



*Mojave Desert habitat containing large shrubs as cover plants, diverse annual plant communities including native annual forb food plants with few non-native grasses, native herbaceous perennials and cacti supplying forage during dry years, minimal anthropogenic disturbance to soil and vegetation, and high spatial connectivity. These are all features perceived as contributing to high-quality desert tortoise habitats.*

## **DESERT TORTOISE HABITAT RESTORATION WORKSHOP: SYNTHESIS OF MAJOR RESTORATION PRINCIPLES AND RESEARCH NEEDS**

This is the fourth in a series of documents produced under the Clark County Desert Conservation Program's Desert Tortoise Habitat Restoration Synthesis and Workshop project. The first three documents included a literature review, fact sheet summarizing the review, and a workshop summary document. The literature review and fact sheet provided a foundation for the workshop, held virtually January 24-26, 2022. The literature review synthesized desert tortoise habitat requirements and restoration practices, effectiveness, and costs for improving soil and vegetative habitat conditions. The review included over 50 published studies now available on restoration in the Mojave and western Sonoran Desert. These studies highlighted that while restoration is challenging in this environment, strategically implementing effective treatments can measurably improve soil conditions, availability of cover plants for tortoises, and native annual and perennial food plants while lowering wildfire risk. Restoration has also succeeded during severe droughts, which are anticipated to intensify, by applying multiple treatment types as a bet-hedging approach to increase chance for success in dynamic environments. Presentations and workshop discussions reinforced and augmented many of the findings emerging from the published literature, along with offering new ideas for a next phase of restoration research and management activities for aiding tortoise recovery actions.

### **SYNTHESIS SUMMARY**

After a brief introduction and context for desert tortoise habitat restoration activities, this synthesis integrates content from the literature review and workshop in a status of knowledge identifying key, relatively well-known principles regarding desert tortoise habitat restoration and summarizes priority research needs likely to be useful for management. The synthesis is structured around using restoration to improve four major features thought to be critical to high-quality desert tortoise habitats: cover plants, quality food plants, water availability, and general safety (e.g., low concentrations of soil toxicants). Major principles and research needs of restoration treatments to improve these habitat features are then outlined. This project established a foundation of tortoise habitat requirements and restoration practices to enhance quality and quantity of these habitat features. Three of the major themes that emerged included that: i) measurable improvements in perceived habitat quality metrics are achievable (even under adverse environmental conditions) but that often careful restoration planning and tailoring restoration practices situationally is required to achieve these success; ii) continued non-native plant invasions, wildfires, fragmentation, and other disturbances potentially interacting with climatic changes are likely to continue stressing tortoises and tortoises habitats and need consideration and mitigation during restoration; and iii) further connecting research on desert tortoise biology and ecology with restoration ecology research is timely. Along with several other major research priorities, a major next step could be beginning to connect short- and long-term indicators of tortoise health as response metrics with habitat enhancement activities.

The Clark County Desert Conservation Program supported this project through a contract with NRC LLC.



**Natural Resource Conservation LLC**

1400 Colorado Street  
Boulder City, NV 89005  
Scott Abella, Ph.D., Founder  
abellaNRC@gmail.com

## INTRODUCTION

Declining populations, poor recruitment, and ongoing habitat deterioration prompted listing of the Mojave desert tortoise (*Gopherus agassizii*) in the Mojave and western Sonoran Desert in 1990 as threatened under the U.S. Endangered Species Act. Since the listing, many agencies and organizations have made major efforts to implement tortoise recovery actions, such as instituting range-wide population monitoring, establishing critical habitat units, and reducing presence of non-native animals within tortoise habitats. In the next phase of tortoise recovery efforts, there is keen interest in exploring the potential for habitat restoration to aid recovery efforts, implement and improve the most effective restoration practices, and connect short- and long-term indicators of habitat quality with tortoise responses. Emphasizing habitat restoration as part of the next phase of recovery actions has consensus from prior research correlating habitat features with tortoise utilization, reviews and modeling studies suggestive of potential benefits of quality habitats to tortoises, recovery plans, and the literature review and desert tortoise habitat restoration workshop associated with this project sponsored by Clark County. While it should be recognized that habitat restoration is unlikely to be a panacea and is perhaps best viewed as part of comprehensive recovery actions that include many other key activities (e.g., protecting habitat connectivity, limiting spread of disease to and within tortoise populations, and limiting tortoise predators subsidized by human activities such as common ravens), restoration represents a tool with among the greatest potential for reversing habitat degradation.

This synthesis builds upon a literature review and fact sheet associated with this project and integrates the literature review findings with diverse information presented during the habitat restoration workshop. The 70-page literature review included over 350 publications on desert tortoise biology and ecology and over 50 publications reporting results of habitat restoration activities in the Mojave and western Sonoran Desert. The review synthesized desert tortoise habitat requirements as they relate to restoration, indicators of habitat quality (e.g., abundance of nutritious, forage plants) relevant to restoration and monitoring effectiveness, 11 major restoration treatment types in three categories (revegetation, environmental site restoration, and restorative management actions), cost estimates and optimizing spatial deployment of restoration resources, and anticipated future habitat changes and restoration research needs. The two-page fact sheet highlighted the key points of the review. The reader is referred to the literature review for detailed citations and data on which this synthesis is partly based. The desert tortoise habitat restoration workshop was held virtually from January 24-26, 2022. There were 79 workshop participants from federal, state, and county governmental agencies, non-profits, universities, and private companies. The workshop included a diverse mixture of overview and project presentations (including research studies and management project case studies), expert panel question and answer sessions, and group topical discussions. A detailed workshop agenda and content is available in a workshop report by Southwest Decision Resources, Inc. associated with this overall project.

This synthesis report has three major goals: 1) identify and summarize best-management practices for restoring and sustaining high-quality tortoise habitats based on the literature review and workshop content, 2) identify current research priorities to improve habitat restoration, and 3) anticipate potential future changes that could influence tortoise habitat restoration activities and necessitate adjustments. After presenting an overall context for tortoise habitat restoration,

the synthesis covers each of these goals and concludes with ideas for research and adaptive management projects for implementing actions recommended in the synthesis.

## **CONTEXT OF DESERT HABITAT RESTORATION ACTIVITIES**

Terrestrial habitat restoration typically must address one or a combination of the following habitat degradation factors: plant communities altered by reductions or removals of key native species, increases in undesirable species such as non-native plants, compromised environmental site conditions (e.g., unnaturally high soil erosion rates, homogenization of topographic diversity), disruption of natural disturbances or impositions of novel disturbances (such as wildfires in many locations of desert tortoise habitat), and changes in ecological processes or the safety and health of biota (e.g., increases in plant and wildlife diseases). While global sources of global change agents, such as rapid climatic changes, are difficult to solve at a local level, effective restoration must often accommodate or seek to mitigate effects of these broader-scale stressors. Restoration must also often work within the constraints of limited financial resources, labor, and equipment for implementing restoration activities; limited availability of plant materials; permitting; site access (e.g., difficult access to remote sites); and numerous ecological constraints such as water availability. Strategies exist for partly overcoming ecological constraints, such as careful selection of species adapted to site conditions discussed later in the report. Strategies also exist for alleviating practical limitations, such as through optimizing spatial deployment of restoration to maximize use of limited restoration resources.

In desert tortoise habitats, combinations of degrading factors often result in denuded sites devoid of native shrubs tortoises need for cover and of native forage plants, dominance by non-native grasses that are poor forage and increase wildfire risk, disrupted soils including sometimes with elevated levels of toxicants potentially harmful to tortoises, reduced topographic heterogeneity (e.g., potentially reducing availability of natural depressions serving as water catchments offering drinking water to tortoises), and increased safety risks (e.g., risk of mortality from habitat fragmentation). The need for restoration should be considered carefully. Habitat restoration is not necessarily the most appropriate management action in all cases either for the habitat overall or for recovering tortoise populations. For example, in some cases simply stopping disturbance and allowing natural recovery to proceed may be an effective, cost-efficient strategy to improve habitat condition over time. Unfortunately, natural recovery of mature shrublands and soils in tortoise habitat is often slow, assuming recovery occurs. Dozens of research studies in the Mojave Desert have shown that particularly after severe disturbances (such as severe wildfires), reestablishment of perennial plant cover can require decades and species composition sometimes centuries. These are long time periods where quality habitat is unavailable to tortoises and could span numerous generations of tortoises. An intention of restoration is to accelerate recovery.

Restoration in desert tortoise habitats usually involves revegetation with native plants and environmental site restoration, or a combination of both. To accomplish this, restoration must contend with low and erratic rainfall, high winds and evaporation rates, generally infertile or eroding soils, high levels of herbivory (especially on potentially nutrient-enriched, propagated plant material), granivory (seed consumption by fauna), and limited existing biophysical structure on denuded sites. Despite the difficulties and if good restoration practices are

employed, the literature review and project descriptions by workshop participants indicate that dozens of habitat restoration projects have measurably improved cover plants, forage plants, and soil conditions within desert tortoise habitats. Restoration in tortoise habitat occurs along a continuum from rehabilitating habitats severely degraded to enhancing certain features (e.g., augmenting food plants) within habitat largely intact. The status of knowledge for restoring cover and food plants, ameliorating environmental site degradation, and restorative management actions (e.g., limiting disturbance) are presented next.

## RESTORING COVER AND FORAGE PLANTS UTILIZED BY TORTOISES

Major treatments for restoring or augmenting desired plant availability include outplanting, seeding, salvaging and transplanting, propagating cuttings, and assisted natural regeneration (encouraging on-site plant regeneration without bringing in plant material). While the literature review and workshop participants described many successful revegetations in tortoise habitat using these techniques, participants stressed the importance of employing current best-management techniques in achieving these successes and avoiding costly failures. Key principles identified by the review and participants follow.

### *Species Selection*

– **Select species** for restoration based on a combination of those **adapted to the site** (e.g., by assessing species composition of nearby undisturbed sites), that **provide desired functions** (such as large shrubs for cover plants and native forbs as forage plants), are **most amenable to restoration** or otherwise **provide key functions** worth including even if revegetation itself is less successful, that **have plant materials available**, and are **native to the Mojave/western Sonoran Desert** and in some cases to particular sub-regions of the desert. The literature review document provides further information on which species have been most successful in restoration thus far.

– There was some disagreement during the workshop regarding use of non-native plants in restoration. While there may be a limited role for non-native plants, such as possibly providing temporary cover until native plants become established, overwhelming consensus is that non-native plants should not be used in desert tortoise habitat restoration. The main reasons are that introducing non-natives can have unintended consequences including resulting in new invasive species, several non-native species are already prime threats to tortoise habitat, and numerous native species exist that are amenable to restoration and that tortoises utilize, generally rendering use of non-natives unnecessary. General **consensus is that tortoise habitat restoration efforts should focus exclusively on native plants**, with perhaps limited exceptions generally to aid eventual establishment of native plant communities.

– In addition to species selection, using **appropriate genetic material** was extensively discussed by workshop participants. Again with limited exceptions, current general consensus is that practitioners should use plant genetic materials as closely **matched to those that would inhabit the site to be restored**. Published seed zones now exist as restoration tools for guiding plant genetic selection in tortoise habitat. At the very least, genetic material from within the Mojave Desert should generally be used but finer-scale genetic variation may also be important.

- Insufficient evidence currently exists to support the idea of using assisted migration (actively transporting plants in attempt to track changing climate). The published literature is sparse and participants noted uncertainty of interactions between tortoises and plant species from outside the region. Moreover, plants may have some adaptive capacity *in situ*. It is possible that assisted migration could interfere with this natural process. Nevertheless, participants noted that efficacy of assisted migration could be evaluated as a potential tool in the future, especially if climate continues rapidly changing.
- Viewing plant species as ecophysiological biota, each with their own unique physiology and habitat requirements (not unlike wildlife species), and integrated within complex interactions within plant communities including plant-plant and plant-fauna interactions, may help illustrate some of the complexity that should be considered in species selection, genetic material use, and plant locations for revegetation.

### *Selecting Revegetation Treatments and Procedures*

- **Each of the major revegetation treatment types (outplanting, seeding, cuttings, and transplanting) have advantages and disadvantages.** No single treatment has been identified as “best” in all situations. The review and participants described numerous examples of successfully using each technique, customized to meet specific restoration goals (e.g., seeding rather than outplanting if a goal is to reestablish annual forage plants), site conditions, resources available, and amenability to different techniques of the species to be restored.
- **Bet-hedging approaches to restoration, by applying multiple treatment types to increase the chance at least one will work, may be particularly suited to the highly variable environments of tortoise habitats.** While applying multiple treatment types can increase the complexity and cost of restoration, it can help avoid project failures.
- **Outplanting is generally considered the most reliable active revegetation technique** because it bypasses the uncertainty of seed germination and vulnerable early seedling stages in the field. Outplanting also generally requires less seed collecting effort than does seeding and enables customizing specific spatial configurations of plants. However, outplanting requires nursery care of seedlings, transport of seedlings to field sites, and usually supplemental treatments to increase seedling survival. In extreme conditions (e.g., major droughts), even outplanting is not immune to complete failures, unless perhaps inputs are major (e.g., installation of irrigation systems). If outplants die, though, they can form vertical mulch which can still provide habitat benefits.
- Selecting appropriate species and genetics (as described above), producing quality plant material in nurseries, and using good planting techniques (such as properly covering roots with soil) all seem likely to improve outplanting success.
- **The most effective treatment identified thus far to increase outplant survival and performance is providing some form of protection to seedlings** (cages, shelters, or perhaps on-site materials like rocks). Evaluating treatments augmenting protection, such as possibly providing shade cloth on the top of cages, should continue given their high potential.

- Other treatments associated with outplanting, such as irrigation, have either been little evaluated or shown inconsistent effects. Several of these treatments have, however, been highly successful in certain projects and warrant consideration when planning outplanting. **Benefits of these treatments should be weighed against an alternative of simply planting more plants.**
  
- **Outplanting generally seems most amenable for restoration on small disturbances or for strategic establishment of vegetation patches to foster recovery within larger disturbances.** Some research has shown that flowering and seed production by outplants can occur within a few years, though more research is required to ascertain how often outplanting fosters self-sustaining populations (or at least stimulating recovery of non-outplanted, native species). Lists of successful species and treatments are provided in the review.
  
- Seeding generally requires collecting large quantities of seed, effectively delivering seeds to sites, and achieving successful germination and seedling establishment. **Results of seeding have thus far been inconsistent in tortoise habitats.** There are examples of total failures (zero plant establishment) and highly successful seedings, such as producing multi-year increases in key tortoise food plants. Weather conditions have not always correlated with success or failure. It should be noted that native seeds sourced from appropriate locations are often difficult to obtain and seeding projects often utilize inappropriately sourced seed. In these cases, it may not be possible to determine whether seeding failure is due to seeding as a technique, maladapted seed, or a combination of the two.
  
- As with outplanting, **careful species selection, using high-quality seed, and sometimes employing associated treatments have potential to increase seeding success.** For example, covering seeds in coatings (pelleting) has enhanced seedling establishment in certain species.
  
- Several workshop participants noted how using **programs such as the Bureau of Land Management, Mojave Desert Native Plant Materials program can be a helpful resource in aiding seed collection and procurement efforts.** Seed procurements generally must be initiated well in advance (sometimes years) of planned restorations. Some years in the desert support minimal seed production or do not result in many viable seeds available to collect. Collecting seed or increasing appropriately sourced wild collected seed was considered by several participants to be as much a part of projects as the implementation of site restoration activities.
  
- Seeding can be highly successful but because of its inherent riskiness, **pairing seeding with other treatments may be a prudent bet-hedging strategy.**
  
- **Salvaging and transplanting plants has advantages and disadvantages** similar to outplanting. An added benefit is that soil salvaged along with a plant can contain seeds and microorganisms beneficial to restoration. When there are opportunities to salvage plants for use elsewhere, transplanting can be an effective restoration tool applicable to contexts similar to outplanting. Where appropriate, salvage efforts can be useful as a partial offset for disturbances to at least mitigate habitat damage in a small way (benefits can be analyzed using metrics such as density of plants recovered at restoration sites).

– For species amenable to propagation by cuttings (a partial list is in the review), advantages include that seed collection and germination is unnecessary (though cuttings must be made to root). Cuttings are applicable in contexts similar to outplanting. **Research efforts to further determine which species are amenable to vegetative propagation, and by which methods, could expand the diversity and availability of plant materials.**

– **Assisted natural regeneration** has succeeded in other regions but largely **failed a cost-benefit analysis** in the one study in which it was attempted in desert tortoise habitat. Research is too limited to recommend or not recommend assisted natural regeneration at the present time. It could be considered an attractive restoration option because it promotes on-site genetics, does not require propagating or carrying plant materials to restoration sites, and facilitates natural plant regeneration processes. Further assisted natural regeneration research seems warranted.

– While dozens of studies in tortoise habitat monitored survival and performance of the plant materials directly introduced during active revegetation, a major theme in the review and workshop was a need to **better incorporate monitoring of how revegetation affects ecosystem functions (e.g., soil fertility) and short- and long-term indicators of the health of tortoises and associated fauna.** This is a major research need, along with assessments of the long-term influences of revegetation on tortoise habitat quality (e.g., enhancing food quality).

## **RESTORING ENVIRONMENTAL SITE QUALITY, SOILS, AND SOIL FEATURES**

Topography, soil properties, and soil features (biocrusts and desert pavements and varnishes) may require rehabilitation to improve habitat quality, and in some cases, may be required before revegetation can successfully occur. In addition to benefitting plants on which tortoises depend, environmental site restoration could have many other benefits to tortoises. For example, reducing transport of toxicants from contaminated areas could improve tortoise health in nearby, otherwise high-quality habitats. Perhaps combined with other management actions, rehabilitation of disturbed desert pavements could potentially curtail further unauthorized disturbances (e.g., via off-road vehicles). Biocrusts, consisting of surface layers of lichens, mosses, cyanobacteria, or other microorganisms, are an important part of native biodiversity on many sites in tortoise habitat. While biocrusts can have variable relationships with vascular plants, biocrusts induce heterogeneity in soil properties which in turn could affect tortoise cover and food plants, along with non-native plants. Furthermore, biocrust cover can reduce soil erosion, helping sustain soil productivity and limiting exposure of tortoises to wind-blown toxicants. Abiotic structural elements of habitats, such as rocks and dead wood, can provide important habitat functions such as supplying protected, shaded locations and microsites for trapping seeds for plant recruitment.

Four of the main treatment types for environmental site restoration in tortoise habitat include abiotic structural restoration (frequently using vertical and horizontal mulch), topsoil salvage and replacement, geomorphic/microtopography treatments, and the restoration of key soil features (biocrust and desert pavement and varnish). These treatments can help recover missing or degraded ecosystem features or provide surrogate features that may partially provide similar benefits. Goals of these treatments are diverse and may include promoting natural plant recruitment, increasing success of active revegetation treatments, reversing soil erosion,

reestablishing topographic heterogeneity including hydrological patterns, and offering structure useable by tortoises and associated organisms. Appropriateness of different treatments often depends on the nature of which features are missing or degraded, resources available, and site accessibility. Key principles and considerations of these treatments are summarized below.

### *Vertical and Horizontal Mulch*

- **Vertical or horizontal mulch are two of the main abiotic structural treatments.** Vertical mulch consists of placing dead plant material upright in the ground, providing shade, potentially trapping soil and seeds, and facilitating plant recruitment. Horizontal mulch materials include straw, wood materials, gravel, and others.
- Several workshop participants noted using vertical mulch in management projects for diverse purposes, such as concealing disturbances from view to deter further disturbance and for habitat improvement such as seeking to curtail soil erosion. **Research studies quantifying benefits of vertical mulch are less common but a small body of recent literature in tortoise habitat revealed benefits.** For example, vertical mulch reversed soil erosion and fostered the appearance of seedlings of shrubs (including species forming cover for tortoises).
- It is possible that vertical mulch partially provides some of the functions of live native perennials, including nurse plant effects. Nurse plants are often important for young plant establishment in desert ecosystems. In restoration sites where nurse plants are no longer available, such as severely burned sites, vertical mulch may simulate some of the protective benefits of nurse plants.
- Compared to active revegetation and many other treatments, **vertical mulch is cheap, often available on or near sites and therefore does not require transport, and is not necessarily contingent on unpredictable rainfall for effectiveness.** Disadvantages of vertical mulch include that donor areas must be available if vertical mulch is to be locally sourced, benefits fully equivalent to live plants are unlikely to be provided, and that vertical mulch can decay/collapse.
- Given that managers attending the workshop reported routinely deploying vertical mulch and recent research studies have quantified benefits, **vertical mulch may be an ideal component of an overall bet-hedging approach to restoration.** For example, relatively cheap vertical mulch could be paired with more expensive (and potentially riskier) active revegetation treatments. Given the low cost of vertical mulch, there may be little downside to routinely including vertical mulch as either a stand-alone treatment or in tandem with other treatments. **Vertical mulch can serve as a relatively precipitation-insensitive treatment that could provide benefits in both dry and moist years.**
- Research on optimal structure, materials, arrangements, and benefits of vertical mulch should be continued and expanded. Generally precipitation-insensitive treatments may become increasingly useful if climates in tortoise habitats continue to warm and dry.
- **Horizontal mulching has generally had inconsistent or limited benefits in tortoise habitat.** When applied together with outplanting or seeding, limited increases in plant establishment were

observed and in some cases, horizontal mulch appeared to hinder plant establishment. There have, however, been studies demonstrating benefits of at least some materials of horizontal mulch. According to workshop participants, use of horizontal mulch appears less common than use of vertical mulch in management projects.

– Given that some studies have found benefits of horizontal mulch but that overall effects have been inconsistent, horizontal mulch can likely be considered generally more experimental than reliable at the present time. Further exploring the numerous permutations to horizontal mulch (e.g., materials, thickness, timing of application) may help clarify the potential circumstances in which horizontal mulch could be most beneficial.

### *Salvaging Topsoil*

– For planned disturbances, **salvaging topsoil for re-application back to the donor site or to another recipient site can provide substantial restoration benefits.** Salvaging, storing, and re-applying topsoil represents a major up-front effort, but it can save restoration effort over the long term. For example, salvaged topsoil benefitted outplant survival nearly equivalently to irrigating plants. Topsoil contains organic matter, microbes, nutrients, and seeds that can stimulate recovery.

– Present knowledge suggests that ideal salvage procedures for Mojave Desert soils include: 1) avoiding areas infested by non-native plants or soil contaminants; 2) consistently salvaging the upper 5-10 cm when a goal is to maximize soil seed bank density; 3) timing salvage to occur in summer from May through September (and later into fall if it is a dry year) to capture winter annual seeds dispersed the previous spring, but before seedlings emerge in fall/winter; and 4) ideally storing topsoil for as little time as possible (to limit loss of biota and nutrients).

### *Geomorphic and Microtopography Treatments*

– **Geomorphic and microtopography treatments can be used to alleviate homogenized land surfaces** (e.g., decommissioned surfaces of dirt roads) by roughening surfaces, de-compacting soil surfaces, creating at least temporary basins or depressions to trap resources (e.g., water, seeds), slow soil erosion, and reestablish hydrological patterns.

– Some papers and presentations at the workshop of ongoing projects reported benefits of microtopographic treatments such as increasing seed retention. Installing wind fences and structures mimicking shrubs also slowed soil erosion.

– **Existing research on microtopographic treatments highlighted benefits but further research is likely required to improve matching specific treatments to site conditions.** For example, a consideration for ripping to de-compact soils are sub-surface salts, which could be raised to the surface and deter plant growth. As with other abiotic treatments such as vertical mulch, microtopographic treatments have potential to be cost-efficient strategies triggering natural recovery and to be less sensitive to unpredictable rainfall than is active revegetation.

### *Biocrusts*

- **Research on biocrust restoration is still in the early stages in tortoise habitat, but the rapidly advancing field of desert biocrust restoration has generated considerable information from other regions likely applicable to tortoise habitat.** Biocrust restoration practices have generally focused on three themes: stabilizing soil conducive to natural biocrust recovery, resource manipulations (e.g., fertilization) to promote biocrust growth, and inoculation-based techniques. These techniques include propagating or salvaging biocrust organisms and reintroducing them at restoration sites.
- Two biocrust studies in tortoise habitat reported that **salvaging biocrusts can foster rapid partial recovery (within two years) at restoration sites.** While further research could likely aid developing scalable, cost-effective techniques, applying biocrust organisms could be a major strategy for triggering ecological recovery similar to for topsoil salvage.
- Ideally from an ecological standpoint, **salvaging biocrust (if present) along with soils, seeds, and plants would accompany planned disturbances** so the salvaged resources could at least be used elsewhere on the landscape. Salvage can require storage, transport, and reapplication but has emerged as among the most effective restoration techniques in tortoise habitat, at least for strategic, priority areas.

#### *Desert Pavements and Varnish*

- Desert pavement is a stone-covered geomorphic surface, consisting of densely packed stones. These are typically ancient surfaces, commonly exceeding 10,000 years old, and recover only slowly (likely millennia for large disturbances) after disruption by human activities. Pavements cover substantial areas in and around tortoise habitat and can support unique plant composition and hydrological properties. **Restoration of desert pavement is not well developed** and complicated by the fact that pavements are integrated geomorphic features including the surface stones and unique subsoils. However, it is possible that certain **raking techniques, adhesives, or other strategies could partially restore some of the surface functions of pavements.** Further research on pavement restoration is recommended.
- Often accompanying pavements but on other surfaces as well, desert varnish is a thin coating on desert rocks. Disturbance can disrupt varnish by overturning and scattering rocks and raising unvarnished, sub-surface rocks to the surface. While a main reason to restore varnish is aesthetics, **varnish could also provide ecological functions**, such as possibly extending growing seasons via varnish warming temperatures. Color amendments to simulate the color and appearance of varnish were examined in one study and could be considered as part of comprehensive restoration in tortoise habitats.

#### **RESTORATIVE MANAGEMENT ACTIONS**

Several activities were reviewed and discussed at the workshop that fall along a continuum of restoration and management. For example, removing non-native plants as a stand-alone treatment would generally be considered a management action (rather than restoration), but non-native management is often part of restoration and in some cases can have substantial restorative benefits. A key point emphasized by workshop participants and in the broader restoration

literature is that restoration is often most effective when merged with management activities to maintain restoration sites or nearby sites to protect restoration sites. Treating non-native plants within and surrounding a desert restoration site to protect the site and restoration investment from wildfire would be a good example. Two of the main management actions emphasized in both the review and workshop included fencing and protection to limit disturbance and managing non-native plants.

### *Protection*

– **Fencing to limit disturbance** by unauthorized human use (e.g., off-road vehicles), other human impacts, and non-native animals **enhanced both habitat quality (based on metrics such as cover of tortoise food plants) and desert tortoise health and population size over multiple decades** at the Desert Tortoise Research Natural Area. **Protection to limit disturbance was emphasized in papers in the literature review and by several workshop participants.**

Protection was viewed as a potentially important part of restoration (such as protecting sites to avoid restoration efforts being negated, depending on the level of disturbance a site could receive) and as an independent restorative management action.

– Several studies have shown protection can enhance habitat condition. Further restoration or management may still be needed to recover certain habitat elements, but an initial action of protection can provide long-term benefits. Disadvantages include that fencing can be expensive to install and requires maintenance and may hinder animal movements. Leaving an opening at the bottom of a fence can enable tortoise movement.

– More broadly, fencing and correlational studies relating degree of disturbance with tortoise presence have highlighted that limiting disturbance improves habitat quality and potentially tortoise health and population sizes. **In areas where sustaining tortoises is a primary goal, limiting disturbance should be an overarching management theme.** Perhaps these areas could be managed for minimal human use or for light use such as designated-trail hiking.

### *Reducing Non-Native Plants*

– **Reducing non-native plants (especially annual grasses including red brome [*Bromus rubens*] and Mediterranean grass [*Schismus* spp.]) is perhaps the highest priority for habitat restoration identified in the literature review and workshop. Non-native grasses are a top threat to tortoise habitat by fueling wildfires that can degrade habitat quality for decades to centuries by removing tortoise cover plants, altering annual food plant composition, and changing soils and site conditions.** Even in the absence of wildfires, non-native grasses can reduce forage quality because **non-native grasses are non-favored food plants and can compete with more desirable, native food plants. Poor nutrition has correlated negatively with measures of tortoise health and juvenile survival.**

– When non-native annuals are reduced, native annual food plants of tortoises have responded positively. **Reducing non-native annuals to improve overall native ecosystem quality and forage conditions for tortoises is a top priority.**

– **Research on reducing non-native grasses in tortoise habitat is not extensive and is a top research priority.**

– Limited research thus far suggests that carefully timed herbicides (such as early in growing seasons to exploit the accelerated phenology of non-native compared to native plants) can reduce non-native annuals while increasing native annuals. The importance of timing is applicable to non-native grasses as well as to priority non-native forbs, such as Sahara mustard (*Brassica tournefortii*). While it is not clear if herbicides directly affect tortoises, early timed herbicides could occur during general periods of minimal tortoise activity.

– Numerous other variations and possible treatments for non-native grasses exist, such as different types of herbicides, carbon addition, and competitive suppression by natives. These treatments, however, have been minimally tested. Further testing is a research priority.

– **A major research program focused on reducing non-native annuals and increasing native food plants is a top research priority to support a potential next generation of tortoise recovery actions.** Potentially dozens of research experiments are needed to test the diversity of candidate control treatments, how different types of sites respond to treatments, options for a range of cost-effectiveness and sizes of treatments, and to evaluate potential for unintended effects on tortoises and habitats. **These research studies should further be conducted across a range of climatic conditions given the likely contingency of results on climatic fluctuations.**

– In addition to well-established non-native plants, **new invasions are an omnipresent threat to tortoise habitat quality. Early detection programs to identify and treat incipient invasions** can be one of the most cost- and ecologically effective strategies to managing non-native plants.

## **RESTORATION FINANCES AND LOGISTICS**

Restoration in tortoise habitat has spanned a range of costs from cheap, volunteer-led projects to expensive mitigation projects costing tens of thousands of dollars per hectare. A key point is that higher costs do not necessarily equate to greater success. For example, an expensive project using poor-quality seed and that mismatches species with sites may have a greater chance of failure than a cheap project using on-site materials, like vertical mulch, effectively. In general, projects that employ active revegetation tend to be more expensive because of costs with plant production, planting, and maintenance. Projects that involve heavy equipment for soil salvage or environmental site treatments can also be expensive, at least in terms of up-front costs, as can projects involving fencing. Table 10 in the literature review summarizes a range of example restoration components and costs in tortoise habitat. Key points are summarized below.

### *Disturbance Severity and Degree of Restoration*

– In general, **increasing disturbance severity either increases restoration costs or decreases the proportional amount of damage that can be repaired at a given cost.** This underscores seeking to limit severe disturbance to the extent possible. When this is not possible, severe disturbances can generally be expected to be the most difficult, expensive, and slow to restore.

### *Restoration Logistical Planning*

– **Careful, advance planning is typically helpful or essential to effective restoration project implementation. Seed collection or orders often need to occur at least a year in advance, or even two years if a year is required to propagate material in the case of outplants.**

– An absence of advance planning for plant materials has often unfortunately resulted in projects using inappropriate species or improper genetics because these are all that are available on short time scales. This should be avoided. Extensive discussion occurred among workshop participants on whether such projects may even do more harm than good. **Current consensus is that proper plant materials should be used in restoration projects, otherwise, it may be better to delay a project or instead focus on using abiotic treatments.**

– Restoration budgets and logistical planning should include elements such as, but not limited to, plant materials (if included), appropriate personnel and access to sites, transport of materials, potentially storage of materials, site infrastructure (e.g., irrigation) as needed, on-site threats such as herbivory or human disturbance, adjacent land uses, inherent site factors like soil parent materials and nearby reference plant composition, a plan for site maintenance (e.g., non-native plant treatments), and effectiveness monitoring.

– **Many workshop participants noted that they would like to see monitoring occur more frequently after operational restoration projects.** While this can add expense and require some expertise, not doing monitoring misses an opportunity to make adjustments during projects and to increase future cost-efficiency by learning what works in what situations.

– The reader is referred to the literature review for access to citations on key elements of project planning, such as availability and costs of restoration materials and equipment.

## **SPATIAL AND LANDSCAPE CONSIDERATIONS**

Prioritizing sites for restoration and optimizing the spatial arrangements and sizes of restoration deployments is an emerging research theme in restoration ecology generally. In the context of desert tortoise habitats, example spatial restoration questions include:

Given limited plant materials and restoration resources, should resources be deployed in small patches within large disturbances to potentially coalesce over time, or should restoration occur in larger or contiguous blocks like creating corridors for tortoises to cross the disturbance?

Should limited resources for non-native plant management for fire prevention create strategic fuel breaks, or instead focus on fully treating the highest priority sites?

Should restoration be prioritized at the most degraded, difficult-to-restore sites to at least increase their usability? Or, should restoration be prioritized at the least degraded sites requiring the least restoration?

Many other questions additional to above were posed at the workshop and the options would not necessarily be mutually exclusive. For example, prioritizing a mixture of severely and lightly degraded sites could be an optimal strategy. A key message is that little research exists on these

relevant questions in tortoise habitat and that these warrant further research given the likelihood of increasing disturbance and restoration needs across diverse landscapes. While few principles yet exist on this emerging topic of spatial allocation, some points are below.

### *Linking Desert Tortoise Ecological Knowledge with Spatial Restoration*

– While imperfect, **home range studies** and studies of **broader-scale tortoise movements** could be integrated with and **help inform spatial allocation and arrangements of restoration units**. Further studies of how tortoises utilize resources spatially, such as patches of food plants, could be informative.

– **Patches as large and unfragmented as possible are likely to contribute to overall tortoise habitat quality**. Restoration could have much to contribute to sustaining large habitat areas. For example, decommissioning and conducting restoration on an unwanted roadway could reduce fragmentation and increase the amount of contiguous, interior habitat. This represents a strategic application of restoration where even a small amount of restored acreage could have landscape-level effects.

– Providing resources for tortoises – such as cover plants, quality patches of forage, and roughened topography for water catchments – at multiple spatial scales through restoration planning could benefit tortoises. Spatial scales could range from individual home ranges to tens of kilometers. **How to best accomplish these types of spatial allocations and determining how tortoises would best utilize them requires further research.**

– **An overarching theme in the workshop was working toward “scaling up” restoration treatments**. This does not negate the common research need to first develop and test restoration practices in small areas. Often, a treatment (such as a particular seeding practice) that does not work in small plots will be unlikely to work in larger areas. **A path forward could be viewing treatment development as a series of stages**, where efficacy is first determined in small plots, separate research then seeks to identify procedures (or equipment and other logistics) effective for applying the treatment to larger areas, and finally treatment effectiveness at multiple spatial scales is assessed.

– **Some treatments may not require scaling up or resources may never be available to scale them up**. For example, it may be possible to achieve plant cover across areas larger than originally outplanted or seeded if strategic use of limited plant materials in small areas triggers plant reproduction.

### **ANTICIPATED FUTURE CHANGES**

Three primary habitat changes identified in the review and that participants expect to continue (and intensify) include continued disturbance/fragmentation, non-native plant invasions and wildfires, and climatic changes. Renewable energy developments have already fragmented and destroyed vast areas of habitat and this trend is anticipated to continue, perhaps for decades. It is not yet fully clear to what extent these facilities can offer some habitat to tortoises (if this is a goal in lieu of full clearing) nor how facilities could have cumulative effects across the

landscape. Wildfires have already burned several percent of tortoise habitat. Given the recovery debt from slow post-fire recovery and the likelihood fires will continue (as reburns and in new areas), wildfires are anticipated to affect a cumulatively increasing area of tortoise habitat. If a general warming and drying trend continues, climatic changes could have numerous effects on tortoises directly (e.g., influencing temperature exposure and activity patterns and availability of drinking water) and indirectly, such as mediated through food plant availability. Moreover, more nuanced changes, such as shifts in the timing or amount per event of rainfall even if total annual rainfall does not change, could have major influences. Workshop participants view these three major potential threats as daunting individually and nearly overwhelmingly intractable in combination. A key message was while keeping in mind the interactive nature of factors, breaking up the topics into components for research and management attention could be a useful path forward. For example, while climate change could have profound overall effects, restoration projects could take workable steps such as emphasizing more drought-tolerant species in restoration projects to begin mitigating potential climate effects. Some key points include:

### *Climate Change*

- **Climatic changes arguably make habitat restoration even more relevant.** For examples, tortoises with adequate plant cover, quality food plants, and intact natural water catchments could be anticipated to better accommodate climatic warming and drying than tortoises in poor condition in poor-quality habitat.
- Conversely, **declining and unhealthy tortoise populations and poor habitat could make tortoises more susceptible to climatic changes** than they otherwise would be.
- **Two main ways restoration could help tortoises adapt to warmer and drier climates include conserving/restoring cover plants and conserving/restoring native food plants while reducing non-native plants.** Cover plants can help keep tortoises below lethal temperatures and enable continued movement and resting. A major concern with non-native plants is they can usurp rainfall that could have been used by native plants. Enabling native plants to utilize any plant-available moisture could become increasingly important if climate dries. Removing competition from non-native plants for water is a top priority.

### *Broad-Scale Disturbances*

- **Reducing hazardous fuels and wildfire risk could be advanced through research priorities in developing treatments for non-native plants,** as discussed previously.
- Alleviating **effects of renewable energy disturbances** specifically was beyond the scope of the literature review and workshop. However, the restoration practices discussed here are applicable to temporary disturbances associated with facility construction and maintenance and perhaps nearby lands affected by facilities.

## RESEARCH AND ADAPTIVE MANAGEMENT NEEDS

In addition to research ideas raised by the review and participants infused throughout the report, six major research priorities to advance habitat restoration are summarized here.

1) To build on the few dozen existing Mojave Desert restoration studies, testing should continue on species performance and treatments for cost- and ecologically effective revegetation and environmental restoration techniques and on how to integrate treatments to maximize bet-hedging in variable environments. As the review and workshop presentations illustrated, existing studies have begun identifying top-performing plant species and the types of treatments required to enable successful revegetation. However, only dozens of native perennials and fewer annuals have yet been examined in even one study for their revegetation potential, whereas tortoises may collectively utilize at least 250 plant species for cover and forage. Furthermore, multiple studies with priority plant species may be needed to develop reliable propagation and restoration procedures to make the species viable for restoration in tortoise habitats. There is a need to avoid a potential misconception that conducting multiple studies focused on similar goals represents a wasteful, duplication of effort. **Instead, testing variations to different candidate restoration practices in different conditions can help provide practitioners with information on expected treatment reliability, a “tool box” of potential treatments to choose among to deploy, and improved matching of treatments to conditions in which they are expected to provide the greatest chance for success.**

2) **Research on how to most effectively deploy restoration resources spatially is likely to be beneficial.** For example, if managers have funds for 3,000 outplants to revegetate a disturbance, how are the outplants best deployed? Should they be evenly spaced to potentially stimulate recovery into coalescing patches? Or, should they be planted in clusters as revegetated islands that could expand while serving as thermal refugia, enabling tortoises to move through and utilize a recovering habitat sooner? Furthermore, “scaling up” restoration can be difficult given limited resources. A complementary approach is focusing on how to maximize landscape benefits of applying restoration strategically to small areas.

3) A major research program is needed to develop local and landscape-scale approaches to **improve the condition of the annual plant community by reducing non-native annual grasses** (in turn reducing hazardous fuels) while promoting native herbaceous food plants.

4) **Research that connects habitat enhancement activities with short- and long-term indicators of desert tortoise health and population traits is likely to be beneficial.** This represents a next step from previous research that correlated extant environmental features with tortoise health (e.g., correlating tortoise growth with forage availability) and in studies and workshop discussion advocating for the potential that habitat restoration may have for improving tortoise health. The opportunities in this realm for collaborations between tortoise biologists and plant ecologists/restoration ecologists seem extensive. There is an existing supportive literature outlining tortoise health indicators that could be assessed for evaluating changes in tortoise health during and after restoration activities.

5) Multiple threats face tortoises and these threats can interact with each other and be cumulative spatially and temporally. Addressing only one or a few threats may not improve tortoise well-being if other threats continue unabated. **A research priority is exploring whether comprehensive habitat restoration is capable of reversing declining short-term indicators of tortoise health and longer-term population declines.** Perhaps this could be examined within a protected, test landscape as an adaptive management experiment. With as many other threats (e.g., anthropogenic disturbance, subsidized predators, disease) as possible minimized or eliminated, comprehensive restoration could be implemented (including but not limited to enhancing perennial cover plant availability, reducing non-native plants and promoting high-quality native forb forage plants, and reconstructing hydrology as needed) across years and short- and long-term indicators of tortoise response measured.

6) Workshop participants described a range of desired information needs, such as site-specific to landscape-scale questions, questions focused on managing/restoring individual species to entire plant communities, nuances of particular treatments that could affect outcomes, a diversity of ecosystem components (e.g., biocrusts, cover plants), a variety of management settings (e.g., wilderness as compared to urban-interface sites), and in different climatic conditions. **This diversity of information needs seems well-matched to a range of research, adaptive management trial, and monitoring approaches along the ecological information-gathering continuum.** For example, relatively low-cost research or adaptive management trials could refine developing candidate treatments for particular non-native plants or identify how to restore certain tortoise forage plants. Contrastingly, broader-scale research studies may be required to identify how spatial distribution of tortoise forage plant availability may shift in response to climatic variation. Utilizing a diverse range of research, adaptive management, and monitoring approaches across scales, while connecting habitat metrics with indicators of tortoise responses, could aid making information-gathering supporting habitat restoration more manageable.