be considered replicates only if the conclusions are limited to the population of individuals exposed to that particular project (i.e., "project level"; see 2.1.c, below). However, to draw general conclusions about the effectiveness of the action (i.e., "action level"; see 2.1.c, below), the projects themselves are considered replicates, and although multiple observations within a project may increase the precision of measurement, only observations of additional projects are truly replicates that can be used to statistically assess the action.

2.1.c. Generality of results: Effectiveness at action and project levels

The effectiveness of recovery actions can be demonstrated at two levels: action level and project level. Action level refers to the broad area in which an action is applicable (e.g., all tortoise habitat can be subject to an action such as removal of grazing); project level refers to a specific place or study area (e.g., the Pilot Knob grazing allotment). To determine effectiveness at an action level, studies of the effects of the action must be conducted across a variety of conditions, with the action serving as the experimental unit (Hurlburt 1984). For example, a study of the effectiveness of 1 cm^2 hardware cloth used as a tortoise-proof fencing material can be conducted, and the results can then be generalized to any case in which conditions are expected to match those of the study. However, conditions at a project site may be sufficiently different from those of the original study so that the fencing material may work poorly; for example, the material may degrade and develop holes too rapidly, local populations may exhibit a different behavioral response to the material, or the material may clog with debris so that animals can climb over it. At a specific project level, then, the material may prove not to be effective. Conversely, studies of single projects can show that actions were effective under conditions present at the site, but may not generalize well to other circumstances. For example, studies of the effects of fencing at a single location with a single fence type, based on measurements of mortality at several locations within the fenced area, can yield reliable information about the effectiveness of that particular project, but the results may not generalize well to fencing as an overall recovery action, and thus may be weak evidence of effectiveness at the action level. As Pullin and Knight (2001) point out, results from several project-level studies can sometimes be combined (using a statistical technique called "meta-analysis") to demonstrate effectiveness across a variety of conditions, and collectively the results may form strong evidence of effectiveness at an action level.

2.1.d. Ecological level of effectiveness: Individual or population

Individuals die, mate, reproduce, and encounter barriers, whereas populations increase, decrease, or remain stable. Removal of threats that are known to impact individuals is a logical approach to species recovery, but whether reduction in individual impacts actually translates into increased population size depends on multiple factors (see section 2.3). Studies of individual impacts, therefore, can be well-designed and reliable, but not qualify as a demonstration of effectiveness at a population level. For example, experimental studies of effectiveness of barrier fencing at blocking tortoise movements and reducing tortoise road mortality may be highly reliable, but without additional data on changes in population size or demographic health of a fenced population, such studies cannot indicate effectiveness at the population level.

2.1.e. Sources of scientific information

Outlets for scientific information are numerous and diverse. Following the classification used by Boarman (2002), sources of information include (1) peer-reviewed open literature, (2) technical books, (3) theses and dissertations, (4) non peer-reviewed open literature, (5) technical reports, (6) unpublished data, (7) professional judgment, and (8) "science lore." The first major division among these sources of information is between information that is based on designed scientific studies (sources 1 to 5, possibly 6) and information that is based on personal opinion (sources 7 and 8). Sources 1 through 6 differ primarily in the degree of peer review. Peer review is the primary mechanism by which the quality of scientific information is judged and controlled. Though peer review is a highly individualistic exercise, reviewers are expected to evaluate whether the methods employed were appropriate, the samples sizes were adequate and the conclusions drawn follow logically from the experimental results. Although peer review does not guarantee quality, knowing that other experts have found the methods to be appropriate and that the conclusions are supported by the data substantially enhances confidence in a study, particularly if it is outside of one's area of expertise.

2.2. Desert tortoises have a life history that greatly complicates studies of the effectiveness of recovery

The most definitive evidence of the effectiveness of a recovery action is the demonstration that a population has recovered after an action was implemented. Although this level of support for recovery is desirable, desert tortoise managers frequently either will have to accept less stringent support for an action or be paralyzed by uncertainties. Demonstrating effectiveness of a recovery action is complicated by the life history of the desert tortoise. Tortoises are slow-growing and have delayed sexual maturity (Woodbury and Hardy 1948). Mortality, fecundity (summarized by Doak et al. 1994), physiology (Naegle 1976), and movements (Coombs 1977, Berry 1978) are all age and size dependent, yet younger, smaller tortoises are notoriously difficult to study (Berry and Turner 1986). Viability analysis requires large amounts of data, but the necessary parameters are rarely available for single populations that are exposed to a recovery action (Doak et al. 1994). Sensitivity of population growth to changes in demographic parameters varies by size class, and in desert tortoises, survival of older, reproductive individuals is most important for population growth (Doak et al. 1994). Consequently, reducing a threat to juveniles may have little effect on population recovery unless accompanied by a reduction in adult mortality (Congdon et al. 1993). Finally, tortoise populations grow slowly, and thus population-level responses to recovery actions may not be observed until many years after the action is taken, which is in sharp contrast with studies documenting threats (Boarman 2002). Many threats to tortoises, such as mortality and habitat damage, can be documented as they are occurring. It is often possible to observe immediate changes in levels of a threat after a recovery action is implemented (for example, tortoise-proof fencing should immediately reduce road mortality), but to document population-level recovery, data must be collected and analyzed for longer time periods. In this sense, it is intrinsically more difficult to measure the effectiveness of recovery actions on desert tortoises than it is to identify threats.

Another reason that documenting the effectiveness of recovery actions for desert tortoises is difficult is that they are subject to multiple threats simultaneously in many parts of their range, making the effectiveness of actions designed to address single threats difficult to gauge (Tracy et al. 2004). When multiple threats are affecting a population, removing a single threat will not increase the population size if other limiting factors remain; removing a single threat may be necessary to increase population size, but it alone may not be sufficient. As Leibig's Law of the Minimum (Huston 2002) states, a population will increase only to the point that the most limiting factor allows; consequently, removing a threat that is not the limiting factor will not increase the population size. Under these circumstances, the effectiveness and necessity of removing a single threat would be masked. For example, desert tortoise populations have continued to decline in the Desert Tortoise Natural Area (DTNA) in spite of perimeter fencing, with disease possibly being the leading cause of the decline (Berry 1997). The lesson from the DTNA is not that perimeter fencing was an unnecessary action, but that it was not sufficient in the face of other uncontrolled threats to the population. Similarly, the concept of compensatory mortality is commonly used in wildlife population biology to explain how mortality from harvesting can be sustained without reducing population size in a density-dependent population (Nichols et al. 1984). Under this paradigm, when animals die from human causes that would have died anyway from density-dependent natural causes, human-caused mortality is considered "compensatory" and will not reduce population size. Applied in the context of population recovery, compensatory mortality implies that if one mortality factor is removed there may be no net gain if other factors remain in place. Under both Leibig's Law and compensatory mortality, it is conceivable that a recovery action could reduce a threat without recovering the population. In either case, known threats should not be left in place. Multiple threats should be addressed simultaneously and as many threats as possible removed to affect population recovery.

Table 1 lists recovery actions that are commonly used or that have been proposed for use for desert tortoises. Many actions, such as fencing, affect multiple threats simultaneously (e.g., vehicle traffic and grazing), whereas other actions, such as predator control, are targeted at specific threats. For still other threats, such as disease, there currently are no recovery actions available to remove the threats, though preventative measures, such as safe handling procedures and public education, may be implemented (Berry 1997). Finally, threats may interact, such that removing anthropogenic threats could hypothetically reduce disease mortality by reducing stress on the tortoises.

Table 1. Recovery actions and the threats that these actions are expected to reduce or eliminate.

Action	Threat
Fencing (for animals)	Grazing, wild horses and burros, road mortality, wild dog or coyote mortality, utility corridors
Stocking level reduction	Grazing
Closures (to humans, seasonal or permanent)	OHVs, mining, military operations, agriculture, recreation, waste disposal, poaching, utility corridors, noise and vibrations
Habitat restoration	Grazing, OHVs, construction, mining, recreation, wild horses and burros, utility corridors, invasive plants, drought
Reduction of vehicle speed limits	Construction, mining, recreation, waste disposal
Translocation	Construction, mining, low population size or local extirpation, disease, military activities
Choosing prescribed burn season	Fire-caused mortality
Predator control	Mortality from feral dogs, ravens, or coyotes.
Feral animal control	Wild horses and burros, feral dogs
Law enforcement	Poaching, handling, collection, unauthorized OHVs
Culvert installation	Road mortality, population fragmentation
Land acquisition	Inadequate protection from many of the threats listed above

Taken together, the slow response of desert tortoise populations to recovery actions, along with the compounding effects of having multiple threats acting in concert or multiple recovery actions implemented simultaneously, make the effectiveness of individual recovery actions difficult to discern. These complexities should be taken into account when interpreting data, with sophisticated statistical methods used to isolate effects.

2.3. Demonstration of effectiveness and tortoise recovery relationships

It is important to define the goals of recovery actions so that their effectiveness can be assessed. For example, the recovery action of fencing the perimeter of the DTNA, which provides protection from OHVs and grazing and habitat destruction, is meant to maintain existing, fairly healthy populations. Successfully implementing actions and maintaining closed areas may be sufficient for success in this instance. In contrast, other recovery actions, such as habitat restoration and individual animal translocation, are meant to increase the size of a previously reduced population, and in these cases, success is judged by whether the population increases in response to the action.

Pullin and Knight (2001) describe a hierarchical system of judging the reliability of evidence of effectiveness based on study design criteria. For this current study, in addition to considering design issues, we also considered whether previous studies addressed individual-level effects or population-level effects. *Table 2* identifies the necessary assumptions in considering a result to be a demonstration of effectiveness of a recovery action, by combining both the reliability of studies and the level (individual vs. population) at which effectiveness is assessed. To illustrate, the intended outcome of fencing a road with hardware cloth designed to exclude tortoises is to increase the tortoise population by reducing road mortality. If the fence is constructed but the effects are not monitored, then confidence that the action is effective depends on (1) the assumption that road mortality is a real threat to tortoise populations; (2) that this mortality is the primary factor limiting a local tortoise population increase; and (3) that this recovery action effectively removes or reduces the limitation (Table 2, rows 2 and 3). If a declining incidence of road mortality is observed by follow-up monitoring, then fewer assumptions are needed to consider the fence effective. The action of fencing thus represents a step toward recovery only if road mortality was previously known, or can be assumed, to reduce the tortoise population in the first place (Table 2, row 3). If road mortality has been demonstrated to be associated with reduced tortoise populations, then confidence that reducing road mortality is necessary for recovery is increased (Table 2, row 4). However, this step alone may not be sufficient if other threats are limiting population recovery. Adding information about population size behind the fence increases confidence that the action has released the population from a limiting factor (Table 2, row 5). However, increases in population size could be due to changes in movements and immigration rather than to changes in mortality rates. Demographic monitoring can demonstrate that local mortality rates have declined, and estimates of the expected effects on population growth rate can be estimated (Table 2, row 6). The assumptions necessary to conclude that the fence has been effective become much less stringent, but might include the assumption that improvements in local demographic performance are contributing to local recruitment rather than to increasing emigration rates. If increased demographic performance is coupled with increased population sizes, then the only remaining assumption would be that the population is viable (Table 2, row 7). Finally, if the assumption that the population is viable is supported by a population viability analysis, this confirms that the population has recovered as a result of the action taken (Table 2, row 8).

Table 2. Relationship between observations of measures of effectiveness and the assumptions made.

[The rows are arranged in order of increasing reliability. Each successive row includes additional observations that more strongly support the effectiveness of an action. See section 2.3 for further explanation]

Observation	Assumptions needed to conclude action was effective
An action is implemented to address a putative threat, but effect is not observed	Putative threat is really a threat, is the limiting factor, and the action removes the limitation.
An action is implemented to address a known threat, but effect is not observed	Threat is the limiting factor, and the action removes the limitation.
Reduction or elimination of a putative threat	Putative threat is a real threat and is the limiting factor.
Reduction or elimination of a known threat	Threat is the limiting factor.
Increased population size	Increased numbers are due to improved demographic performance, rather than re-distribution of tortoises, changes in observability, etc.
Improved demographic performance	Assumes that the change in survival and/or fecundity will increase the population, rather than increasing emigration, etc.
Improved demographic performance and increased population size	Assumes that the improvements create a viable population.
Improved demographic performance, increased population size, and viable population (Population Viability Analysis, PVA, observations over time)	None (recovery is observed)

3. Methods

3.1. Kinds of information collected

Information was collected from a variety of sources. We searched peer-reviewed journals and books for studies that dealt with the effects of recovery actions on desert tortoises or with the effectiveness of recovery methods in general that might be applied to desert tortoise recovery. These included title and keyword searches in the BIOSIS Previews database (which covers materials published from 1969 to the present), and Web of Science searches for articles that cited papers dealing with desert tortoise recovery (coverage from 1975 to the present). We looked through all proceedings of symposia published by the Desert Tortoise Council, which is the primary source of scientific information about desert tortoise management. Additionally, Ed LaRue (U.S. Bureau of Land Management) visited biologists' offices at the U.S. Bureau of Land Management (BLM), the U.S. Fish and Wildlife Service (USFWS), the National Park Service (NPS), the California Department of Parks and Recreation, the U.S. Marine Corps, and the U.S. Navy, which are located throughout the Mojave Desert in California (*Table 3*). During these visits, biologists' files were examined, and two kinds of documents were obtained. The first type of document reported on scientific studies that could be used as support for the effectiveness of recovery actions. These included published articles, unpublished reports, and monitoring reports that were based on a designed sample (as opposed to qualitative observations). Reviewers of drafts of this current report suggested additional documents that could be used for support. These documents were assessed for reliability (see section 3.2 below). The second type of document detailed monitoring efforts at a particular management unit, such as memos and internal reports of permit compliance. These documents were not assessed individually, but were used as a measure of the observation effort expended on desert tortoises across the region. Ed LaRue also interviewed representatives at each office to determine whether any additional monitoring was conducted that would be useful that had not been documented or that was documented elsewhere (for example, by independent researchers conducting studies within the management unit). The entire bibliographic database of these documents is available in the U.S. Department of Interior, BLM files.

Table 3. Offices visited by E. LaRue for document collection, and key personnel providing assistance and verbal input.

Agency, City	Key Personnel Providing Input
Bureau of Land Management, Barstow	C. Sullivan, A. Chavez, C. Burns
Bureau of Land Management, Needles	G. Meckfessel, K. Allison, L. Smith
Bureau of Land Management, Ridgecrest	J. Aardahl, B. Parker, J. McEwan
California Department of Parks and Recreation	M. Faull
U.S.Marine Corps, Marine Corps Air-Ground Combat Center	R. Evans, B. Husung
U.S. Navy, China Lake	T. Campbell
U.S. Air Force, Edwards Air Force Base	M. Hagan
U.S. Army, Fort Irwin	M. Quillman
National Park Service, Joshua Tree National Park	A. Fesnock, C. Collins
U.S. Fish and Wildlife Service, Carlsbad	M. McDonald, D. Miles
U.S. Fish and Wildlife Service, Ventura	R. Bransfield

3.2. Document assessment

For each document collected, we recorded the kind of action taken, following categories described by Boarman (2002), and the findings and conclusions of the study. Documents reporting on designed studies were evaluated for reliability and on whether the individual study assessed the “project” or the “action” level of effectiveness. Reliability of the study results was assessed by determining whether the following tenets of experimental design were included in the study: experimental manipulation, use of controls, and replication. The level of effectiveness assessed by a study was determined by observing the replication level (project, action) and the level at which the observations were made (e.g., individual tortoises, tortoise populations, tortoise habitat). Some documents reported on more than a single measure of effect (e.g., effects of grazing on diet breadth and on population size), and thus the number of documents evaluated was less than the number of studies. Multiple documents could be produced from studies of a single population over time. To avoid inflating the document count, we evaluated only final reports, when available, or the most recent draft reports from long-term studies. Follow-up studies were considered separate studies (for example, studies at grazing exclosures in the Ivanpah Valley that were separated by 10 years were considered two different studies).

3.3. Kinds of information not evaluated

We concentrated on studies related to changes following a recovery action so as not to repeat Boarman's (2002) analysis of threats; thus, reports of tortoise mortalities due to known threats were not evaluated. Furthermore, we did not evaluate popular articles, information circulars, and pamphlets because they were intended as interpretive tools for the general public and therefore did not present new results that would be useful to our efforts. Finally, for logistic reasons, we limited our search of offices to California. Although documents were collected regardless of study location, papers and reports from Nevada, Arizona, and Utah are underrepresented in our sample.

4. Results

4.1. Kinds of information available

Of the 395 documents obtained in our search of biologists' files and published literature, 151 were directly relevant to recovery actions. Of these, 45 were reports of designed studies and 104 were other kinds of relevant information (*Table 4*), such as permit compliance reports, letters, memos, and other materials that dealt with implementation of recovery actions. Several of these 45 documents addressed more than one treatment or more than one measure of effectiveness, such that we assessed 54 measures of the effectiveness of recovery actions (*Table 5*). Although not designed as an exhaustive enumeration of the individual study materials found, collected data indicate little information on implementation of recovery actions arising from designed scientific studies. This impression was further reinforced by interview data that showed that many agency biologists knew that recovery action implementation was occurring without any follow-up monitoring.

On the basis of Boarman (2002), we selected several significant issues related to desert tortoise recovery. These are listed in sections 4.2 through 4.9 below, along with (1) a description of the related management actions; (2) an assessment of the strength of the evidence that the actions are effective in reducing threats; and (3) a discussion of the limits to our current knowledge on the subject.

Table 4. Numbers of documents found in biologists' files pertaining to recovery actions that were either designed studies, or other forms of information.
[See Table 5 for list of documents of designed studies]

Topic	Other documents	Designed study	Total
Construction compliance	30	4	34
Grazing	15	5	20
Guzzlers	1		1
Habitat change	1		1
Habitat restoration	7	2	9
Headstarting		1	1
OHV closure	14	3	17
OHV route marking	8	14	22
Perimeter fence	8	1	9
Predator control	1	1	2
Reserve establishment		3	3
Road closure	1		1
Shooting	1		1
Tortoise fencing	2	5	7
Translocation	15	6	21
Total Result	104	45	149

Table 5. Characteristics of assessed documents.

[Explanations of terms are in text. OHV = off-highway vehicles, Observ. = Observation, Exper. = Experimental]

Author	Action	Measure	Finding	Study type	Replication	Replication level	Control
Avery 1998, Avery and Neibergs 1997	Exclude grazing	Habitat	Positive	Exper.	Replicated	Project	Yes
	Exclude grazing	Tortoises	Positive	Exper.	Replicated	Project	Yes
Baxter 1986	Translocation	Homing	Negative	Exper.	Replicated	Project	No
Berry et al. 1999	Fencing reserve	Population	Positive	Observ.	Replicated	Project	Yes
Boarman and Sazaki 1996	Tortoise fencing	Tortoises	Positive	Exper.	Replicated	Project	Yes
	Tortoise fencing	Population	Positive	Exper.	Replicated	Project	Yes
Bowser et al. 1997	Restore habitat	Habitat	Positive	Exper.	Unreplicated		No
Brooks 1995	Fencing reserve	Habitat	Positive	Exper.	Replicated	Project	Yes
Burge 1986	Post routes	Habitat	Negative	Observ.	Replicated	Project	Yes
Bury and Luckenbach 2002	OHV	Habitat	Positive	Observ.	Replicated	Project	Yes
	OHV	Tortoises	Positive	Observ.	Replicated	Project	Yes
Campbell 1981, 1985	Fencing reserve	OHV use	Positive	Observ.	Replicated	Project	Yes
	Fencing reserve	Shooting	Positive	Observ.	Replicated	Project	Yes
	Fencing reserve	Hunting	Positive	Observ.	Replicated	Project	Yes
Circle Mountain Biological Consultants 1994	Post routes	Tortoises	Positive	Observ.	Replicated	Project	No
	Post routes	Burrows	Positive	Observ.	Replicated	Project	No
	Post routes	Habitat	Positive	Observ.	Replicated	Project	No
EnviroPlus Consulting 1995	Tortoise fencing	Tortoises	Positive	Exper.	Replicated	Action	Yes
Everett et al. 2001	Predator control	Capture rate	Negative	Exper.	Replicated	Project	No
Field et al. 2002	Translocation	Survival	Positive	Exper.	Replicated	Action	Yes
	Translocation	Tortoises	Uncertain	Exper.	Replicated	Project	Internal
Fusari et al.1981	Tortoise fencing	Tortoises	Positive	Exper.	Replicated	Action	No
Goodlett and Goodlett 1993	Post routes	OHV use	No effect	Observ.	Replicated	Project	Yes
Guyot and Clobert 1997	Tortoise fencing	Tortoises	Positive	Exper.	Replicated	Project	No
	Translocation	Tortoises	Positive	Exper.	Replicated	Project	No
Kazmaier et al. 2001	Exclude grazing	Population	No effect	Exper.	Replicated	Action	Yes
	Exclude grazing	Tortoises	No effect	Exper.	Replicated	Action	Yes
Kutiel 1999	OHV	Habitat	Positive	Observ.	Replicated	Project	Yes

Table 5. Characteristics of assessed documents–Continued.

[Explanations of terms are in text. OHV = off-highway vehicles, Observ. = Observation, Exper. = Experimental]

Author	Action	Measure	Finding	Study type	Replication	Replication level	Control
Larsen et al. 1997	Exclude grazing	Habitat	Uncertain	Exper.	Replicated	Project	Yes
LaRue and Dougherty 1999	Construction	Tortoises	Positive	Observ.	Replicated	Meta analysis	No
Medica 1994a	Post routes	Habitat	Negative	Observ.	Replicated	Project	Yes
Medica 1994b	Post routes	Habitat	Negative	Observ.	Replicated	Project	Yes
Medica et al. 1982, Turner et al. 1981	Exclude grazing	Habitat	Uncertain	Exper.	Replicated	Project	Yes
	Exclude grazing	Tortoises	Positive	Exper.	Replicated	Project	Yes
Miller-Allert 2000	Post routes	Habitat	Mixed	Observ.	Replicated	Project	No
Miller-Allert 2001	Post routes	Habitat	Mixed	Observ.	Replicated	Project	No
Morafka et al. 1997	Protect hatchlings	Hatchling survival	Positive	Exper.	Replicated	Project	Yes
Mullen and Ross 1996	Translocation	Tortoises	Positive	Exper.	Replicated	Project	Yes
Musser 1983	Post routes	Habitat	Positive	Exper.	Replicated	Project	No
Nicholson and Humphreys 1981	Exclude grazing	Habitat	Negative	Observ.	Unreplicated		Yes
Olson 1996	Construction	Tortoises	Uncertain	Observ.	Unreplicated		No
Olson et al. 1992	Construction	Survival	Mixed	Observ.	Replicated	Project	No
Ruby et al. 1994	Tortoise fencing	Tortoises	Positive	Exper.	Replicated	Action	Internal
Sazaki et al. 1995	Tortoise fencing	Tortoises	Positive	Observ.	Replicated	Project	No
Stewart 1993	Translocation	Weight change	Positive	Exper.	Replicated	Project	Yes
	Translocation	Survival	Positive	Exper.	Replicated	Project	Yes
Stewart and Baxter 1987	Translocation	Survival	Positive	Exper.	Replicated	Project	No
BLM 1984	Post routes	Habitat	Mixed	Observ.	Replicated	Project	No
Walker and Mastin 1999	Post routes	Habitat	Positive	Observ.	Replicated	Project	Internal
BLM 2000a	Post routes	Habitat	Mixed	Observ.	Replicated	Project	No
BLM 2001b	Post routes	Habitat	Mixed	Observ.	Replicated	Project	No
BLM 2002	Post routes	Habitat	Mixed	Observ.	Replicated	Project	No
Woodman 1986	Post routes	Habitat	Negative	Observ.	Replicated	Project	No
	Post routes	Tortoises	Positive	Observ.	Replicated	Project	No

4.2. Reserves

4.2.a. Actions

Dedicated reserves are areas in which public access is controlled or eliminated, and in which management is directed solely to protection of the desert tortoise. Establishment of dedicated reserves provides increased protection for tortoise populations against multiple threats (e.g., OHVs, mining, military operations, agriculture, etc.; *Table 1*). The 1994 USFWS Desert Tortoise Recovery Plan emphasized effectively protecting large areas containing healthy tortoise populations as a significant recovery action. Protecting habitat is perhaps the least controversial action from an ecological perspective, in the sense that a species' dependence on suitable habitat for persistence is true by definition. However, design of a reserve is a complex issue, requiring a great deal of basic information on life history, ecology, and population genetics of the species. A great deal of research effort has been expended to build the necessary knowledge base for successful reserve design; reviewing this information was beyond the scope of this report. Landscape-scale planning is proceeding (Tracy et al. 2004), but the effectiveness of an entire reserve network ultimately is judged by the recovery of a species. At a finer scale, the effectiveness of a reserve network depends on the effectiveness of its components at maintaining populations, and at this scale, data on effectiveness are available.

Before completion of the recovery plan, the DTNA (established in 1980) was the only dedicated reserve for desert tortoises and has been the focus of intensive study. Much is known about the tortoise population, habitat, and behavior there (Berry 1997, Brooks 2000). Reserve fencing and patrolling of the DTNA perimeter has reduced human use of the area, and thus reduced threats such as shooting and unauthorized OHV travel within its boundaries (Campbell 1981). Fencing of the reserve has also reduced unauthorized livestock grazing and improved tortoise habitat characteristics (Brooks 2000). In addition, it has increased (1) annual and perennial plant biomass, cover, and diversity of natives, (2) soil seed biomass, (3) nocturnal rodent density and diversity, (4) breeding bird abundance and species richness, and (5) lizard abundance and species richness (Brooks 1992, 1995, 1999a, 1999b). Fencing also has decreased (1) biomass of alien annual plants, and (2) an abundance of black-tailed hares (*Lepus californicus*). The DTNA perimeter fence is not tortoise-proof, so individuals that move outside of the reserve are still subject to impacts.

The DTNA illustrates two vexing points about measuring the effectiveness of recovery. First, it is impossible to assess the relative effects on tortoises of each of the several changes that occurred in the DTNA as a result of establishing it as a reserve. A change in population size could be attributed to the "treatment effect" of fencing, but the relative contribution of factors such as reduced grazing versus reduced OHV use could not be determined without additional studies that isolate these effects. Second, although there are no known detrimental effects of establishing reserves, the tortoise population in the DTNA has, in fact, declined (Berry et al. 1999). Uncontrolled threats, such as disease, drought, and predation, may explain this paradoxical outcome (Berry 1997). Similarly, following establishment of the Red Cliffs Desert Reserve within the Upper Virgin River Recovery Unit, Utah, in 1996, tortoise populations were stable for several years (McLuckie et al. 2002). However, after a drought year in 2002, tortoise populations declined by 40%. This population has also been subject to URTD infection, which may have contributed to the decline in numbers (K. Berry, pers. comm.). These two well-studied cases demonstrate the complexities of studying population responses to multiple factors. These declines in the tortoise population have made it difficult for researchers to use the DTNA as evidence of the general importance of establishing reserves.

4.2.b. Limits to our knowledge

Of all of the recovery actions taken, establishing reserves is the one most likely to receive unanimous agreement among biologists as an appropriate measure to undertake. Experiences at the DTNA and Red Cliffs have shown that even the best-supported practices can fail to produce the expected result if other threats are not controlled. Reserves theoretically have the advantage of simultaneously reducing multiple threats, but inferences about the importance of particular threats and the effects of implemented actions to address these threats can be difficult. Furthermore, whether desert tortoise reserves protect isolated populations and/or function as part of a network of interacting populations is not currently known.

Table 6. Possible threats to desert tortoises (from Boarman 2002), strength of the supporting evidence, and best-supported possible impacts.
[OHV, off-highway vehicle; NA, not available]

Individual threats	Strength of evidence	Best supported possible impact
Agriculture	Weak	Habitat loss
Collecting	Weak	Direct mortality[1]
Construction	Strong	Habitat loss, burrow damage, direct mortality
Disease	Weak	Direct mortality
Drought	Weak[2]	Dehydration, predation[3]
Energy and mineral developments	Strong	Habitat loss, direct mortality during construction
Fire	Strong	Habitat loss, habitat degradation, direct mortality
Garbage and litter	Weak	Direct mortality
Handling and deliberate manipulation	Weak	Water loss
Invasive plants	Strong	Habitat degradation[4]
Landfills	Strong	Direct mortality[5]
Livestock grazing	Strong	Direct mortality[6], burrow damage[7], habitat degradation[8], food competition
Military operations	Strong	Habitat loss, direct mortality
OHV	Strong	Reduced tortoise density, habitat degradation, direct mortality, soil compaction, soil erosion
Predation/raven predation/subsidized predators	Strong[5]	Direct mortality
Non-OHV recreation[9]	NA	NA
Roads, highways, and railroads	Strong	Habitat loss, habitat degradation, direct mortality, population fragmentation
Utility corridors	Strong	Habitat loss, direct mortality, increased predation risk[10]
Vandalism	Strong[11]	Direct mortality
Wild horses and burros	Unstudied	

[1]Removal of animals from the population (functional mortality, if not actual mortality).
[2]Tortoises are expected to be adapted to drought, but it may make them more susceptible to other stressors.
[3]Coyotes may increase predation on tortoises as preferred prey become less common.
[4]That grasses are less nutritious than forbs is well established, but the effects of introduced grasses on tortoise habitat quality and population size is less well studied.
[5]Increased raven numbers and increased risk of raven predation are well-established. Consequences of raven predation to tortoise population size are less well-studied.
[6]Few mortalities observed, but damage to styrofoam tortoise models indicates rates can be high.
[7]Rates of burrow damage depended on tortoise size, with juvenile and immature burrows more susceptible to damage than adult burrows.
[8]Changes in soils and in vegetation structure and composition.
[9]Largely unstudied as a group, though several possible activities (such as target shooting) are included in other categories.
[10]Transmission towers may facilitate raven population growth in areas previously lacking nesting substrates.
[11]That tortoises are killed is well supported, but the population-level consequences are not known.

4.3. OHV use

4.3.a. Actions

Boarman (2002) identified several studies that measured impacts of OHVs on desert habitat; he cited the study by Bury and Luckenbach (1986) as the best evidence of the impacts of OHVs on tortoise density. This work has now been published (Bury and Luckenbach 2002). Although both habitat damage and direct mortality may occur, habitat damage is the most strongly established effect (Boarman 2002). Evidence that OHVs are a threat to desert tortoises is therefore considered strong because of well-documented alterations to tortoise habitat (*Table 6*). The relative importance of direct mortality and habitat alteration is not well understood, however, and cannot be inferred from Bury and Luckenbach (2002). Studies of response by desert tortoise populations following the exclusion of OHV use from an area were not found.

If habitat damage is the primary cause of reduced densities of tortoises in these referenced instances, then the slow recovery of desert plant diversity (Lovich and Bainbridge 2003) may make such studies impractical. Habitat restoration may be applied in damaged areas, however. Recent applied restoration strategies are showing promise in accelerating desert vegetation recovery, such that post-restoration tortoise responses may be observed in experimentally tractable time periods (T. Egan, pers. comm.).

Although we did not find studies of the before and after effects of OHV closures on tortoises, several studies were found that examined the relative effectiveness of Federal agency permitting and relevant resource management plan (RMP) requirements, such as vehicle route designation, for minimizing impacts of competitive races on tortoise habitat (Musser 1983; Woodman 1986; Burge 1986; U.S. Bureau of Land Management 1984, 2000a, 2001a; Goodlett and Goodlett 1993; Circle Mountain Biological Consultants (CMBC) 1994; Medica 1994a,b; Walker and Mastin 1999; Miller-Allert 2000, 2001; Sullivan 2002). These studies are only indirectly related to the effects of OHV "free-play" areas, but they provide examples of a before/after design that yielded detailed information about impacts of OHVs on these areas. Although only Woodman (1986) and Circle Mountain Biological Consultants (1994) stated that they searched for dead desert tortoises, all the referenced studies were conducted in a way that such mortalities could have been detected (i.e., either pre- and post-event surveys were done, or monitors were present on race day). Although the experience of personnel monitoring tortoise habitat for these studies varied considerably, no injured or dead tortoises were detected. All the studies assessed habitat damage, in the form of either route widening, new OHV track formation, or damage to vegetation adjacent to established routes.

Although some form of damage was observed in all studies, the actual amount reported differed substantially. For example, Federal agency monitoring of the 1983 Barstow to Vegas motorcycle race (U.S. Bureau of Land Management 1984) showed minimal change in vegetation occurring in 22 plots. In contrast, Medica (1994a) found approximately one damaged shrub per 60 m of race event course in one transect, for an estimated 225 shrubs damaged during one particular event. Course widening and new tracks along posted routes were commonly observed in all reports evaluated. Explanations for race entrants straying from the designated route included (1) poor route marking (particularly at sharp turns or at unauthorized trails connected to the official race event); (2) lack of race monitors; (3) race vehicle passing; and (4) "silt avoidance" by event riders, who moved to more solid, outer portions of a route once its interior became unstable. Several referenced reports cited problems with permit compliance by event spectators (Medica 1994b). Compliance with event-use limitations generally was good when vehicle routes were well-posted and the Federal agency established some form of presence. Problems reported for the most recent events (U.S. Bureau of Land Management 2000a) were similar to those reported for earlier events. Interpretation of damage resulting from race events was completely subjective, based only on authors' personal judgment (that is, they did not refer to a standard for how much damage is acceptable; to our knowledge, no such standard exists).

The effectiveness of route network reductions, area closures and completed route designations as a means of reducing inappropriate OHV traffic has also been studied. One such study, conducted in Israel (Kutiel 1999), involved comparing the development rate of vehicle and pedestrian tracks in protected and unprotected areas over a 50-year period; the comparison was based on air photo interpretation techniques. Reported results indicated that the rate of change in track length per square kilometer was four times greater in the unprotected area than in the protected area. The number of "area cells", or habitat areas between tracks, increased in number geometrically in the unprotected area but increased linearly in the protected area, indicating rapid habitat fragmentation in the unprotected area. Consequently, the number of area cells in the unprotected, non-designated area increased with time as their size decreased. A similar approach was taken by Matchett et al. (2004) in a study of the Dove Springs Open Area in the western Mojave Desert, although comparisons were limited to change over time with no comparison with the closed area. Matchett et al. (2004) reported that track densities continued to increase from the 1960s through the 2000s within this area of unlimited OHV use. This increase was highest between 1965 and 1982 when OHV recreation began to dramatically increase; the increase continued through 2001. The total length of OHV routes increased from 49 to 576 km between 1965 and 2001, and the amount of land exhibiting some form of OHV disturbance increased from 7 to 30%. In addition, heavy OHV use did not stop at the boundaries of the Open Area, but spread into surrounding public land managed as "limited use," where vehicles were supposed to stay on designated routes. The most concentrated OHV use occurred near large washes and utility rights-of-way.

In another study of route network formation conducted within desert tortoise habitat, Goodlett and Goodlett (1993) found that posted, but unrestored closed areas in Rand Mountain and Fremont Valley, Calif., had similar numbers of new vehicle tracks as the unposted areas closed to vehicle use. In addition, the number of OHV tracks observed increased with proximity to open vehicle-use areas, suggesting that posted vehicle route closures alone were not effective at eliminating all unauthorized OHV use. In contrast, the regularly maintained perimeter fence at the DTNA has been effective at reducing OHV use (Campbell 1985). It should be noted, however, that the relatively longer-term effectiveness along the DTNA fence-line came about only after an initial period when vandalism was high and that maintenance of the fence continued until the vandalism problem subsided. Further, all the above instances were aimed at understanding route network development, and whether the level of the threat or impact could be reduced; the effects of threat reduction on wildlife populations were not assessed.

Restoration of routes may further reduce unauthorized use of closed areas by obscuring the route from view (Egan 2000). A rapid, inexpensive process called "vertical mulching" has been proposed (U.S. Bureau of Land Management 2001b) for closed route restoration in desert tortoise and other special status species' habitats (National Applied Research Science Center 2000). Vertical mulching involves placement of boulders and vegetation (living or dead) across a closed route so that it visually blends in with the surrounding landscape. The *West Mojave Route Designation, Ord Mountain Pilot Unit, Biological Resource Screening Components* (U.S. Bureau of Land Management 1997) identified route closure as a high-priority objective, and the U.S. Fish and Wildlife Service (2001) concurred with the BLM that vehicle route designation and closed route restoration using "vertical mulching" as outlined above would not adversely affect, and might benefit, the federally listed desert tortoise and the Ord-Rodman Critical Habitat Unit. Egan (2000) reports that the BLM has demonstrated that this technique can be economically implemented, although tests of its effectiveness were not cited.

4.3.b. Limits to our knowledge

Although it is logical to conclude that excluding or restricting OHV use will reduce damage to tortoise habitat and that higher-quality habitat will promote healthier populations, we did not find any studies that removed only OHV use before measuring responses of a desert tortoise population. Several of the studies we identified may be prime candidates for further research by removing OHVs then measuring tortoise responses, particularly since a number of years have passed since actions were initiated in these areas such as the actions at the Ord Mountain Project (U.S. Bureau of Land Management 2000b, 2001b).

There is correlative evidence that OHV use and dirt road densities promote exotic plant invasions (Brooks 1999b, Brooks and Esque 2002, Brooks and Berry accepted), but whether excluding OHVs prevents invasions in impacted areas has not been studied. Studies comparing the rates of exotic plant invasion in open areas, in impacted areas that have been closed, and in areas that have not been impacted by OHV use would be valuable.

We also did not find any studies that tested whether measures reducing OHV use, short of complete area closures, are effective at recovering desert tortoise populations. It is relatively well-established (Boarman 2002) that unrestrained OHV use over time reduces tortoise densities; however, no studies were found that test how much habitat loss to OHV use can be sustained by the species, or whether limited vehicle use is less destructive than unrestricted use to desert tortoise habitat. Lacking such studies, it is difficult to extrapolate what is currently known to a population level. For example, monitoring requirements for race events have produced a relative wealth of information about the effectiveness of vehicle route marking for protecting tortoises and habitat. However, although some degree of habitat damage was observed in all cases, different investigators reached different conclusions about the extent and acceptability of the damage. Population-level studies would be needed to determine how much damage a tortoise population could withstand if objective criteria for acceptable damage are to be devised.

4.4. Grazing

4.4.a. Actions

Boarman (2002) identified several ways in which cattle grazing impacts tortoise habitat, particularly near water sources (*Table 6*). Sheep grazing, on the other hand, has hardly been studied (Nicholson and Humphreys 1981). Direct impacts of livestock grazing to tortoises have not been well-documented, and little research has been conducted on the effectiveness of grazing restrictions on tortoise populations. We found only one case (in the Ivanpah Valley of California) in which researchers removed cattle and then tracked changes in tortoise populations (Turner et al. 1981, 1985; Avery and Neibergs 1997). Turner et al. (1981, 1985) found no differences in plant species composition within and outside an exclosure in the 2 years following cattle removal. Plant biomass was greater in grazed areas than in ungrazed areas. No differences in home range size or number of clutches between tortoises in grazed and ungrazed areas were found in this instance, suggesting that cattle grazing has no effect on tortoises or tortoise habitat. However, there are three reasons to be cautious about this literal reading of Turner et al.'s results. First, this study utilized only one exclosure and one comparison plot, which makes comparisons at the level of the action tenuous. Second, the above study was conducted over the 2-year period following exclosure, and although they did concentrate on measurements that would be expected to respond quickly to removal of cattle, such as cover of annuals and tortoise reproductive output, the study duration may have been too short for a slowly recovering vegetation type and a slowly growing population of tortoises. Third, this study reported that grazing intensity declined substantially as the exclosure was being established, so that the grazed plot was not heavily grazed at any time during the study. It is thus questionable as to whether their findings can be applied to real-life allotments where grazing levels may be consistently high for extended periods.

Between 1991 and 1993 Avery and Neibergs (1997) and Avery (1998) studied the same cattle exclosure established 10 years earlier by Turner et al. (1981, 1985). This more recent study found greater cover of *Hilaria rigida*, a palatable perennial grass, where cattle were excluded, as well as increased desert dandelion (*Malacothrix glabrata*), whereas grazed areas had more compacted soils. In addition, 50% of actively-used burrow entrances were damaged by grazing cattle, which contributed to a 2.5-fold increase in tortoises remaining above ground overnight. Although predation rates were not measured, burrows are thought to provide tortoises protection from predators, and predation risk may have been greater in grazed areas as a consequence. Dead or dormant *Ambrosia dumosa* were more common in grazed plots. Unpalatable shrubs, such as *Hymenoclea salsola* and *Larrea tridentata* were favored by grazing; *L. tridentata* had greater canopy areas, aboveground volumes, and estimated biomass, and *H. salsola* was also more abundant in grazed areas. Furthermore, diet composition overlapped between tortoises and cattle in the late spring when forage dried out, suggesting that these two herbivorous species may compete for food at these times. Conclusions drawn in Avery and Neibergs' study are similarly restricted because of a lack of replication at the action level. Although the study did extend the timeframe for recovery from 2 to 12 years, they still were not certain that enough time had passed for plant or animal population recovery to be detected.

Larsen et al. (1997) studied exclosures that had been established for long periods. Two exclosures were located at an abandoned gunnery range (time of closure not reported); a third exclosure had been closed since the early 1940s. Livestock grazing outside of the exclosures was reported to be "light" to "moderate," though the moderate livestock-use sites had been recently rested for 2 to 6 years. Changes in vegetation were small and idiosyncratic, with no clear, consistent effect of livestock grazing apparent. No differences in soil compaction or abundance of tortoises or tortoise sign were observed. Although the study included replicate sites, grazing intensity was not quantified, and site-specific differences dominated the results. Additionally, these results were preliminary, and the authors considered definitive conclusions to be unwarranted.

Studies at the DTNA provide some insight into the effects of sheep grazing. Although fenced exclusions of livestock also excluded OHV use of the area, the observed increases in annual plant biomass (Brooks 1995, 1999b) and soil seedbank densities (Brooks 1995) inside of the DTNA were likely due to protection from forage utilization by livestock.

Livestock activity and their effects are often concentrated around watering sites. In a study of nine watering sites at the Pilot Knob Grazing Allotment in the central Mojave Desert, Brooks et al. (accepted) documented patterns of vegetation responses that are useful in developing management plans for watering sites. These authors found that absolute and proportional cover of alien annual plants increased with proximity to watering sites, whereas cover and species richness of native annual plants decreased. Not all alien species responded the same: the alien forb Erodium cicutarium and the alien grass Schismus spp. increased with proximity to watering sites, whereas the alien annual grass Bromus madritensis ssp. rubens decreased. Perennial plant cover and species richness also declined with proximity to watering sites, as did the structural diversity of perennial plant cover classes. Significant effects of livestock activity were focused within 200 m of the watering sites, suggesting that efforts to control alien annual plants and restore native plants should optimally be focused within the central part of the disturbance gradient.

4.4.b. Limits to our knowledge

Livestock grazing-related impacts to desert tortoise habitat are well-established, but whether there is a threshold stocking level below which tortoise populations are unaffected is not known. Larsen et al. (1997) did not find grazing effects at three sites with light to moderate cattle grazing, but without more careful quantification of the grazing level this result should be considered suggestive rather than confirmatory. The question –whether there is a threshold stocking level– is complicated by the fact that impacts of livestock presumably vary annually with changes in precipitation and primary productivity (Avery 1998). When tortoise populations are low and forage is abundant, livestock grazing may have little or no effect on tortoises. But, when forage is less abundant, livestock and tortoises may be forced to compete. Additional research is needed to establish whether limited livestock grazing can be done without detrimental effects on desert tortoises. Studies of other species may be of limited use for desert tortoise management. Kazmaier et al. (2001) studied the effects of grazing on the Texas tortoise and found no effects of grazing on growth or survival of this species. However, they expressed reservations about extrapolating the results of their study to desert tortoises and the more arid, low-productivity environments of the Mojave Desert. A recent synthesis of the grazing literature by The Nature Conservancy reached similar conclusions (The Nature Conservancy 2005) about the lack of information needed to set environmentally safe grazing regulations in the Sonoran Desert, and recommended more research into the efficacy of ephemeral allotments, based on seasonal patterns of rainfall and plant growth.

4.5. Road mortality and barrier fencing

4.5.a. Actions

Tortoise mortality along unfenced roads has been well-documented (Boarman 2002). Reduced densities of tortoises along roads suggest that road mortality is sufficient to affect population sizes (von Seckendorff Hoff and Marlow 2002). The size classes of tortoises killed by traffic include larger, reproductive individuals (Boarman et al. in prep.) which are most important for population viability in this species (Doak et al. 1994). Support for considering roads a threat to desert tortoises, therefore, is strong at the individual and population levels (*Table 6*).

Boarman and Sazaki (1996) compared fenced and unfenced sections of Highway 58 and found that fencing with tortoise-proof materials reduced the number of road-killed tortoises by 93% (Boarman and Sazaki 1996). Radio-transmittered tortoises making long-distance movements were not able to cross the fence (Sazaki et al. 1995), supporting the interpretation that reduced road kill was due to the reduction in tortoises crossing the road, rather than to a difference in population density between fenced and unfenced areas. A similar reduction in the incidence of road kill was observed in a study of the Hermann's tortoise in southern France (Guyot and Clobert 1997), which further supports the overall effectiveness of fencing for reducing tortoise mortality.

The major criticisms of fencing are that it fragments populations into smaller units that are more prone to local extinction, and it genetically isolates tortoise populations. Isolation is a risk to long-term viability as it may reduce the genetic diversity within the species. As a solution to this problem, culverts have been used in combination with fencing to allow tortoises to disperse safely (*Table 1*). Fusari et al. (1981) and Fusari (1985) found that tortoises use culverts made of corrugated steel or panelboard in combination with barrier fences under experimental conditions. Boarman et al. (1998) found that desert tortoises use existing culverts running under Highway 58 that are associated with fenced sections of highway. It is unlikely that tortoises preferentially use culverts in the absence of barrier fencing, but in concert with fencing projects they may prove effective at allowing some degree of movement across roads without excessive risk of mortality.

Effectiveness of different kinds of fencing materials has been studied under controlled experimental conditions (Fusari 1985, Spotila et al. 1993, Ruby et al. 1994, EnviroPlus Consulting 1995). These studies generally support the use of 1-cm hardware cloth as fencing material (EnviroPlus Consulting 1995 recommended 1×2 inch welded wire). Tortoises were less likely to fight against this material than materials with larger mesh sizes because they were able to see that the hardware cloth formed a barrier. Solid barriers also prevented tortoises from struggling against the fence, but discouraged them from moving along the barrier to find openings. Hardware cloth appeared to balance the need to provide a visual stimulus to encourage searching for passage through the fence, and the need to prevent tortoises from wasting time trying to breach, and possibly becoming ensnared in, the barrier.

4.5.b. Limits to our knowledge

Fencing reduces the incidence of tortoise road kills, but it is not known whether this protection is sufficient to recover the population. Analysis of distances of marked tortoises from a fenced section of Highway 58 (Boarman, unpubl. data) reveals that tortoise numbers near the road increased slightly between 1991 and 1997, but then declined again in 1998. Whether this was the beginning of a full recovery is not known, as insufficient time had elapsed to draw such a conclusion. Also, interpretation of results is complicated by other possible effects of roads that are not controlled by fencing, such as increased predation risk and exotic plant invasion. Future studies should attempt to quantify these effects to properly account for them in judging the success of individual recovery efforts. Furthermore, fencing is expected to isolate populations compared with unfenced, roadless areas, but it is not known whether fences increase isolation of tortoise populations compared with unfenced sections of road. Roads, particularly heavily traveled ones, are already a barrier to movements, so this is an empirical, not a theoretical, question. Mortality is logically expected to increase with traffic volume and vehicle speeds, but this has not been tested with tortoises. The thresholds for which roads become safe for tortoise populations are not known.

The culverts that are put in place to alleviate the isolating effects of fences and roads may carry their own element of risk to tortoises. Culverts are used not only by tortoises, but by a variety of species, including those that are potential threats to tortoises (e.g., dogs, coyotes, people; Boarman unpubl. data). Additional research is necessary to determine whether the risk of predation is elevated at culverts, as well as to quantify the population-genetic benefits of culverts so as to determine if any such benefits are outweighed by risk of mortality. At this time, no studies of population-level effects of culvert use have been conducted that would help select roads needing culverts and the culvert densities required.

Roads can also have direct local, indirect local, and dispersed landscape effects on ecosystems (Brooks and Lair 2005). Most studies of the effects of roads on desert tortoises have focused on their direct effects (e.g., mortality), whereas most management decisions related to roads (aside from fencing) are focused on determining acceptable densities per unit area as it related to habitat fragmentation. Future research on the ecological effects of roads needs to focus on their dispersed landscape effects to best match the needs of land managers.

4.6. Mortality from construction activities

4.6.a. Actions

Construction activities have a variety of effects on individual tortoises, tortoise habitat, and tortoise populations (Boarman 2002; *Table 6*). Direct habitat loss, mortality, burrow damage, and fugitive dust have all been identified as possible problems (Boarman 2002). As part of their compliance with the Federal ESA, agencies and entities that are undertaking construction projects where desert tortoises are likely to be killed operate under the provisions of section 7(a)(2) consultations or section 10(a)(1)(B) permits; in both cases, project proponents are required to report any tortoises that are killed during construction operations. These reporting requirements have generated information about both the impacts of construction and the effectiveness of terms and conditions.

Actions designed to minimize the impacts of construction activities are specified in biological opinions (BOs), along with required compliance reporting. Measures imposed are a heterogeneous mix and include fencing of construction areas and roads, physically moving tortoises out of harm's way, conducting on-site biological monitoring, implementing reduced vehicle speed limits at construction sites, and others. These measures are primarily aimed at preventing tortoise mortality during construction (*Table 1*). Biological opinions and incidental take permits attempt to anticipate the number of desert tortoises that may be killed during implementation of the project, and the number of animals killed during construction is reported by the permittee. LaRue and Dougherty (1999) analyzed 171 BOs that had been implemented in California or Nevada, and found a small fraction of the number of tortoises that could have legally been killed (1,096 anticipated) were actually killed (59, or 5.4% of allowable take). LaRue and Dougherty (1999) concluded that the terms and conditions attached to construction permits by BOs were effective at protecting desert tortoises because the actual take was well below anticipated take. Although not a formal meta-analysis, this study addressed effectiveness at an action level across many independent projects, and is a positive step in the direction of effectiveness evaluation. Confidence in the study would increase to the extent that BO compliance reporting could be shown to be a reliable method of data collection. Additionally, the conclusion that tortoises were adequately protected was based on the assumption that anticipated take numbers specified in BOs are harmless to tortoise populations, an assumption that, to our knowledge, has not been tested.

Linear construction projects, such as pipelines, fiber optic cable lines, and transmission lines, have the potential to impact large numbers of tortoises, as they stretch across many hundreds of miles of tortoise habitat and may intersect many different tortoise populations (Olson et al. 1992, Olson 1996). The effectiveness of tortoise protection measures during construction was assessed by comparing the number of tortoises killed (29 on the 646 mile-long Kern River pipeline, and 9 on the 384 mile-long Mojave pipeline) with the total number that were moved out of harm's way (401 on the Kern River pipeline, 158 on the Mojave pipeline), under the assumption that some large, but unknown, fraction of the tortoises would have been killed if they had been left in the construction zone. Gas pipelines have a wider construction impact zone than fiber optic lines, such that gas pipelines are expected to have greater impacts. Conclusions about the reduction in impact are difficult to evaluate because the number of tortoises that would have been killed is not known (that is, the study lacks a control). Additionally, the fate of the tortoises moved is not known, and whether they later died or impacted other tortoises was not studied, though these problems have not been found in translocation studies (see section 4.9, "Translocation").

Not all linear construction projects impact tortoise populations in the same way. Comparisons among project types show that gas pipelines kill more tortoises than fiber optic lines or transmission lines, a fact attributed to differences in construction practices among the project types (Olson et al. 1992). As in the example above, the number of tortoises that would have been killed if none were moved is unknown; although increased mortality is a reasonable assumption, the amount of increased mortality cannot be measured.

4.6.b. Limits to our knowledge

Available studies demonstrate that direct mortality to individual tortoises is reduced by adherence to permitting requirements. Although comparing mortality with allowable take is straightforward, setting allowable take numbers is not. It is generally best to consider allowable take to be a hypothesis, rather than a definitive statement, about the amount of mortality that a population can withstand. Because this hypothesis has always been assumed and not tested, no studies on the effectiveness of measures for protecting tortoise populations from construction activities have been performed.

Linear construction projects may also be a source of habitat fragmentation. Although the footprint of the construction may persist for long periods, it is not known whether populations are subdivided as a result. Whether such projects have long-term effects on the genetic structure of a population or the probability of extinction is not known.

4.7. Habitat restoration

4.7.a. Actions

A recent review of natural recovery and habitat restoration in southern California deserts is available from Lovich and Bainbridge (2003). They found that revegetation efforts have been attempted at small spatial scales, but that most efforts have had limited success and are labor-intensive and expensive. Some natural recovery has been observed in protected areas (Brooks 2000) in which grazing and OHVs have been removed. In contrast, unrestored tank tracks from military maneuvers have persisted for more than 55 years (Belnap and Warren 2002). The need for revegetation thus depends on the severity of impact. Natural recovery of severely degraded habitat is expected to occur over centuries, not decades (Belnap and Warren 2002). Restoration may be facilitated by placement of vertical structure (National Applied Research Science Center 2000), even in severe situations, which may help prevent additional degradation. It is not known whether this type of restoration leads to re-formation of soil crusts and recovery of natural nitrogen cycling.

4.7.b. Limits to our knowledge

Successful revegetation has been demonstrated in the Mojave Desert over the years in a wide variety of studies, resource notes, and pipeline/transmission line project reclamation plans (Clary 1983, University of California Davis Agronomy and Range Science Department 1977, 1978, University of California Davis Cooperative Extension 1990). Some restoration approaches are unlikely to be practical at large spatial scales, because of the cost or logistical difficulties involved (Lovich and Bainbridge 2003). It is also not known whether revegetated areas provide high-quality habitat for desert tortoises, or what degree of restoration is necessary to achieve success.

4.8. Translocation

4.8.a. Actions

We did not find any published studies that used translocation to re-introduce tortoise populations, although ongoing studies by Field et al. (e.g., Field et al. 2000, 2002) are investigating whether pet tortoises can be repatriated to the wild to augment existing populations. For example, Field et al. (2002) compared survivorship between released tortoises that were formerly pets to tortoises that were wild caught and found no difference in survival. Nussear et al. (2002) found no difference in survival or reproduction between resident and translocated tortoises in Nevada. Rainfall increased survival and reproduction in both groups. Stewart (1993) also reported no substantial differences in survival between wild and translocated tortoises, although differences were not statistically tested. Field et al. (2000) found that removal of *ad-libitum* water prior to release also had no effect on survival, but that males given supplemental water prior to release moved more than twice as far in their first season post-release. Translocated tortoises had more variable movements in their first year post-release, but not their second (Nussear et al. 2002). Thus, the initial experiments indicate that translocations and repatriations can be done without negative impacts to wild populations (Tracy et al. 2004).

Several studies followed tortoises that had been moved out of construction zones to assess their survival and movements. For example, Mullen and Ross (1996) reported that relocated individuals (guests) had similar condition index values (a measure of mass corrected for differences in length) to individuals that had not been moved. Furthermore, “residents” that did not have tortoises introduced to their area and “hosts” that did have tortoises released in their area had similar condition index values, suggesting that translocating tortoises did not negatively impact hosts. Irrigation increased the condition index for tortoises during the driest period of the 3 years of the study. High mortality rates in translocated tortoises were attributed to a lower initial pre-release condition index (mortality rate was not reported). This study, which focused on an index of health of individual tortoises, supported the contention that tortoises can survive translocation without impacting tortoises already present at the release point.

4.8.b. Limits to our knowledge

Studies by Field et al. (2000), Nussear et al. (2002), and Mullen and Ross (1996) have shown that tortoise translocation can work and that resident tortoises are not negatively impacted by the practice in the short term. Moving tortoises out of harm’s way at construction sites generally involves shorter displacements that may not even remove tortoises from their home ranges; whether this practice has the same effects as longer-range translocations is not known. Whether releasing tortoises augments long-term population size also is not known, but may depend on characteristics of the site (e.g., habitat quality, tortoise population density, etc.). Releasing pet tortoises and handling tortoises is considered a risk factor because of the potential for disease transmission (Berry 1997). Translocation efforts, therefore, would need to observe rigorous protocols to avoid harming target populations (for example, testing for an immune response to *Mycoplasma agassizii* prior to release to avoid release of infected but asymptomatic individuals; Tracy et al. 2004). It is not known how many individuals would need to be released to establish new populations or to have a positive effect on extant populations. Population-level effects would be expected to be greatest for releases of sexually mature individuals, given that population growth is most sensitive to changes in this age class (Doak et al. 1994). Headstarting programs show promise for protecting hatchlings (Morafka et al. 1997), but would probably have a smaller positive impact on tortoise population growth.

4.9. Predator control

4.9.a. Actions

Both native predators, such as common ravens, coyotes, and mountain lions (P. Medica, unpubl. data), and exotic predators, like feral or domestic dogs, have been implicated as threats to desert tortoises (Boarman 2002). Predator control is controversial and has not been attempted on a large scale. Raven control is notoriously difficult because they are believed to learn quickly to avoid most lethal control methods. Breeding pairs and large aggregations of non-breeding ravens at landfills and other resource sites are threats to tortoises (Kristan and Boarman 2003). Changes in landfill management can reduce raven abundance at the landfill site (Boarman et al., in prep.), but effects on breeding pairs and regional population size are not known. Targeting breeding pairs can be problematic because removing one individual alerts the other, and shooting generally is effective at removing only one member of a breeding pair (Boarman, unpubl. data). In Iceland, 9 years of removing ravens has not reduced population abundance (Skarphédinsson et al. 1990). Local reductions in predation risk, however, may be achievable (Boarman 2003).

Pilot efforts to live-trap feral dogs have had limited success, with only a single individual trapped during a pilot program at the Marine Air Ground Task Force Training Command,Twentynine Palms, Calif. (Everett et al. 2001). During the 158 six-hour trapping periods conducted, 1 coyote and 6 kit foxes were also captured, raising concerns about non-target species impacts. Shooting was offered as an alternative, humane removal method, but without supporting data.

4.9.b. Limits of our knowledge

Both the extent and importance of raven predation on juvenile tortoises is not fully understood. Raven predation on juvenile desert tortoises alone may have little effect on the population levels of tortoises compared with other sources of mortality (Ray et al. 1993, Doak et al. 1994). However, in declining populations, reducing juvenile mortality may be very important in promoting recovery (Congdon et al. 1993, Boarman 2002).

Raven populations are not uniformly distributed across the desert tortoise's range, thus predation risk is mixed (Kristan and Boarman 2003). Where ravens are abundant, the risk of predation approaches 100%, but areas of great raven abundance are restricted to sites of human resource subsidies where groups of primarily non-breeding individuals aggregate. Breeding ravens are also a threat, and though they distribute more evenly over open desert, they still aggregate near human developments (Kristan and Boarman, in prep.). The regional effects of ravens on population levels of desert tortoises is not fully understood, and thus it is not yet known whether raven control should be expected to be an effective recovery action. The most effective methods for raven population control have not been well-studied. Predators of adult tortoises, such as feral dogs and coyotes, are expected to have a larger impact on population levels than that of ravens, but no data are available to test this hypothesis. Effects of canid removal on tortoise populations were not found.

4.10. Other threats

Boarman (2002) found that some commonly accepted threats to tortoises have not been studied sufficiently to establish them as such, and we found that the effectiveness of actions to control these unproven threats also has not been studied. For example, competition for forage between tortoises and wild horses and burros may occur, but its impact on tortoises is unknown. Several threats treated as separate categories by Boarman (2002) all led to habitat loss or degradation (e.g., military maneuvers, agricultural development, construction). Habitat loss is clearly a threat to desert tortoises, but there are many practices that fall short of causing complete habitat destruction. It is likely that their effects on tortoises vary depending on their intensity, but we did not find any studies that undertook an assessment of how varying degrees of habitat degradation affect tortoises. Finally, several possible or demonstrated threats to tortoises, such as disease and invasive exotic plants, are not currently under direct control of resource managers (although this may change with future research) and so are not addressed here. Indirect effects and synergistic effects of threats on tortoise populations were also not specifically addressed by Boarman (2002), but are interesting and important areas for further research. For example, as one reviewer of this current report (P. Medica) suggested, predation on tortoises may depend on an abundance of alternative prey, such as rodents and rabbits, which in turn are strongly affected by drought. Drought conditions may thus increase the intensity of threats to tortoises, thus impacting them in both direct and indirect ways. Although drought is not under the control of managers, managing threats so that tortoises can withstand drought conditions may be necessary and will require additional research.

4.11. Summaries of interviews with desert managers

As part of the search for documents at field offices of desert tortoise managers, Ed LaRue interviewed key personnel (listed in *Table 3*) who had firsthand knowledge of management activities in their resource areas. Although these interviews have to be treated as anecdotal, they indicate that many recovery actions are currently being implemented and that unpublished monitoring data exists that may be useful in assessing the effectiveness of these actions at reducing tortoise threats.

One example of a recovery action is livestock fences, which were reported to be in use by most of the units we visited (BLM, U.S. Navy, U.S. Marine Corps, U.S. Army, and U.S. Air Force). Many of these fences also serve as boundary fences, meant to exclude trespassing by OHVs and livestock. Monitoring levels at Ridgecrest, a BLM site, varied from routine maintenance of fences to periodic vegetation monitoring and photograph documentation. Fencing generally is viewed as effective at keeping livestock out of sensitive areas, provided that the fences are in good repair and gates are kept closed. Smooth wire fence, used at the BLM Needles site because of concerns about harm to native ungulates, is less effective than barbed wire, as cattle are reported to cross over and under it (K. Allison, pers. comm.). Two-strand barbed wire fencing is reported to be less effective than four-strand wire fencing at keeping sheep off of Edwards Air Force Base (M. Hagan, pers. comm.). However, no cattle have entered Fort Irwin National Training Center from the Cronese Lakes Allotment since a two-strand wire fence was completed (M. Quillman, pers. comm.). An 11 mile, three-strand wire fence has been effective at keeping livestock and burros from entering China Lake Naval Air Weapons Station from the Grass Valley area (T. Campbell, pers. comm.).

Another action that has been recommended by managers for implementation across the desert is emergency closures of OHV-use areas, enforced and not, as well as a variety of projects on restoration of closed routes. Managers reported that area closures are difficult to maintain, although livestock fencing can help to discourage OHV use (A. Chavez, pers. comm.). Areas closed to OHV use with only simple barbed-wire fencing often are subject to vandalism. Cut fences have allowed initial trespass access by OHV users into closed areas, followed by unrelated subsequent vehicle trespass, as evidenced at Red Rock Canyon State Park (M. Faull, pers. comm.). Similarly, the perimeter fence at EAFB, in proximity to the El Mirage OHV Use Area, has been breached in several spots and trespassing by OHV users occurs often there (M. Hagan, pers. comm.). In contrast, solid barrier fencing along roads, construction sites, or other hazards has been used frequently, and appears to work well in these applications. For example, at EAFB, tortoises were occasionally found in mine shafts before fencing, but not after (M. Hagan, pers. comm.). Along U.S. Highway 395, areas lacking “K-rail” tortoise barriers during 1990s highway expansion work resulted in the take of desert tortoise on at least one occasion, whereas areas with barriers placed between potentially-occupied tortoise habitat and work activity did not (T. Egan, pers. comm.).

The frequently-recommended management action of vehicle route rehabilitation appears to have had mixed results. For example, vehicle route rehabilitation in the Kingston Range, the Shadow Valley area of the east Mojave Desert, has apparently had positive results, though quantitative data have not been collected (L. Smith, pers. comm.). At Red Rock Canyon State Park, rehabilitation with one particular technique has resulted in minimal natural recruitment of shrubs along closed routes (M. Faull, pers. comm.). Vehicle routes in the Kramer Hills of the west Mojave Desert also have been rehabilitated, but no follow-up data are available (C. Burns, pers. comm.). However, the rate of native plant establishment and closed vehicle route compliance garnered just 4 years after the technique of “vertical mulching” was first applied in the Ord Mountain (National Applied Research Science Center 2000) is promising (T. Egan, pers. comm.). Many of these formerly used vehicle routes are no longer visible, and contain native plant communities. Similar success has been observed by National Park Service route restoration efforts in Death Valley and Joshua Tree National Parks.

5. Conclusions

5.1. Few studies have been designed specifically to evaluate the effectiveness of recovery actions

Given that the early emphasis in desert tortoise research has been on characterizing threats, filling gaps in knowledge of desert tortoise ecology and life history, and estimating the population status and trends, it is not surprising that relatively few studies have been conducted to evaluate the effectiveness of recovery actions. Studies of threats are useful for directing recovery efforts, but they may not be helpful for selecting the best recovery action to implement. For example, knowing that road mortality is a threat to desert tortoises does not provide information to managers about how to alleviate the problem. Once fencing is selected as a preferred method, it is still necessary to decide how much road must be fenced, the kind and spacing of culverts needed to allow passage across the road, and how much maintenance is needed to preserve the fence’s effectiveness. Additionally, although it may be possible to isolate the single effects of threats through careful experimental design, recovery actions usually have multiple effects and may be exposed to multiple confounding variables that prevent tortoise population response. Because of these complicating factors, studies of threats may not provide much guidance to managers seeking the best way to recover tortoise populations.

5.2. Recovery actions are necessary, but may not be sufficient

Recovery actions must be done in the face of uncertainty about which threat, or threats, are limiting. Although removal of a single known threat does not guarantee recovery, it is most conservative to assume that a population cannot recover until all known threats are removed. Short of removing all threats, as many known threats as possible should be eliminated. In this sense, removal of each known threat is supported as a necessary condition for recovery, although removing single threats may prove to be insufficient. Theoretically, one of the most comprehensive recovery actions is to set aside a dedicated reserve, but as the DTNA has demonstrated, the tortoise population can still decline if threats remain after a reserve is established. Consequently, lack of recovery because of disease, drought, or predators does not prove that excluding OHVs and livestock was unnecessary. If this level of certainty is desired, studies of these individual effects must be conducted.

5.3. Strengths and weaknesses of available information

This report compares desert tortoise research with an experimental ideal. It would be difficult to find an ecological field study in any publication that met all the criteria of an ideal study. For example, lack of random allocation of subjects to treatment and control groups is extremely common, and replication becomes difficult as the spatial scale of the study increases. Because we did not expect to find ideal studies, we identified the assumptions necessary to apply the results from a variety of studies to populations of wild tortoises (*Table 2*). This approach is meant to encourage prudent interpretation of studies, rather than to dismiss those that failed to match the ideal.

The rows in *Table 2* are arranged in ascending order of reliability, with each successive row adding additional observations that more strongly suggest the effectiveness of an action. For example, removing wild horses or burros from desert tortoise habitat without any follow-up monitoring would fall into the first row because competition with wild horses and burros has not been established as a threat to tortoises (although it is a logical extension of related work on cattle), and if no information was collected about the effects of the removal, there is little to support a conclusion that this was a successful recovery effort. If the threat has been well-established, such as the threat of mortality along an unfenced road, then observations of a reduction of the threat is an indication of success. The latter does not, however, imply that the action is sufficient to recover the population. Most of the studies we reviewed were those in which an assessment was conducted following implementation of a management action taken to reduce a threat. We did not find many examples of assessment of population-level responses to recovery actions, probably because a reduction in threat often can be assessed immediately following implementation of an action, whereas population responses can be assessed only over longer time periods. There may be no easy solution to this problem because the final test of effectiveness of recovery actions is whether these actions result in an increase in population size, which is a slow process for this long-lived species.

Most of the previous studies of effectiveness took place in concert with construction activities or recreational vehicle racing events or after area fencing of tortoise habitat. Because of this, most of these studies were a form of field experiment, the most reliable type of scientific evidence. However, these studies were aimed at measuring the effect of a single project, so they were not replicated at the level of the recovery action. Generalizing results becomes difficult under these circumstances, and such studies would be difficult to publish in peer-reviewed outlets. One approach to this problem is to analyze results from a number of project-oriented studies to evaluate action-level effectiveness. When done using formal, rigorous statistical procedures, this is called "meta-analysis" (Pullin and Knight 2001). LaRue and Dougherty (1999) attempted an informal, non-statistical version of this type of analysis, but formal attempts to integrate results across studies have not been reported.

In addition, most of the studies that we examined also lacked formal peer review or were not widely available to the managers who would benefit from their findings. Publishing studies in peer-reviewed outlets not only encourages high-quality work, it increases the availability of the work. The large amount of information found in biologists' files that is unpublished, and thus not widely available, suggests that opportunities to improve implementation of recovery actions are being missed.

5.4. The absence of proof of effectiveness is not proof of ineffectiveness

Pullin and Knight's (2001) analogy between studies of the effectiveness of conservation efforts and medical treatments for humans suggests that the effectiveness of the methods used will improve if an effectiveness evaluation is approached with a critical eye, using scientifically rigorous methods. However, given that such a system is not currently in place, it is important to bear in mind that the current practice of making decisions based on established conservation principals is much better than using no scientific input whatsoever. By analogy, the fact that medical treatment of humans has improved by quantitatively testing effectiveness is encouraging, but it does not show that medical treatments were ineffective before the program was implemented. We assert that the same is true of desert tortoise recovery actions: they are based on logical applications of principles of ecology and population biology, and, although we have concluded that recovery actions can improve with better information, current practices should not be considered baseless.

6. Recommendations

6.1. Implement more scientifically-based monitoring of actions

Actions that lack effectiveness monitoring will be difficult to defend, particularly if they cannot be assumed 100% effective. Scientific monitoring allows the effectiveness of particular actions to be demonstrated quantitatively at the project level, and repeated, consistent demonstration of effectiveness at the project level can collectively establish effectiveness at the action level. Additionally, greater emphasis on population-level responses will ultimately yield the most definitive answers, although these studies are the most difficult, require the greatest commitment of time and money, and have the greatest chance of failure. The need for ongoing effectiveness monitoring may decline as certainty of an action's effectiveness increases.

6.2. Coordinate monitoring activities among projects to facilitate meta-analysis of effectiveness

Follow-up monitoring of recovery actions should be a routine part of implementation. Monitoring efforts are generally site-specific and unreplicated at the level of the action, and thus are difficult to publish. To make maximal use of the information, it should be collected using standardized methods, and then submitted to a central location where it can be incorporated into formal statistical analysis using meta-analysis methods. The recently established Desert Tortoise Recovery Office (Tracy et al. 2004) could coordinate data collection from follow-up monitoring.

6.3. Pursue peer-reviewed publication of effectiveness studies

Studies that have relevance to effectiveness of recovery action should be published in peer-reviewed outlets. Peer review is important to increase reader confidence in the work, and publication increases accessibility of the results. Electronic indexing and document availability has had the positive effect of making papers published even in regional journals with small readerships available, but it may also decrease the likelihood that unpublished work will be found.

6.4. Commission studies to assess tortoise population responses to recovery actions

Recommendation 6.1 in this report is intended to improve our ability to learn from our collective experience with desert tortoise management. However, this recommendation would not eliminate the need for carefully designed studies of effectiveness, given that projects often produce complex "treatment effects" that can be confounded by uncontrolled variables like drought, disease, and predation. The desert tortoise research community has appropriately concentrated on establishing the status and trend of the species and on identifying threats to its persistence. However, a study of threats does not necessarily provide managers with guidance about how best to recover populations. Studies should be commissioned that specifically address the effectiveness of protective measures in recovering the desert tortoise population in question. The DTRPAC report (Tracy et al. 2004) includes detailed recommendations for data needs along these lines.

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