**ARTICLE**

**Title**

Something for nothing: a synthesis of active versus passive restoration in drylands

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**Abstract**

Restoration is a fundamental priority globally. Dryland ecosystems are biodiversity hotspots and ideal to explore different restoration strategies. These regions face serious threats due to land conversion and degradation. Using drylands as a case study, a formal synthesis including meta-analyses contrasted two general restoration strategies, active versus passive, and specific practices to examine restoration outcomes. This synthesis included research from 19 countries, described almost 25 practices, and examined outcomes associated with habitats and different taxa. Active restoration practices yielded significant positive outcomes for soils, vegetation, and animals. Passive restoration was a viable option only for limited recovery of vegetation but not for soils. These findings suggest that direct interventions are critical in many ecosystems especially those experiencing severe anthropogenic pressures and environmental stress.

**Introduction**

Restoration is a complex field of research and crucial in all ecosystems1. Restoration of degraded ecosystems provides multiple benefits to people2 including fundamental services as food and water3. Consequently, functional and healthy ecosystems are indispensable for the sustainability of humanity and all other forms of life4–6, and ecological restoration links the interface between people and nature7,8. Active and passive restoration strategies typically differ in the resources invested such as time, money, and human assistance9. These resources are likely to be scarce, and we need to identify interventions that generate consistent and positive outcomes that support enhanced ecosystem function and services.

Dryland ecosystems are an exemplary case study to evaluate the effectiveness of restoration practices because they encompass different biomes such as grasslands, shrublands, and deserts10. Agricultural lands comprise almost 40% of the terrestrial surface on Earth and are present in all drylands with significant impacts11,12. Drylands are hotspots of biodiversity supporting some of the most endangered species worldwide (e.g. large herbivores in Africa)13. Furthermore, a wide variety of ecosystem services that contribute to the quality of life for people14 such as food, water, energy, carbon sequestration, cultural identity and aesthetic values10 are provided by drylands15. However, dryland ecosystems are some of the most degraded systems in the world16, and continued land conversion (e.g. to agriculture), land degradation, and climate change17 all threaten delivery of ecosystem services from these systems14.

While increased land protection such as conservation easements18 and better land management practices19 will benefit remaining habitat in drylands, changing conditions and water scarcity in particular have created an opportunity to re-claim and restore degraded agricultural drylands for plants and wildlife19,20. In order to seize the opportunity to restore dryland habitat, practitioners need clear guidance on the relative merit of restoration practices that have the greatest positive outcomes with most likely resource limitations. Here, we performed a formal synthesis using meta-analyses to compare active and passive restoration practices and their outcomes in dryland ecosystems globally.

**Results**

Among the diverse disturbances reported in drylands (Supplementary Fig. 1), we focused on restoration within agricultural lands on both farmland and grazed natural lands. This meta-analysis included 40 peer-reviewed publications that compared restoration practices and control groups from 19 different countries in dryland ecosystems (Fig. 1). Moreover, the effect of active and passive restoration practices on specific outcomes, that reflected the main restoration goals from original articles, was evaluated. Outcomes categories included the restoration of soil, vegetation, animal communities and habitat; the habitat classification was used for studies that reported measures of both soil and vegetation recovery or of vegetation community structure (Supplementary Table 1). The data were extensive at more than 1400 independent observations measured across all studies. The mean spatial grain size for studies that implemented active and passive restoration strategies was 2,116 m2 and 1,950 m2, respectively.

**Restoration practices and outcomes**

Active restoration consistently led to positive responses providing evidence for a commitment to active restoration strategies in planning management for drylands (Table 1). All three specific categories of active restoration (see Methods) had net positive responses (Table 1A, Fig. 2); water supplementation was the most effective restoration practice followed by soil then vegetation remediations (Table 1A, Fig. 2). Soils, vegetation and habitat can be restored by active practices, except for animal communities (Table 1B). Passive recovery of vegetation and grazing exclusion (i.e. passive because grazing was removed and no other interventions were applied) also had positive effects on restoration outcomes (Table 1A, Fig. 2) such us vegetation and habitat (Table 1B). Nonetheless, passive recovery had lower and more variable effect sizes, and this strategy for soils such as fallowing typically led to negative responses (Table 1A, Fig. 2). Soils did not passively recover in drylands, but plants and habitat can to some extent recover (Table 1B).

**Model covariates**

Aridity had a weak negative impact on direct interventions suggesting that environmental limitations are critical drivers of change in these systems while increasing duration of study had a significant but minimal positive impact suggesting longer studies and time-frames be considered (lrr aridity = -0.01, 95% CI = -0.02 to -0.01; lrr time = 0.003, 95% CI= 0.003 to 0.0035). Duration of recovery positively influenced passive strategies but variation in aridity was not generally relevant (lrr aridity= 0.004, 95% CI = -0.002 to 0.01; lrr time = 0.01, 95% CI = 0.008 to 0.01).

**Discussion**

Findings from this meta-analysis support the conclusion that investment in active restoration is a more reliable strategy in meeting ecological outcomes in dryland ecosystems and that something for nothing is a risky strategy to adopt. In contrast, recent meta-analyses in tropical and temperate forests concluded that passive recovery through natural succession was the most effective strategy21,22. This difference profoundly suggests that environmental limitation and anthropogenic pressures are critical criteria to consider in weighing restoration options for an ecosystem. Rainfall, soil fertility, and productivity are severely constrained in dryland ecosystems10, and the extent of land transformation and prior land use history further exacerbate these issues23.

This synthesis shows that agricultural lands will need active restoration strategies to overcome the legacies of soil disturbances, nutrient additions, and pesticide usage24. Several studies (active n =16 and passive n =14) were not included in the meta-analysis due to the absence of control groups. This highlights the likely difficulty in securing undisturbed reference sites and the further challenges we face in identifying general baselines for restoration25. Restoration is a relatively new discipline, but its importance to inform ecosystem health cannot be overstated for drylands because of the need to redress global change and mitigate drought and species loss.

We face global threats to biodiversity, natural resources and ecosystem services. Resources to restore ecosystems will always be in short supply relative to need, particularly in developing countries and in those with limited political incentives to address environmental deterioration5. However, active investment in restoration interventions will certainly lead to more consistent positive outcomes for soils, vegetation, and habitats - arguably the foundations of ecosystem functions. We show here that while humans are certainly part of the problem, we can also be the solution to some of the recovery of drylands.

**Methods**

**Literature search and eligible criteria**

PRISMA guidelines were used to structure this synthesis and meta-analysis (Preferred Reporting Items for Systematic reviews and Meta-Analyses; Supplementary Fig. 2)26. We systematically searched Scopus and The Web of Science using the following term combinations: [restoration\* desert\* vegetation\*] OR [restoration\* grassland\* desert\*] OR [restoration desert\* plant\*] OR [restoration "agricultural lands"] OR ["restoration techniques" desert\*] OR ["passive restoration" desert\* plant\*] OR ["active restoration" desert\* plant\*] OR [revegetation abandoned desert\*] OR [restoration "agricult\*land\*" desert\* plant\*] OR [restoration dryland\* vegetation] OR [restoration semiarid\* plant\*] OR [restoration arid\* plant\*]. The searches were done in September 2018 and returned 1504 published articles. We collected data from studies that met the following inclusion criteria: (1) research articles including results, review articles were not included; (2) agriculture as the main disturbance reported (farmland and grazing lands); (3) studies with restoration practices and control groups specifically compared; (3) reported statistical analysis and significance of treatments. After the application of the above inclusion criteria, a total of 40 studies were included in the meta-analysis (Supplementary Fig. 2).

**Data extraction**

The specific restoration practice described in each study was recorded and subsequently classified as active or passive restoration. Passive restoration refers to the natural regeneration of degraded ecosystems with minimal to no human interventions such as the cessation of disturbance by installing fences to terminate grazing locally9,27. Active restoration strategies were always direct human interventions on ecosystems to assist and accelerate their restoration23. We also extracted response data outcomes describing target goals from each specific restoration practice28. We grouped active restoration practices into the following three categories based on their primary focus: soil, vegetation, and water supplementation (Table 1A). Thus, for example those restoration practices that implied plant interventions such as planting or seeding, were included within the vegetation classification (Supplementary Table 1). Soil, vegetation, and grazing exclusion were tested passively (Table 1A). Soil, vegetation, animals, and habitat categories were examined directly as active restoration outcomes (Table 1B). The response variables related with plant measures, for example plant cover, diversity and abundance, were included within the vegetation category of restoration outcomes; while those response variables associated with soil measures, such as nutrient content, were included within the soil outcome category; and, the response variables related with animal communities measures, such as invertebrates diversity and richness, were grouped within the animal outcome classification (Supplementary Table 1).

We collected data of all the response variables reported in each article (Supplementary Table 1). For each response variable we extracted the mean and standard deviation, the number of replicates, and *p*-values for the restoration practice implemented, either active or passive, and the control condition. When these data were provided in figures within a publication, we used WebPlotDigitizer29 to extract values. In addition, we collected data of the mean annual temperature and annual precipitation from the study sites of each article to calculate the aridity index30 and recorded the reported duration of study in months. When climatic data were not provided in studies, we used the latitude and longitude listed to look up the means from WordClim (www.worldclim.org). The aridity index and duration of studies were used as covariates in statistical models. The spatial grain size (i.e. minimum size of units of observation)31 of each article was also reviewed.

**Statistical analysis**

To estimate the effect of the restoration practice in dryland ecosystems, either active or passive, over the control group, we calculated the log response ratio (*lrr*)32. This effect size quantifies the log-proportional change between the means of the two groups compared33. In this case, a negative value of *lrr* implies the effect of the control group was higher than that of the restoration practice while a positive value indicates that a restoration practice leads to an increase in some responses evaluated, and zero represents no effect34.

We used random effects models to account for the variability within the studies evaluated35 (e.g. different restoration practices implemented, and response variables measured), and then applied post hoc meta-regressions to test the potential influence of two moderator variables, aridity30 and time from onset of study, on the outcomes36. Statistical significance of active and passive restoration strategies was tested by t-test against a value of 0. Restoration practices and outcomes were considered significant if their estimated 95% confidence intervals did not overlap 0. All analyses were done in R version 3.5.537, and both the packages meta38 and metafor35 were used for meta-analytical analyses.

**Data and code availability**

Data collected and support code to a meta-analysis comparing active and passive restoration practices and their outcomes in dryland ecosystems globally are published (Lortie C.J. and Miguel M.F. 2019. A set of R code to test dryland restoration efficacy using meta-analysis. Zenodo. DOI: 10.5281/zenodo.2653943).

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**Author contributions**

H.S.B. and C.J.L. formulated the ideas, M.F.M. and H.S.B. compiled the data, C.J.L. and M.F.M. analyzed the data, M.F.M., H.S.B. and C.J.L. wrote the manuscript, H.S.B. and C.J.L. acquired the financial support for the project.

**Additional information**

**Supplementary information**

Supplementary Fig. 1. Disturbances reported in dryland ecosystems globally and the restoration strategy implemented, active or passive.

Supplementary Fig. 2. PRISMA report.

Supplementary Table 1. List of restoration practices, outcomes and response variables included in a meta-analysis comparing active versus passive restoration strategies in dryland ecosystems globally.

**Competing interests**

The authors declare no competing interests.

**Table 1.** The effect of active and passive restoration practices on dryland ecosystems globally. The log response ratio (effect size) and 95% confidence interval (CI) were from random effects models (Lortie C.J. and Miguel M.F. 2019. R code, DOI: 10.5281/zenodo.2653943). Effect of active and passive restoration strategies was tested by t-test against a value of 0, and restoration practices and outcomes were considered significant if their estimated 95% confidence intervals did not overlap 0. (A) Random effects model results comparing restoration practices. (B) Random effects model results comparing restoration outcomes. The outcomes listed describe target goals from each restoration practice; the habitat classification includes studies that reported measures of both soil and vegetation recovery or of vegetation community structure.

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| --- | --- | --- |
| **Restoration** | **Log Response Ratio** | **95% CI** |
| *(A)* | | |
| **Active practices** | 0.22 | 0.20, 0.23 |
| Water supplementation | 0.64 | 0.55, 0.73 |
| Soil | 0.31 | 0.30, 0.33 |
| Vegetation | 0.18 | 0.17, 0.20 |
| **Passive practices** | -0.34 | -0.37, -0.31 |
| Soil | -0.76 | -0.82, -0.70 |
| Vegetation | 0.26 | 0.21, 0.32 |
| Grazing exclusion | 0.13 | 0.03, 0.24 |
| *(B)* | | |
| **Active restoration outcomes** | | |
| Vegetation | 0.51 | 0.49, 0.52 |
| Soil | 0.22 | 0.15, 0.28 |
| Habitat | 0.06 | 0.04, 0.08 |
| Animals | -0.11 | -0.12, -0.11 |
| **Passive restoration outcomes** | | |
| Soil | -0.76 | -0.82, -0.70 |
| Vegetation | 0.44 | 0.03, 0.85 |
| Habitat | 0.16 | 0.1, 0.22 |

**Fig. 1.** Global distribution of studies evaluating active or passive restoration practices in dryland ecosystems (n = 178). Articles included in the meta-analysis reported agriculture (farmland and grazing natural lands) as the main disturbance (n = 40). Red points represent the location of studies that used active restoration while blue points show those studies using passive restoration.

Imagen que contiene texto, mapa

Descripción generada automáticamente

**Fig. 2.** Overall effect sizes (log response ratio) and 95% confidence intervals for active and passive practices included in a meta-analysis on restoration in dryland ecosystems globally. The dashed vertical line denotes no effect of restoration practices, or a mean of 0. A positive log response ratio value indicates the mean of the practice was higher than that of the control group and a negative value indicates the mean of the control group was higher than that of the restoration practice. The *p*-values are from random effect models comparing subgroups differences among restoration practices.

Imagen que contiene captura de pantalla

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