Component 1: Guidance Document

A Strategic Approach to Restoration: Using the Science of Ecological Restoration to Guide Habitat Restoration for the Mojave Desert Tortoise

Photo of Desert Tortoise Research Natural Area, courtesy of Desert Tortoise Preserve Committee

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1. Abstract

Ecological concepts provide insight into understanding how ecosystem and human dynamics together influence habitat restoration for the Agassiz's Desert Tortoise. Here, we identify attributes of restored ecosystems that are fundamental to desert tortoise habitat. These attributes are represented in four categories: form, function, stability, and feasibility. Using a conceptual framework, we identify the pathways through which these categories and their associated attributes can influence the effectiveness of habitat restoration. Furthermore, we detail how these attributes can be strategically applied to on-the-ground restoration actions. This guidance document, used together with a site assessment tool and site-specific restoration plan, is meant to serve as a framework for strategic habitat restoration. Using this approach, we show that the outcomes of habitat restoration can be both efficient and effective; thus, our framework provides useful information for managers focused on habitat restoration for the desert tortoise.

2. Background

Restoration Ecology is a relatively young yet rapidly growing scientific field. In 2002, the Society of Ecological Restoration (a group composed of scientists and policy makers) published the first edition of *The SER Primer on Ecological Restoration* (Primer). Referred to by many as a foundational document in the field of restoration ecology (Shackelford et al 2013; Hallett et al 2013), the Primer aimed to clearly define ecological restoration and to describe the process in terms of its attributes (SER 2002). Since the Primer was published, the science of restoration ecology has become a well-represented academic field, with a significant increase in research and publications in peer-reviewed journals (Young et al 2005). Along with this growth, has come an increasing desire to define a scientific identity for restoration ecology and its relationship to ecological restoration. Following this movement, a number of academics have sought to update the Primer, as the concepts, methods, and goals of ecological restoration continue to evolve (Shackelford et al 2013; Hallett et al 2013). Together, the Primer and its successors provide essential background for studying ecological restoration.

Understanding the principles of ecological restoration is key to proper application of the science. According to the Primer, ecological restoration refers to an "intentional activity that initiates or accelerates the recovery of an ecosystem with respect to its health, integrity and sustainability" or "the process of assisting in the recovery of an ecosystem that has been degraded, damaged, or destroyed". In these simple statements, the need to intentionally establish goals, apply actions, and manage outcomes becomes clear. Hence, goals should be based on recovering an ecosystem's health and integrity and promoting its sustainability. This requires an understanding of present ecological condition and potential or, put another way, the attributes that support the desired condition and potential. Actions should be applied in support of goals; therefore, the present ecological condition should serve as the basis for determining appropriate actions. Additionally, comprehensive and informative restoration planning can be delivered by explicitly accounting for the benefits, costs, and risks of different restoration techniques, as opposed to considering restoration as a single monolithic action (Shackelford et al. 2013). Records of past restoration efforts provide a wealth of knowledge as to the potential outcomes of various actions;

and though many factors may influence outcomes, past efforts can serve as a basis for anticipated outcomes. Used together with effective monitoring, evaluation and adaptive management, this goal - action - outcome approach can be thought of as the backbone of strategic restoration. As stated in the Primer, the science of restoration ecology provides clear concepts, models, methodologies, and tools for practitioners in support of their practice; as such, linking theory to application is essential to employing ecological restoration in a strategic manner.

In addition to the general scoping of ecological restoration, other fundamental concepts are detailed in the literature. First discussed in the Primer, and echoed throughout the literature, are important concepts concerning appropriate scales and the inclusion of reference ecosystems. Selecting an appropriate scale, both in space and time, is key to successful restoration. Choosing a spatially explicit landscape perspective will ensure that energy flows, interactions, and exchanges are suitable with contiguous ecosystems. Similarly, choosing an appropriate time scale will be based on the ecological trajectory for restoration, as it dictates the developmental pathway of an ecosystem through time (SER 2002). Choosing a comparable and appropriate reference ecosystem is another important consideration. Notably, with an increased understanding and appreciation of global environmental change, comes the realization that the restoration of historical conditions is often unrealistic (Hallett et al. 2013). In light of this perspective, many projects have shifted focus from returning the ecosystem to a historical reference and instead focus on restoring specific functional attributes (Hallett et al. 2013). Stochasticity and uncertainty are also important to consider, as they represent natural ecosystem processes that cannot be predicted, but may have significant effects on restoration activities. In reality, the possibility that desired outcomes will not be realized is seldom dealt with, although accounting for the possibility of failure will likely influence which sites are prioritized for restoration and when the restoration should occur (McBride et al. 2010). Though these concepts are not the focus of this document, they are important to consider. Here, we integrate these concepts as they relate to key ecological attributes.

Restoration would not be complete without explicitly considering monitoring, evaluation and adaptive management. Monitoring of a restoration site should take place throughout the restoration process from concept to completion. Through monitoring, objectives can be evaluated on the basis of performance standards or success criteria. These standards may be conceived, in part, from an understanding of the reference ecosystem (SER 2002). Next, based on the results of evaluation, adaptive management may be employed — providing a strategy for altering or changing current management actions and thus adapting to the present conditions. Even when the restoration process is complete and the future health and integrity of the site can be sustained without manipulation, monitoring and management remain essential to continued success. In fact, both restored and undamaged natural ecosystems may be vulnerable to threats from invasive species, human activities, or climate change; and therefore require continued monitoring and management (SER 2002). What's more, the use of imperfect reference ecosystems and natural variations in the ecosystem from stochasticity and uncertainty highlight the need to explicitly monitor, evaluate, and adapt throughout the restoration process (SER 2002). Through incorporating these fundamental components of ecological restoration, we can ensure that habitat restoration is well-informed and flexible, increasing the chance of success.

Alongside the application of ecological principles, the attributes of a restored ecosystem serve to guide strategic restoration. In the Primer, nine attributes of restored ecosystems are identified, and then grouped into three distinct categories: form, function, and stability. Through the process of ecological restoration, the ecosystem will: contain sufficient biotic and abiotic resources to continue its development without further assistance or subsidy, demonstrate resilience to normal ranges of environmental stress and disturbance, and interact with neighboring ecosystems in terms of biotic and abiotic flows and cultural interactions (SER 2002). Though these attributes remain central to employing strategic restoration, they do not adequately address a key element of restoration: the human element (Hallet et al. 2013, Shackelford et al. 2013). A number of research articles, including an update to the Primer published by Hallett et al. (2013) in *The Journal of the Society for Ecological Restoration*, have stressed that the explicit inclusion of social goals is critical to the success and value of ecological restoration (Hallet et al. 2013). Here, we will represent this attribute by the addition of a fourth category, referred to as feasibility. Thus, these four categories: form, function, stability and feasibility, serve to represent the fundamental attributes of restored ecosystems.

3. Method

The principles and attributes of ecological restoration serve as the foundation for application. From this foundation, other attributes of restored ecosystems may be added or adapted based on goals of the restoration project (SER 2002). Here, we aim to restore habitat for the desert tortoise, with the term habitat referring to "the dwelling place of an organism or community that provides the requisite conditions for its life processes." As detailed above, we will use the categories of form, function, stability, and feasibility to represent the essential components of restored ecosystems. These categories are further described in Table 1, *Components of Restored Ecosystems*. Using these categories as a starting point, we developed a conceptual model to explore and identify the attributes of restored ecosystems that are fundamental to desert tortoise habitat (Figure 1). By mapping these four categories to the attributes of desert tortoise habitat, we are able to represent all essential features of desert tortoise habitat in an ecologically and scientifically sound way.

Table 1. Components of Restored Ecosystems

Category	Description
Form	Form refers to the form or structure of the ecosystem. It is based on a characteristic assemblage of the species that naturally occur in an ecosystem and provide appropriate community structure. It consists of indigenous species to the greatest practicable extent. Additionally, it contains the physical features that naturally occur based on the ecosystem type.
Function	Function refers to the ecological processes of the ecosystem. It is based on the presence of functional groups (or potential presence) necessary for systems to remain stable or persist without outside interference. It consists of the dynamic processes that act on the structural components (form) of the ecosystem.
Stability	Stability refers to the resilience of an ecosystem, based on its ability to maintain integrity and be self-sustaining. This resilience is measured by the restored ecosystem's ability to endure normal periodic stress events and resist threats. It also includes the physical environment and climatic features that function to sustain reproducing populations of the species necessary for its continued stability or development along a desired trajectory.
Feasibility	Feasibility refers to the practicality of restoring the ecosystem. Obstacles to ecological restoration may limit success and make restoration impractical.

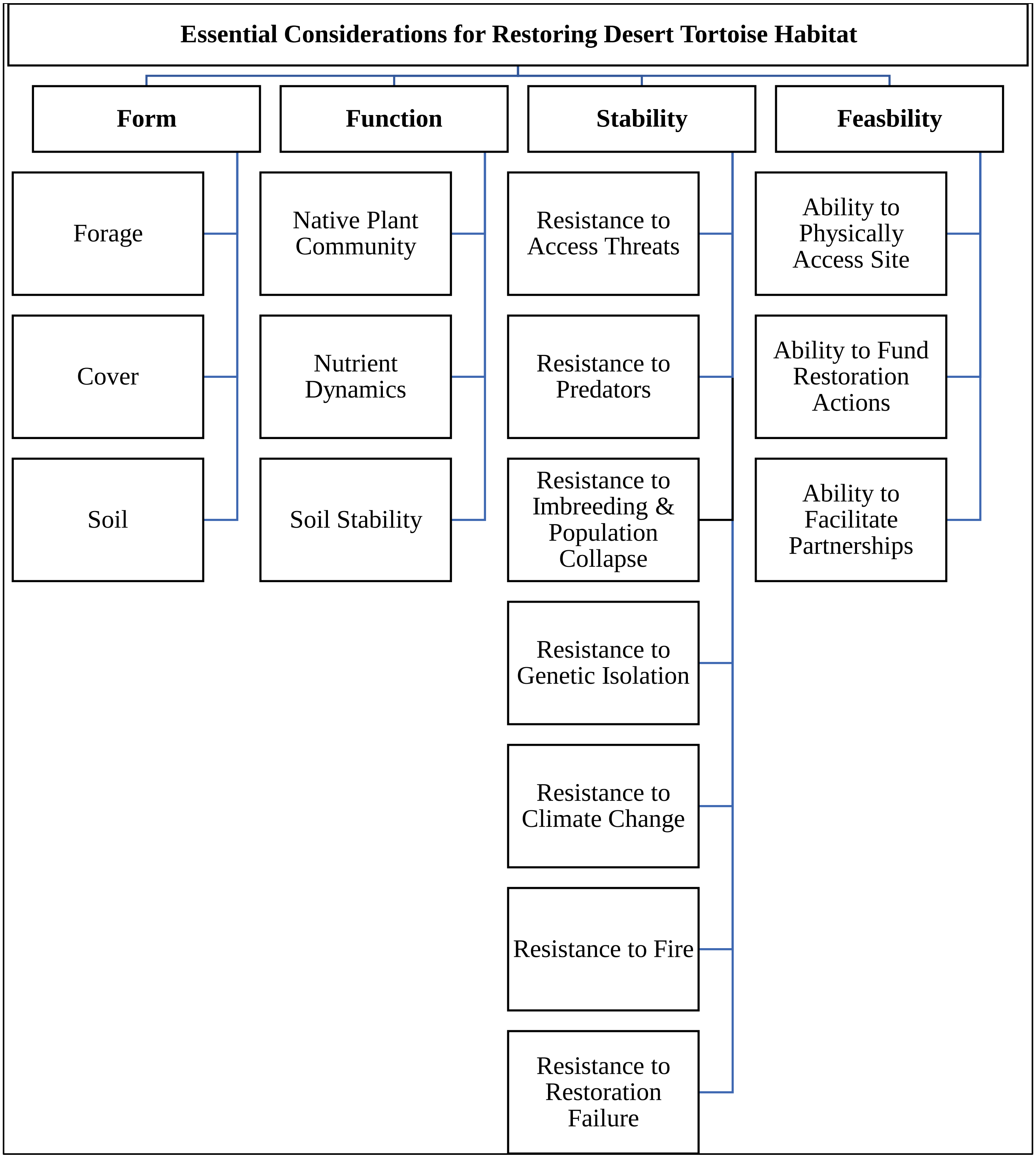

Figure 1. Conceptual Model

4. Application

The conceptual model (Figure 1) is used as the foundation for applying strategic habitat restoration. The features represented in each of the four categories refer to attributes that are important for healthy desert tortoise habitat, and thus, are essential considerations for restoring desert tortoise habitat. Here, we discuss the significance of each attribute as well as the management actions that should be considered for restoration. Table 2 defines and describes management actions that may be considered based on the current conditions of the habitat.

4.1 Form

4.1.1 Forage

Desert tortoise habitat should contain a variety of native annual and herbaceous perennial forbs that are favored as forage by the desert tortoise, which are known to be very selective foragers (Henen 1998, Esque et al. 2014, Jennings and Berry 2015, Abella and Berry 2016). Preferences for these plants can often be species-specific and usually overlap with the diets of other non-native animals (e.g., herbivores such as sheep and cattle). Tortoises of different age have been observed to prefer different species, based on varying sizes and, more specifically, leaf heights (Morafka and Berry 2002, Oftedal et al. 2002). Invasive plants can decrease both the quantity and quality of forage, by competing with native forage as well as increasing other threats, such as the proliferation of wildfires, which negatively affect the tortoise's nutritional needs (Oftedal 2002, Hazard et al. 2009, 2010). Overall, there is extensive literature detailing the importance of quality forage for the desert tortoise (Drake et al. 2015, Jennings and Berry 2015). Therefore, annual and herbaceous perennial forbs must be augmented and competition with non-native species must be reduced.

Management actions that may be considered for improving forage include: seeding, planting, excluding non-native herbivores, removing invasive plant species, and caging. These, and all other management actions, are further described in Table 2.

4.1.2 Cover

Desert tortoise habitat contains a mix of native perennial shrubs. Perennial plant species (representing canopy and shrub species) act as an obligatory source of cover for desert tortoises, providing protection from both predators and the harsh desert environment. Studies suggest tortoises avoid areas of very low plant cover (Andersen et al 2000; Drake et al 2015). Thus, by increasing the density of best performing shrub species and decreasing competition with non-native species, adequate cover can be maintained.

Management actions that may be considered for improving cover include: seeding, planting, excluding non-native herbivores, removing invasive plant species, and caging.

4.1.3 Soil

Desert tortoise habitat contains soil that supports the appropriate forage and cover species. In addition, soils must be friable (or malleable), allowing for burrow creation. Burrows are an essential components of desert tortoise habitat as they provide shelter from predators and help with thermoregulation (Germano et al. 1994, Andersen et al. 2000, Abella and Berry 2016). These burrows are important for survival, and tortoises spend the majority of the year inside burrows in order to escape predation and temperature extremes (Andersen et al. 2000, Mack et al. 2015). The ability for a tortoise to burrow is dependent on a site having soil which is easy for a tortoise to move aside when digging, but is not so fine that burrow structures collapse (Andersen et al. 2000, Abella and Berry 2016). Soil compaction from off-road highway vehicle (OHV) access and non-native herbivores can greatly reduce the quality of desert tortoise habitat, compacting them to levels unsuitable for forage and cover species establishment (Lovich and Bainbridge 1999).

Management actions that may be considered for improving soil condition include: salvaging topsoil, vertical mulching, ripping, imprinting, and re-contouring berms.

4.2 Function

4.2.1 Native Plant Community

A functioning native plant community is a crucial component of desert tortoise habitat. As stated above in ‘forage’, desert tortoises prefer native annual and herbaceous perennial forbs and tend to be selective foragers. The re-establishment of a functioning native plant community, which includes the reproduction and growth of organisms, is what leads recovery to being autogenic (SER 2002), where self-sustaining feedback loops lead to continued improvement of functional attributes. In low resource ecosystems, like deserts and rangelands, resource loss is mediated abiotically. Therefore, to initiate autogenic recovery in severely degraded systems, restoring abiotic functions such as nutrient dynamics and soil stability is a priority (King and Hobbs 2006). Overall, recovering autogenic processes to the point where external manipulation of the system is no longer needed, is a common goal for restoration. In desert tortoise habitat, focusing on actions that restore abiotic processes may serve as a starting point for ecosystem restoration.

Management actions that may be considered for promoting the establishment of the native plant community include: seeding, planting, excluding non-native herbivores, removing invasive plant species, and caging.

4.2.1 Nutrient Dynamics

The balance of nutrients is vital to a functioning biotic system and crucial to desert tortoise habitat. The term ‘nutrient dynamics’ specifically refers to the process through which nutrients like nitrogen and phosphorus move between the soil and plant communities. In desert tortoise habitat, nutrient dynamics may be improved by increasing soil stability. This in turn increases the diversity of soil microorganisms, increases infiltration, and promotes nutrient cycling and balance. If the balance of nutrients is lost, the native plant community may lose its capacity to function, potentially creating a shortage of forage or allowing increased proliferation of invasive species.

Management actions that may be considered for improving nutrient dynamics include: salvaging topsoil, vertical mulching, ripping, imprinting and re-contouring berms.

4.2.2 Soil Stability

Soil stability refers to the ability of the soil to support nutrient dynamics, a native plant community, and tortoise burrows, and is therefore an essential feature of desert tortoise habitat. See section 4.1.3 *Soil* for more information on the significance of soil in desert tortoise habitat.

Management actions that may be considered for improving soil stability include: salvaging topsoil, vertical mulching, ripping, imprinting, re-contouring berms.

4.3 Stability

4.3.1 Resistance to Access Threats

Access threats such as OHV use, grazing, and access roads are some of the most important factors leading to degradation of desert tortoise habitat. OHVs and grazing animals harm habitat by crushing vegetation and compacting soil to levels unsuitable for plant establishment (Lovich and Bainbridge 1999). Roads provide easier access routes for both OHVs and grazing animals, while also creating linear disturbance corridors which allow invasive plants to penetrate habitat (Abella and Berry 2016). Roads also have detrimental effects on tortoise densities, most likely due to direct kill from vehicles (Boarman and Sazaki 2006, Nafus et al. 2013), but possibly from effects such as high noise levels. Dirt trails made by OHVs further contribute to these same direct detrimental effects. In addition to threats from OHV use, grazing animals may selectively browse important forage plants (Abella 2008, Berry et al. 2014), compact soils (Lovich and Bainbridge 1999), and are correlated with an increase in invasive plant abundance (Brooks and Berry 2006).

Management actions that may be considered for promoting resistance to access threats include: fencing, road camouflage, signage, and siting restoration sites further away from access roads.

4.3.2 Resistance to Predators

Predators subsidized by human activities can have significant effects on desert tortoise survival. Ravens are known predators of the desert tortoise (e.g. Boarman 1995), and due to resource subsidies from human dominated areas, have undergone population booms which make them difficult to manage for apart from site selection. Ravens are opportunistic and often congregate around landfills which provide consistent food and water resources (Boarman et al. 2006) and utility corridors which provide structures for building nests (Boarman 2003).

Management actions that may be considered for promoting resistance to predators include: exclusionary fencing, selecting restoration sites away from landfills and utility corridors, and capturing/caging known repeat predators with the purpose of relocating them far away from tortoise populations. Lethal control of predators such as coyotes or ravens is also an option to consider for repeat predator individuals who are not deterred by nonlethal methods.

4.3.3 Resistance to Inbreeding and Population Collapse

Desert tortoise habitat must contain viable desert tortoise populations to be considered successful. When populations are small in size, they face increased risk from threats such as inbreeding which lead to unviable populations and population collapse. The desert tortoise also has more complex concerns related to slow maturation rates and the need for viable populations to contain multiple age structures. Regardless, the viability of a population is closely related to its size. Sites which are not large enough to sustain a viable population cannot be considered good tortoise habitat.

Management actions that may be considered for promoting resistance to inbreeding and population collapse include selecting sites with existing tortoise populations and selecting sites which are large enough to promote genetic diversity.

4.3.4 Resistance to Genetic Isolation

The viability of tortoise populations can also be influenced by genetic isolation of a population. When there is a lack of gene flow between populations, separate populations can become more homogenous and be less adaptable to stochastic events or changes in the environment. Gene flow can also mitigate against population collapse from inbreeding and genetic depression. Successful tortoise habitat should be close to other habitat patches to foster movement between populations.

Management actions that may be considered for promoting resistance to genetic isolation include: selecting sites with existing tortoise populations, select sites near known tortoise populations, and carefully considering translocation.

4.3.5 Resistance to a Changing Climate

Climate change is an impending reality which will have unknown but potentially drastic effects on desert tortoise habitat. Without precise knowledge of the way climate change will affect desert tortoise habitat, restoration efforts need to consider and manage for risks associated with climate change. Some areas will undoubtedly be more severely affected by climate change than others. Distributing restoration efforts in different areas of the desert tortoise's known range can serve to spread out the risk of areas being severely affected by climate change. Therefore, risk management for desert tortoise habitat will need to center around fostering habitat diversity - both diversity within sites which are being restored and diversity in choosing areas to restore.

Management actions that may be considered for promoting resistance to climatic change include: planting and seeding diverse assemblages of plants and selecting sites across the desert tortoise's range.

4.3.6 Resistance to Fire

Fire has the potential to severely degrade desert tortoise habitat and is tightly coupled with the invasion of invasive grasses in arid ecosystems (D'antonio and Vitousek 1992). The ability for invasive grasses to recover rapidly after fire allows them to outcompete native cover and forage. Desert tortoises have been shown to recolonize areas that have recently undergone a single fire (Drake et al. 2015), but plant communities can take decades to recover from burns (Abella 2009, Engel and Abella 2011). Due to the heightened ability of invasive grasses to recolonize quickly after fire, multiple fires can change the plant composition of a site drastically enough that it may no longer be suitable for desert tortoise habitat without large amounts of restoration effort (D'antonio and Vitousek 1992, Abella 2009).

Management actions that may be considered for promoting resistance to fire include: removing invasive plant species to decrease ignition sources.

4.3.7 Resistance to Restoration Failure

Despite best efforts, restoration does not always succeed in creating stable habitat for the desert tortoise. While many of the factors that contribute to a restoration project failing can be directly managed for, there are potential stochastic events which are difficult to predict but provide additional unforeseen stress to habitats. The management of these stressors must be adaptive, as they are unknowns but still need to be considered in the planning of restoration activities.

Management actions that may be considered for promoting resistance to restoration failure include: monitoring restoration sites and creating adaptive management plans.

4.4 Feasibility

4.4.1 Ability to physically access site

The ability to physically access a site is necessary to conduct restoration. Sites located near existing infrastructure such as roads may still be considered for restoration, though threats from access may be present. Having an access point during active restoration activities can help contain vehicle movement and safely deliver equipment at a proposed restoration site. Post-restoration access to a site should be minimized as the negative impacts of roads on desert tortoises is well documented (see section 4.3.1, *Threats from Access*).

Management actions that may be considered for ensuring the ability to physically access the site include: carefully planning access points for facilitating restoration, fencing, road camouflage, and signage.

4.4.2 Ability to fund restoration actions

The ability to fund restoration actions is a fundamental component of any restoration project, as restoration cannot occur without proper funding. Restoration requires sufficient funding both to accomplish planned actions, monitor success, and adapt to changing conditions. More intensive restoration such as soil decompaction and planting is more expensive than less intensive actions because they require specific materials, equipment, and labor that would not be possible without funding.

Surveys and site assessments should occur at the start of a project to assess the current condition of the site. These activities are an essential part of restoration planning as they can help determine appropriate restoration actions and subsequently can inform funding needs. If necessary, fundraising should be considered prior to the start of restoration to ensure the highest likelihood of success. Fundraising may also need to occur in phases depending on the type and length of restoration occurring onsite.

The creation and use of adaptive management is an important consideration for funding restoration actions. Creating an adaptive management plan that is responsive to changing levels of funding, for example, could be designed from inception to be implemented in phases as funding becomes available.

Management actions that may be considered for ensuring the ability to fund restoration actions include: budgeting based on best available information, fundraising early in the restoration planning process, and creating an adaptive management plan.

4.4.3 Ability to facilitate partnerships

The ability to facilitate and maintain relationships with fellow stakeholders is critical to performing restoration. Neighboring landowners, managers, and/or community members with similar goals should be considered for potential partnerships, as partnerships can increase the likelihood of restoration success.

Management actions that may be considered for ensuring the ability to facilitate partnerships include: engaging managers and landowners, community outreach, and education.

Table 2. Restoration Management Actions (listed in alphabetical order)

Action	Description
Budgeting based on best available information	Best available information may refer to researching past restoration efforts in similar ecosystems or local areas and/or utilizing local vendors and labor. It may also refer to accounting for monitoring time and potential adaptive management strategies. Using best available information to budget will ensure the most effective and efficient use of project funding.
Caging	One of the biggest threats to planted species is herbivory by other animals. Wire cages and other protective enclosures provide the best protection from herbivores, increasing the rate of growth and likelihood of successful establishment.
Creating adaptive management plans	Adaptive management calls for the consideration of multiple different restoration techniques, with the adoption of the most effective techniques at a given site. Monitoring of these techniques is important, but means little without a plan for how to incorporate that information into management decisions.
Educating	Education is an important activity for supporting restoration effects. Through education, additional stakeholders, volunteers and partnerships may be gained.
Engaging in community outreach	Community outreach involves engaging local community members. This activity can translate to additional stakeholders and volunteers or potential partnerships.
Engaging landowners	Landowners should be engaged with both the process of planning and implementing restoration. In order to complete successful restoration, open communication of goals and the establishment of a working relationship should occur as part of restoration planning.
Excluding non-native herbivores	Removing non-native herbivores from a restoration site will ensure the availability of preferred forage for the desert tortoise by reducing competition. Non-native herbivores can be excluded through the use of fencing surrounding the entire site.

Fencing	Physical barriers that prevent access to a site are the most effective way to minimize habitat disturbance. Effective fencing should fully enclose a site and potentially allow for tortoise movement into and out of the site.
Fundraising	Fundraising should be considered prior to implementing a restoration plan. This activity should be conducted following the design of a restoration project with a carefully calculated budget. Fundraising can be used to raise funds to support restoration actions.
Imprinting	Imprinting refers to the indentation of soil in a pattern which can be used to enhance water retention, de-compact soil and promote plant establishment on a decommissioned road, OHV trail, or other area severely damaged by grazing and/or OHV use. The most common tool for this technique is a machine known as an Imprinter.
Monitoring restoration sites	Monitoring an essential action effective restoration. Monitoring throughout restoration process allows for managers to adapt to stochastic events and changing conditions.
Outplanting	Outplanting is the process by which nursery-grown plants are translocated to a restoration site. Plants used for outplanting must be in good health before translocation as this will increase the chances of survival.
Planning access points for facilitating restoration	The ability to access a site is important for facilitating restoration activities such as irrigating and ripping. At the same time, however, redundant and unnecessary access points can increase threats from access.
Planting & seeding diverse assemblages of plants	Plant responses to climate change are one of the most important, and difficult, aspects of a changing climate to predict. Therefore, it is important for a diversity of plants to be selected for restoration efforts, allowing for a greater chance that some plants survive despite climate change.
Ripping	Ripping refers to the process of decompacting the surface soil. Common tools for this technique include a subsoiler or rock ripper. When considering ripping, it is best practice to

	focus on the surface soil, represented by the upper 15 cm, to avoid disrupting the subsoil and potentially changing the soil properties. In general, ripping can be used to roughen compacted soil and promote plant recruitment, but this action can also promote nonnative plant recruitment.
Re-contouring berms	Re-contouring berms refers to the reshaping of contour lines along slopes or road sides. The most common tool for this technique is a dozer. This method can be used to re-connect washes and reestablish drainage patterns.
Removing invasive plant species	Non-native forbs and grasses can often outcompete native forbs and must therefore be removed to the greatest extent possible from the restoration site. Some removal techniques include manual removal of non-natives and the use of properly timed herbicide.
Road camouflage	Camouflaging dirt roads and trails can help prevent fencing from being cut or run over, which can occur as a means of accessing what people perceive to be roads. Road camouflage involves techniques such as soil ripping, vertical mulching, and rock placement to make roads resemble the rest of the habitat. These techniques should be done on road extents within line of sight of fence lines.
Salvaging topsoil	Salvaging topsoil is among the most ecologically beneficial ways to enhance recovery, and specifically ecosystem function, after disturbance. The upper 5-10 cm (2-4 inches) of soil contains most of the soil organic matter, nutrients, and microorganisms and the upper 5 cm (2 inches) of soil contains the entire or nearly entire viable soil seed bank. Planting on salvaged topsoil can greatly increase survivability of new established plant species.
Seeding	Seeding can often be expensive and result in low success, but it can produce the desired results under the right conditions. Seeds must be collected onsite or at the nearest location possible to ensure proper adaptability and can be done in conjunction with other practices, such as pelleting, or encapsulating the seed in a biodegradable coating to protect the seed. The augmentation of annual and perennial

	plant forage through seeding can help maintain a diverse menu of forbs preferred by the desert tortoise.
Selecting restoration sites away from landfills and utility corridors	Raven predation is difficult to manage due to the ability of ravens to travel long distances and fly over physical barriers. Siting restoration efforts a minimum of 1km away from utility lines and landfills can reduce the effects of raven predation on recovering desert tortoise populations.
Selecting sites across tortoise range	Some areas will undoubtedly be more severely affected by climate change than others. Siting restoration efforts across the entire range of the desert tortoise can mitigate the risk of areas being severely affected by climate change to the point that they are unsuitable habitat.
Selecting sites near known tortoise populations	Restoring sites near existing good habitat decreases the likelihood of genetic isolation. This allows for gene flow between tortoises in different habitat patches, while also allowing tortoises in both patches to move across a larger area in response to stochastic events and environmental stressors.
Selecting sites which are large enough to promote genetic diversity	Not all sites are large enough to support the long term goal of restoration efforts. How large a site needs to be changes depending on the goals of a restoration project. Restoration efforts that expand or enhance existing habitat patches can be focused on smaller areas than more isolated projects which need to be large enough to support tortoise populations by themselves.
Selecting sites which have existing tortoise populations	Sites with existing tortoise populations, even when at low density, can be good targets for restoration efforts. By increasing the amount of suitable habitat, tortoise density at a site may increase, resulting in a more stable tortoise population.
Signage	Signs are designed to display important information and educate people. In the case of desert tortoise restoration, signs may be used to both education visitors and warn trespassers of areas where restoration is set to occur and where desert tortoises may be present.

Vertical Mulching	Vertical mulching is the insertion of dead creosote branches into the ground in a vertical orientation to resemble a living plant. Vertical mulching serves multiple purposes, including: camouflaging the road from passersby, decompacting the soil, and providing additional shade for tortoises. The soil is loosened through the insertion of the dead creosote materials, thus breaking up compacted soils to allow for better nutrient and water retention. As a result of vertical mulching, fertile islands of native plant communities can be established, aiding in the reestablishment of a native plant community.

5. Conclusion

This guidance document shows how the principles of ecological restoration can be used to employ strategic restoration of desert tortoise habitat. Through thoughtfully establishing goals, applying actions, and managing outcomes, we can ensure that restoration efforts are both efficient and effective. Using the established principles of ecological restoration as a foundation, we adapted the attributes of a restored ecosystem to represent important features for restoring desert tortoise habitat. Using a conceptual model, we mapped out the pathways through which these features are represented, based on four categories: form, function, stability and feasibility. We described the significance of the features as they relate to habitat restoration and detailed how they can be represented by management actions. Through the process of: (1) understanding the essential features for strategically restoring desert tortoise habitat, (2) using the Site Assessment Tool to make prioritize restoration actions, and (3) applying the necessary actions for restoration through restoration planning, desert tortoise habitat can be restored efficiently and effectively. It is our hope, that managers focused on habitat restoration for the desert tortoise adopt the used of strategic restoration for future projects.

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