Evaluation of Evidence Supporting the Effectiveness of Desert Tortoise Recovery Actions

[REVIEW DRAFT-2]

U.S. DEPARTMENT OF THE INTERIOR
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WESTERN ECOLOGICAL RESEARCH CENTER

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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 for delisting by the Desert Tortoise Recovery Plan (U.S. Fish and Wildlife Service 1994), 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 growth rates at or above 1.0, regulatory measures are in place to ensure continued management, and there is no longer reason to believe that the species will require ESA protections 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, and management efforts for recovery are generally 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 (Tracey 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 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, than 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 that might not be equally effective. 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. Each approach involves some investment of resources, and some may be less 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. Additionally, it is important to evaluate how well managers' needs for scientific support are being met by the current state of knowledge.

This 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 due to their long generation time and low detectability (Tracey et al. 2004). However, recovery actions are most likely to be 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 officers 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 increase tortoise populations, and 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 effectiveness of particular recovery actions should be tested scientifically. 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, where science and statistical analysis of the effectiveness of historic practices should also serve as a guide to 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 was often 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, since patient health can 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 is a review of a limited number of cases; it is probably an inadequate sample size 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

The primary questions addressed by this report are as follows:

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 reports of an observational or anecdotal nature. Therefore, we rate 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 concern to managers is the reliability of studies used to demonstrate effectiveness, which depends on the experimental methods employed. Before an action is implemented based on previous studies, a manager should decide if the conclusions are justified based on the methods employed, both in data collection and analysis. Second, effectiveness can be evaluated at different levels. Based on 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 results can also be evaluated, in that 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 experimentally 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 can't 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. Also, 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 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. If the desired effect is achieved in a management context this problem may not be viewed as important. 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.

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” 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), while “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 (Hurlbert 1984). For example, studies of the effectiveness of 1 cm^2 hardware cloth 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 it 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 may thus be only 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 they 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. Individual impacts are regulated by the ESA, but whether reduction in individual impacts translates into increased population size depends on multiple factors (see section 2.3). Studies of individual impacts can therefore be well-designed and reliable, but not qualify as 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 do not indicate effectiveness at the population level.

2.1.e. Sources of scientific information

Outlets for scientific information are both 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 types of information is between information that is based on designed scientific studies (1-5, possibly 6) and information that is based on personal opinion (7-8). Categories 1-6 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 judge whether the methods employed were appropriate, samples sizes were adequate, and whether 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 will frequently either 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, and 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. This 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 immediately observe 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 over 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. When multiple threats are affecting a population, removing a single threat will not increase the population size if other limiting factors remain; in other words, 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 only increase 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 being the leading candidate to explain the decline (Berry 1997). The lesson from the DTNA is not that perimeter fencing was not a necessary 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). When animals that die from human causes under this paradigm would have died anyways from density-dependent natural causes, human-caused mortality is considered “compensatory.” Applied in the context of population recovery, compensatory mortality implies that if one mortality factor is removed there may be no net gain if others 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. However, under neither Leibig's law nor the theory of compensatory mortality should known threats be left in place; rather, multiple threats should be addressed simultaneously, with as many threats as possible removed to affect population recovery.

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

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. Relationship between levels of demonstration of effectiveness and tortoise recovery

It is important to define the goals of recovery actions so that their effectiveness can be assessed. For example, some recovery actions afforded by the DTNA, such as the protection from OHVs, grazing and habitat destruction, are meant to maintain existing, relatively healthy populations. Successfully implementing actions and maintaining closed areas may be sufficient criteria for success in these cases. In contrast, other actions, such as habitat restoration and translocation, are meant to increase the size of a reduced population, and in these cases, success is judged on 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. Additionally, we need to consider whether studies are designed to address individual-level effects or population-level effects. Table 2 identifies the assumptions that need to be made to consider 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. For example, the intended outcome of fencing a road with tortoise-proof mesh is to increase the tortoise population by reducing road mortality. If this action is taken but the effects are not monitored, then confidence that the action is effective depends on whether it is correct to assume that road mortality is a real threat to tortoise populations, that it is the primary factor limiting tortoise population increase, and that the action effectively removes or reduces the limitation (Table 2, rows 2 and 3). If 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 represents a step toward recovery only if road mortality was 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 it increases our confidence that reducing road mortality is necessary for recovery (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 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 needed to conclude that the fence has been effective become much less stringent, but might include the assumption that improvements in local demographic performance is contributing to local recruitment rather than 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).

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 dealing with effects of recovery actions on desert tortoises, or studies that dealt with 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 visited biologists' offices at the Bureau of Land Management (BLM), the U. S. Fish and Wildlife Service (USFWS), the National Park Service (NPS), California Department of Parks and Recreation, the U.S. Marine Corps, and the U.S. Navy headquarters throughout the Mojave Desert in California (Table 3). During these visits, biologists' files were examined, and two kinds of documents were retained. 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). These documents were assessed for reliability (see “Document assessment”, below). The second type of document detailed monitoring efforts at a particular unit, such as memos and internal reports of permit compliance. These documents were not assessed individually, but were used as a measure of observation effort expended on desert tortoises across the region. Additionally, Ed LaRue interviewed representatives at each office to determine whether additional useful monitoring was conducted that was either not documented, or was documented elsewhere (for example, by independent researchers conducting studies within the management unit). The entire bibliographic database of these documents is available.

3.2. Document assessment

For each document, we recorded the kind of action taken, following categories in Boarman (2002), and the findings and conclusions of the study. Documents reporting on designed studies were evaluated for reliability, and for whether they assessed the "project" or the "action" level of effectiveness. Reliability was assessed by recording whether the following tenets of experimental design were included: 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).

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 to offices in California. We did collect information at those offices regardless of the study location, but papers and reports from Nevada, Arizona and Utah are under-represented in our sample.

4. Results

4.1. Kinds of information available

Of the 395 documents obtained in our search of biologists' files, 100 were directly relevant to recovery actions. Of these, 22 were reports of designed studies and 78 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. This was not meant to be an exhaustive enumeration of materials found, but does support the overall impression that relatively little of the material available to support implementation of recovery actions is coming from scientific studies. This impression was further reinforced by notes from interviews conducted by Ed LaRue, which showed that many biologists knew of recovery actions that were being implemented without follow-up monitoring.

Based on Boarman (2002), we selected several significant issues related to desert tortoise recovery. These are listed in sections 4.2-4.9 below, along with a description of the related management actions, an assessment of the strength of the evidence that the actions are effective in reducing threats, and a discussion of the limits to our current knowledge that research should address in the future.

4.2. Reserves

4.2.a. Actions

Establishment of reserves provides protection to tortoise populations against multiple threats (e.g. OHVs, mining, military operations, agriculture, etc.; Table 1). The Desert Tortoise Recovery Plan emphasized protecting large areas containing healthy tortoise populations, which served as the impetus for establishing the DTNA. As the most prominent reserve, the DTNA has been the focus of intensive study, and much is known about the tortoise population and habitat there (Berry 1997, Brooks 2000). Fencing and patrolling the DTNA perimeter has reduced human use of the area, and reduced threats such as shooting and OHV's within its boundaries (Campbell 1981). Fencing also reduced grazing, and improved tortoise habitat characteristics (Brooks 2000), although the full magnitude of beneficial effect to habitat may take decades to be complete.

The DTNA also illustrates two vexing points about measuring effectiveness. 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 and OHV use could not be determined without additional studies. Second, although there are no known detrimental effects of establishing reserves, the tortoise population in the DTNA has, in fact, declined. Uncontrolled threats, such as disease and predation, may explain this paradoxical outcome (Berry 1997). Similarly, following establishment of the Red Cliffs Desert Reserve within the Upper Virgin River Recovery Area, UT, 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%. However, even in these well-studied cases the complexities of population responses to multiple factors have made it difficult for researchers to use the DTNA as evidence of the 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. Experience at the DTNA has shown that even the best-supported practices can fail to produce the expected result if other threats are not controlled. Reserves have the advantage of simultaneously reducing multiple threats, but inferences about the importance of particular threats are difficult. Whether desert tortoise reserves protect isolated populations or function as part of a network of interacting populations is not easily known.

4.3. OHV Use

4.3.a. Actions

Boarman (2002) identified several studies that showed impacts of OHVs on desert habitat, and cited Bury and Luckenbach (1986) as the best evidence for 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 5). 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 tortoise populations following the exclusion of OHVs from an area were not found, but if habitat damage is the primary cause of reduced densities, then the slow recovery of desert vegetation (Lovich and Bainbridge 2003) may make such studies impractical.

Although we did not find studies of the before and after effects of OHV closures on tortoises, several studies examined the effectiveness of permitting requirements, such as route designation, for minimizing impacts of competitive races on tortoise habitat (Woodman 1986, Burge 1986, Musser 1983, BLM 1984, 2000, 2001, Circle Mountain

Biological Consultants (CMBC) 1994, Goodlett and Goodlett 1993, Medica 1994a,b, Walker and Mastin 1999, Miller-Allert 2000, 2001, Sullivan 2002). Although only Woodman (1986) and CMBC (1994) specifically searched for dead desert tortoises, all of the 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), and none reported direct mortalities. All of the studies assessed habitat damage, either in the form of route widening, new OHV track formation, or damage to vegetation. Some form of damage was observed in all studies, although the amount of damage differed substantially. For example, monitoring of the 1983 Barstow to Vegas motorcycle race (BLM 1984) showed minimal change in vegetation in 22 plots. In contrast, Medica (1994a) found approximately 1 damaged shrub per 60 m of course in one transect, for an estimated 225 shrubs damaged. Course widening and new tracks along posted routes were commonly observed. Explanations for straying included poor route marking (particularly at sharp turns or at unauthorized trails connected to the official route), lack of race monitors, passing, and "silt avoidance" by riders that moved to more solid, outer portions of the route once the middle became unstable. Several reports cited problems with permit compliance by spectators. Problems reported in the most recent reports available (BLM 2000) were similar to problems reported at earlier events. Compliance was generally good when routes were well posted. Although all studies reported some damage, interpretation of the degree of damage was based on the authors' personal judgment (that is, they did not refer to a standard for how much damage is acceptable, and to our knowledge no such standard exists).

The effectiveness of closures as a means of reducing OHV traffic has been studied. In one such study Goodlett and Goodlett (1993) found that posted closed areas in the Rand Mountain and Freemont Valley had similar numbers of new tracks as unposted closed areas, and that the number of OHV tracks observed increased with proximity to open areas, suggesting that posted route closures alone were not effective at eliminating OHVs. In contrast, the perimeter fence at the DTNA has been effective at reducing OHV use (Campbell 1985). These studies were aimed at understanding whether the level of a threat could be reduced, but the effects of threat reduction on populations were not assessed.

4.3.b. Limits to our knowledge

Although it is logical to conclude that excluding OHVs will reduce damage to tortoise habitat, and that better habitat will promote healthier populations, we did not find studies that removed only OHVs and then measured tortoise population responses. There is correlative evidence that OHV use promotes exotic plant invasions (Brooks 1999, Brooks and Esque 2002), but whether excluding OHV's prevents invasions has not been studied. We also did not find studies that tested whether measures reducing OHV use, short of area closures, are effective at recovering populations. It is relatively well established (Boarman 2002) that OHV use 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 use is less destructive than open use to desert tortoise habitat, which makes it difficult to extrapolate results to a population level. For example, monitoring requirements for race events have produced a relative wealth of information about the effectiveness of route marking for protecting tortoises and habitat. However, in spite of the fact that 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 is safe for tortoise populations.

4.4. Grazing

4.4.a. Actions

Boarman (2002) identified several ways in which cattle grazing impacts tortoise habitat (sheep grazing is relatively poorly studied; see Nicholson and Humphreys 1981), particularly near water sources (Table 5). Direct impacts to tortoises were not as well documented, and little research has been conducted on the effectiveness of grazing restrictions on tortoise populations. We found only one case in which researchers removed cattle and then tracked changes in tortoise populations (Turner et al. 1981, 1985, Avery and Neibergs 1997), in the Ivanpah Valley of California. Turner et al. (1981, 1985) did not find differences in vegetation species composition inside and outside of an exclosure in the two years following removal of cattle, and plant biomass was greater in grazed areas. They found no differences in home range size or number of clutches between tortoises in grazed and ungrazed areas, 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 their results. First, they had only one exclosure and one comparison plot, which makes comparisons at the level of the action tenuous. Second, their study was conducted over the two- year period following exclosure, which may not be adequate for a study of a slowly recovering vegetation type and a slowly growing population of tortoises (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). And third, they 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. Because of this, it is questionable as to whether their findings can be applied to real-life allotments where grazing levels may be consistently high.

Between 1991 and 1993 Avery and Neibergs (1997) and Avery (1998) studied the same cattle exclosure established by Turner et al. (1981, 1985). They found greater cover of *Hilaria rigida*, a palatable perennial grass, where cattle were excluded, whereas grazed areas had more compacted soils in addition to some burrow entrances that were collapsed by cattle. 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, above-ground volumes, and estimated biomass, and *H. salsola* was more abundant. Furthermore, diet composition overlapped between tortoises and cattle in the late spring when forage dried out, suggesting that the species may compete for food at these times. However, conclusions drawn in this study are similarly restricted by the lack of replication at the action level. And although they did extend the time frame for recovery from two years to 12, Avery and Neibergs (1997) were still not certain that enough time had passed for recovery to be detected.

Larsen et al. (1997) studied exclosures that had been established for longer periods, two at an abandoned gunnery range (time of closure not reported), and a third that had been closed since the early 1940’s. Grazing outside of the exclosures was reported to be “light” to “moderate,” though the “moderate” sites had been recently rested for 2 to 6 years. Changes in vegetation were small, and idiosyncratic, with no clear, consistent effect of 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.

4.4.b. Limits to our knowledge

Grazing-related impacts to 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 grazing, but without more careful quantification of grazing level this result should be considered suggestive rather than confirmatory. This question is complicated by the fact that impacts of livestock presumably vary annually with changes in precipitation and primary productivity (Avery and Neibergs 1997). When tortoise populations are low and forage is abundant, 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 grazing can be done without detrimental effects on desert tortoises. Kazmaier et al. (2001) studied the effects of grazing on the Texas tortoise, and found no effects of grazing on growth or survival in this species. However, they expressed reservations about generalizing their study to the arid, low-productivity environments of the Mojave, and discouraged direct application of their results to desert tortoises.

4.5. Road mortality and barrier fencing

4.5.a. Actions

Tortoise mortality along unfenced roads has been well documented (Boarman 2002). Additionally, reduced densities of tortoises along roads suggest that road mortality is sufficient to affect population sizes. The size classes of tortoises killed by traffic include larger, reproductive individuals (Boarman et al. in prep.) that 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 5). 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 Hermann's tortoise in southern France (Guyot and Clobert 1997), further supporting 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, 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, while 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 immigration 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 support the use of 1 cm hardware cloth as fencing materials. 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 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 to unfenced, roadless areas, but it is not known whether fences increase isolation of tortoise populations compared to 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, and thresholds beneath 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 the population-level effects of culvert use have been conducted.

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 5). Direct habitat loss, mortality, burrow damage, and fugitive dust have all been identified as possible problems (Boarman 2002). Because construction in desert tortoise habitat requires Incidental Take Permits, USFWS is able to impose terms and conditions on permittees, including reporting any tortoises that are killed during construction operations. Reporting requirements have generated information both about the impacts of construction, and the effectiveness of terms and conditions.

Actions designed to minimize impacts of construction activities are specified in biological opinions (BOs), along with required compliance reporting. Measures imposed are a heterogeneous mix, 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 and minimizing habitat damage during construction (Table 1). Biological opinions specify allowable take for 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 allowed) 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, based on the fact that actual take was well below allowable 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 allowable 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 (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. This conclusion is 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," below).

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, so we cannot affirm that moving tortoises is an effective action compared to leaving them in the path of construction.

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.

4.7. Habitat restoration

4.7.a. Actions

A recent review of natural recovery and restoration is available from Lovich and Bainbridge (2003). They found that revegetation efforts have been attempted at small spatial scales, but 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, tank tracks from military maneuvers have persisted for over 55 years (see Boarman 2002 for a more detailed description). The need for revegetation thus depends on the severity of impact, but severe habitat degradation is not expected to recover naturally over spans of decades.

4.7.b. Limits to our knowledge

Whether revegetation can be effective in the Mojave is not known, but current approaches are unlikely to be practical at large spatial scales (Lovich and Bainbridge 2003). It is also not known whether revegetated areas provide high-quality habitat for desert tortoises.

4.8. Translocation

4.8.a. Actions

We did not find published studies that used translocation to augment wild populations or to re-introduce populations, although ongoing studies by Field et al. (e.g. Field et al. 2000, 2002) are investigating whether pets can be repatriated to the wild. 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, though rainfall increased survival and reproduction in both groups. Field et al. (2000) found that removal of ad-lib water prior to release also had no effect on survival, but 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).

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 in the driest of the three 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. Whether releasing tortoises augments populations 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 due to the potential for disease transmission (Berry 1997), and translocation efforts would need to observe rigorous protocols to avoid harming target populations. It is not known how many individuals would need to be released to establish new populations, or 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 less positive impact on tortoise population growth.

4.9. Predator control

4.9.a. Actions

Both native predators, such as common ravens and coyotes, 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 both 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; for example, shooting generally is only effective at removing one member of a breeding pair (Boarman, unpubl. data). Removing ravens has not reduced population abundance after nine years in Iceland (Skarphedinsson et al. 1990), but local reductions in predation risk 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, 29 Palms (Everett et al. 2001). During the 158 six-hour trapping periods conducted, one coyote and six kit foxes were also captured, raising concerns about non-target species impacts. Shooting was offered as an alternative, humane removal method, 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 population-level effect on 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 tortoises' range, and predation risk is likewise heterogeneous (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, population-level effect of ravens on 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 also have not been well studied. Predators of adult tortoises, such as feral dogs and coyotes, are expected to have larger population-level impacts, but no data are available to test this hypothesis. Tests of effects of canid removal on tortoise populations were not found.

4.10. Other threats

Boarman (2002) found that some proposed 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 have 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 studies that undertook an assessment of how varying degrees of habitat degradation affects tortoises. Finally, several possible or demonstrated threats to tortoises, such as drought, disease, and invasive exotic plants, are not currently under direct control of resource managers and so are not addressed here.

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 that 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, in many cases, unpublished monitoring data exists that may be useful in assessing the effectiveness of these actions at reducing the threats.

One example 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 also serve as boundary fences, meant to exclude trespassing by OHVs and livestock. Monitoring levels varied from routine maintenance of fences to periodic vegetation monitoring and photo-documentation (Ridgecrest BLM). Fencing was generally viewed as effective at keeping livestock out of sensitive areas, provided that they are in good repair and gates are kept closed. Smooth wire fence, used at the Needles BLM due to concerns about harm to native ungulates, is less effective than barbed wire, as cattle are reported to cross over and under it (K. Allison). Two-strand barbed wire fence is reported to be less effective than four-strand wire at keeping sheep off of Edwards Air Force Base (EAFB, M. Hagen). However, cattle have not been found entering Fort Irwin National Training Center from the Cronese Lakes Allotment since a two-strand fence was completed (M. Quillman). An 11 mile, 3-strand fence has been effective at keeping livestock and burros from entering China Lake Naval Air Weapons Station from the Grass Valley area (T. Campbell).

Another action that was widely implemented across the desert by managers was OHV closures. Managers reported that these were difficult to maintain, although livestock fencing may help to discourage OHV use (A. Chavez). Areas closed to OHVs were often subject to vandalism and trespassing into fenced areas at Red Rock Canyon State Park (M. Faull). Similarly, the perimeter fence at EAFB has been breached in several spots and trespassing by OHVs often occurs (M. Hagen). In contrast, barrier fencing, along roads, construction sites, or other hazards, has been used frequently, and, in many cases, appears to work well in these applications. For example, at EAFB, tortoises were occasionally found in mine shafts before fencing, but not after (M. Hagen).

Another frequently applied management action, route rehabilitation, appears to have had mixed results. For example, rehabilitation in the Kingston Range, Shadow Valley area of the Needles BLM district has occurred with positive results, though data are not available (L. Smith). At Red Rock Canyon State Park, rehabilitation has resulted in minimal natural recruitment of shrubs along closed routes (M. Faull). And in the Kramer Hills, rehabilitation has occurred, but no follow-up data are available (C. Burns).

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 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, though it is 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 their 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. One of the most comprehensive recovery actions is to set aside a reserve, but as the DTNA has demonstrated, the tortoise population can still decline if threats remain after a reserve is established.

5.3. Strengths and weaknesses of available information

This report compares desert tortoise research against an experimental ideal. It would be difficult to find an ecological field study in any journal that met all of the criteria of an ideal study; 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 wild populations (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; competition with wild horses and burros has not been established as a threat to tortoises (although it is a logical extension from related work on cattle), and since 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, though it does not 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, while population responses can only be assessed over longer time periods. There may be no easy solution to this problem, since the final test of effectiveness of recovery actions is whether they increase population size, which is a slow process for this species.

Most effectiveness studies took place in concert with construction activities, recreational racing events, or after fencing of tortoise habitat. Because of this, most studies of effectiveness 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. 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 attempted.

In addition, most of the studies that we examined also lacked 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 work's availability. The large amount of information found in biologists' files that is unpublished, and 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 effectiveness of conservation efforts and medical treatments suggests that the effectiveness of our methods will improve if we approach effectiveness evaluation 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 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 are cannot be assumed to be 100% effective. Scientific monitoring allows the effectiveness of particular actions to be demonstrated quantitatively at the project level, and repeated demonstration of effectiveness at the project level collectively establishes effectiveness at the action level.

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. However, the best use of follow-up monitoring data would be achieved by standardizing methods so that the effectiveness of recovery actions could be assessed across many projects with formal statistical methods in a meta-analysis. If the DTRPAC recommendation to establish a Desert Tortoise Recovery Office (Tracey et al. 2004), they could coordination data collection from follow-up monitoring.

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

Recommendation 6.1 is intended to improve our ability to learn from our collective experience with desert tortoise management. However, this would not eliminate the need for careful, designed studies of effectiveness, given that projects often produce complex “treatment effects” that can be confounded by uncontrolled variables like disease and predation. The desert tortoise research community has appropriately concentrated on establishing the status and trend of the species, and 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 includes detailed recommendations for data needs along these lines (Tracey et al. 2004).

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Table 1. Recovery actions and the threats that they 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, preventative management of good habitat, 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
Culvert installation	Road mortality, population fragmentation
Land acquisition	Inadequate protection from many of the threats listed above

Table 2. The relationship between observations of particular measures of effectiveness of a recovery action, and the assumptions that must be made to consider the action effective at the project level or at the action level. 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 (PVA, observations over time)	None (recovery is observed)

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

Agency, City	Key Personnel Providing Input
BLM, Barstow	C. Sullivan, A. Chavez, C. Burns
BLM, Needles	G. Meckfessel, K. Allison, L. Smith
BLM, Ridgecrest	J. Aardahl, B. Parker, J. McEwan
Calif. Dept. Parks and Rec.	Faull, M.
Marine Corp, MCAGCC	R. Evans, B. Husung
Navy, China Lake	T. Campbell
Army, Fort Irwin	M. Quillman
NPS, Joshua Tree N.P.	A. Fesnock, C. Collins
USFWS, Carlsbad	M. McDonald, D. Miles
USFWS, Ventura	R. Bransfield

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

	Designed study		
Topic	No	Yes	Total Result
Construction	30	4	34
Road Fencing	10	3	13
Exclude grazing	16	4	20
OHV closures	14	1	15
OHV routes	8	10	18

Table 5. Possible threats identified by Boarman (2002). The strength of the supporting evidence, and the possible threat that is best-supported by data are also given.

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

Individual threats	*Strength of evidence*	*Best supported possible impact*
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 burrows	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 to 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, changes 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.