



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.

SUMMARY FACT SHEET: DESERT TORTOISE HABITAT RESTORATION LITERATURE REVIEW

A comprehensive literature review is available supporting the desert tortoise habitat restoration workshop to be held January 24-25, 2022 in Las Vegas, Nevada. The review synthesizes desert tortoise habitat requirements and restoration practices, effectiveness, and costs for improving soil and vegetative habitat conditions. Over 50 published studies are now available on restoration in the Mojave and western Sonoran Desert. These studies highlight 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. Key findings are summarized here.

- **High-quality desert tortoise habitats** can be generalized as providing **four features**: adequate perennial cover plants, high-quality food plants, free water for drinking, and safety (e.g., few roads and toxicants).
- On **severe disturbances without restoration**, recovery of perennial cover (though not necessarily of the original species) averages 76 years and species composition over 215 years. This represents a long-term, **cumulative recovery debt** and highlights potential for restoration to accelerate ecological recovery.
- **Restoration in tortoise habitat must contend with** sparse and variable precipitation, extreme temperature and evaporation rates, intensive herbivory often targeting nutrient-enriched plant materials, infertile soil and degraded or missing environmental features (e.g., loss of microtopographic diversity otherwise retaining water), high winds and soil erosion, pervasive and competitive non-native plants, and potential external stressors such as continued anthropogenic disturbance and climate change. **Carefully prepared and implemented restoration techniques can ameliorate or accommodate these challenges.**
- **The review covers 11 major restoration treatments (and their variations) in three categories**: active **revegetation** (e.g., seeding, outplanting nursery-propagated seedlings), **environmental site restoration** (e.g., vertical mulching using dead plant material for inexpensively restoring structure), and **restorative management actions** (limiting disturbance and reducing non-native plants and fire risk).
- **Sixteen outplanting studies assessed survival of 46 outplanted native perennial species** for at least one year at field sites. Top-performing species, exhibiting $\geq 50\%$ survival, included major tortoise cover plants such as creosote bush (*Larrea tridentata*) and Anderson thornbush (*Lycium andersonii*). Treatments such as placing protective shelters around plants are often required to achieve good survival. Outplanting can be spatially deployed strategically and has potential to revegetate larger areas than were originally planted, via reproduction of the outplants themselves or stimulating recruitment of other species.
- **A total of 44 species were evaluated for amenability to salvage and transplanting** and 25 of them achieved at least 50% survival in a study. **Cacti** are among the species most amenable to transplanting, which is significant as cacti have been important **forage to tortoises**, especially during dry years.

- **Propagating plants** using cuttings from stems, rhizomes, or roots avoids a need for collecting and successfully germinating seed. **Four studies** demonstrate that this practice is another potential tool practitioners can use for revegetating tortoise habitats or augmenting plant availability.
- **Thirteen seeding studies** in the Mojave Desert included a total of **44 native seeded species** and monitored plant establishment for at least one year. **Results have been highly variable.** Seeding in some projects failed to result in plant establishment of most or all species, while all species seeded in other studies became established in the short-term, with uncertain long-term persistence. One of the more successful studies found that a combination of pelletizing seed and fencing persistently increased abundance of the annual forb desert plantain (*Plantago ovata*), a native forage species favored by tortoises.
- **Assisted natural regeneration** has potential as a technique for enhancing the natural recruitment of desired species, such as by protecting natural seedlings to increase their survival.
- **Abiotic structural restoration**, especially **vertical mulching**, shows promise as an inexpensive technique for slowing soil erosion, reestablishing structure, and fostering conditions for plant recruitment. It can be used independently or combined with active revegetation as a bet-hedging strategy. For example, one study found that all outplants died during the worst drought conditions in the last 47 years, but vertical mulch nevertheless reduced soil erosion and facilitated native seed germination. Compared with active revegetation, abiotic treatments are **less sensitive to timing of their implementation.** Thus, they may become an increasingly important part of restoration in the variable climates of tortoise habitats.
- Where **salvaging topsoil** is feasible and appropriate, it is likely to be among the most ecologically and cost-effective strategies for promoting recovery. One study found that planting on salvaged topsoil doubled plant survival and was nearly equivalent to irrigation.
- Geomorphic and microtopography treatments, such as soil surface roughening or de-compaction, have shown mixed results and require further research to identify where and how they can be most successful.
- Research on **restoring soil features**, such as **biocrusts**, is in the early stages in tortoise habitat but shows promise. For example, one study found that 18 months after applying biocrust inoculation, severely disturbed soils had **recovered 43% of their cyanobacteria density** and **contained lichens and mosses**, whereas non-inoculated plots did not.
- **Restorative management actions**, such as **strategically fencing or treating non-native plants**, have high potential for improving degraded tortoise habitat. For example, a study found that tortoise density was 2.5× higher inside a fenced area after 30 years compared with no fencing. When treatments have reduced non-native annuals, native annuals, including high-quality tortoise food plants, have responded positively.
- **Restoration cost estimates** vary with the severity of disturbance and restoration intensity and can range from < \$1000/ha to > \$10,000/ha. Further research could aid cost effectiveness by improving tailoring effective treatments to specific site conditions and plant materials with the greatest chance for success.
- The review presents **five main suggested topics for further research**, ranging from research on optimizing the spatial deployment of limited restoration resources to developing more effective treatments for reducing non-native annual grasses to limit a top threat to tortoise habitats. Further **linking habitat restoration activities** with short- and long-term **indicators of tortoise health** offers opportunities for research collaborations among restoration and plant ecologists, tortoise biologists, and land managers.

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