A meta-analysis contrasting active versus passive restoration practices in dryland agricultural ecosystems

M. Florencia Miguel [Corresp., 1] , **H. Scott Butterfield** [2] , **Christopher J. Lortie** [3, 4]

[1] Consejo Nacional de Investigaciones Científicas y Técnicas, Mendoza, Argentina

[2] The Nature Conservancy, San Francisco, California, United States of America

[3] National Center for Ecological Analysis and Synthesis (NCEAS), Santa Barbara, CA, United States

[4] Department of Biology, York University, Toronto, Canada

Corresponding Author: M. Florencia Miguel
Email address: fmiguel@mendoza-conicet.gob.ar

Restoration of agricultural drylands globally, here farmlands and grazing lands, is a priority for ecosystem function and biodiversity preservation. Natural areas in drylands are recognized as biodiversity hotspots and face continued human impacts. Global water shortages are driving increased agricultural land retirement providing the opportunity to reclaim some of these lands for natural habitat. We used meta-analysis to contrast different classes of dryland restoration practices. All interventions were categorized as active and passive for the analyses of efficacy in dryland agricultural ecosystems. We evaluated the impact of 19 specific restoration practices from 42 studies on soil, plant, animal, and general habitat targets across 16 countries, for a total of 1,427 independent observations. Passive vegetation restoration and grazing exclusion led to net positive restoration outcomes. Passive restoration practices were more variable and less effective than active restoration practices. Furthermore, passive soil restoration led to net negative restoration outcomes. Active restoration practices consistently led to positive outcomes for soil, plant, and habitat targets. Water supplementation was the most effective restoration practice. These findings suggest that active interventions are necessary and critical in most instances for dryland agricultural ecosystems likely because of severe anthropogenic pressures and concurrent environmental stressors – both past and present.

1   A meta-analysis contrasting active versus passive restoration practices in dryland agricultural

2   ecosystems

5   M. Florencia Miguel[1], H. Scott Butterfield[2], Christopher J. Lortie[3,4]

8   [1] National Council for Scientific and Technical Research (CONICET), Mendoza, Argentina.

9   [2] The Nature Conservancy, San Francisco, CA, United States of America.

10   [3] Department of Biology, York University, Toronto, Canada.

11   [4] National Center for Ecological Analysis and Synthesis (NCEAS), Santa Barbara, CA, United

12   States of America.

15   Corresponding Author

16   M. Florencia Miguel[1]

17   Av. Ruiz Leal s/n Parque General San Martín, Mendoza, 5500, Argentina.

18   E-mail: fmiguel@mendoza-conicet.gob.ar

23 **Abstract**

24 Restoration of agricultural drylands globally, here farmlands and grazing lands, is a priority for

25 ecosystem function and biodiversity preservation. Natural areas in drylands are recognized as

26 biodiversity hotspots and face continued human impacts. Global water shortages are driving

27 increased agricultural land retirement providing the opportunity to reclaim some of these lands

28 for natural habitat. We used meta-analysis to contrast different classes of dryland restoration

29 practices. All interventions were categorized as active and passive for the analyses of efficacy in

30 dryland agricultural ecosystems. We evaluated the impact of 19 specific restoration practices

31 from 42 studies on soil, plant, animal, and general habitat targets across 16 countries, for a total

32 of 1,427 independent observations. Passive vegetation restoration and grazing exclusion led to

33 net positive restoration outcomes. Passive restoration practices were more variable and less

34 effective than active restoration practices. Furthermore, passive soil restoration led to net

35 negative restoration outcomes. Active restoration practices consistently led to positive outcomes

36 for soil, plant, and habitat targets. Water supplementation was the most effective restoration

37 practice. These findings suggest that active interventions are necessary and critical in most

38 instances for dryland agricultural ecosystems likely because of severe anthropogenic pressures

39 and concurrent environmental stressors – both past and present.

40

41

43 **Introduction**

44 Dryland ecosystems are a dominant land cover type globally (White & Nackoney, 2003),

45 encompassing many natural habitats such as grasslands, shrublands, and deserts (Reid et al.,

46 2005). Human-influenced agricultural ecosystems such as farmlands and grazing lands are also

47 common in drylands globally (Ramankutty et al., 2008; Kennedy et al., 2019). Natural habitats

48 within dryland ecosystems are hotspots of biodiversity and provide important ecosystem services

49 including food provision, water regulation, and carbon sequestration (Millennium Ecosystems

50 Assessment (MEA), 2005; Castro et al., 2018; Díaz et al., 2018). These services support nearly

51 40% of the world's population (Castro, Quintas-Soriano & Egoh, 2018). However, land

52 conversion, land degradation and climate change (Reynolds et al., 2007; Webb et al., 2017) have

53 greatly impacted these ecosystems (Millennium Ecosystems Assessment (MEA), 2005) leading

54 to some of the highest concentrations of threatened and endangered species worldwide

55 (Bonkoungou, 2001). Drylands are thus an important set of ecosystems to manage from both

56 anthropogenic and ecological perspectives, and synthesis of existing research will inform

57 knowledge for balancing restoration with opportunity and change.

58   Dryland ecosystem degradation has led to an increase in restoration actions recognizing the

59 high vulnerability of these systems to human impacts (Reynolds et al., 2007; James et al., 2013)

60 and the multiple restorative benefits both to natural systems and human populations (Clewell &

61 Aronson, 2006; De Groot et al., 2013; Castro et al., 2018). Ecological restoration includes many

62 different types of practices oriented to the recovery of degraded ecosystems and focuses on

63 diverse targets such as plants, animals, soils, habitats, and ecosystem functions (Clewell &

64 Aronson, 2006; Perino et al., 2019). Based on the amount of resources and human effort

65 invested, restoration practices can be classified as active (i.e. requiring human input) or passive

66   (i.e. requiring limited to no human input or removal of input such as perturbations) (Hobbs &

67   Cramer, 2008). The class of restoration practice to implement depends on the type and extent of

68   damage to the ecosystem. For example, the type and extent of damage can vary greatly from

69   farmlands – where natural plant cover and animal species have been completely removed – to

70   grazing lands – which still have a significant presence of both. Generally, more degraded

71   ecosystems will require more active efforts to be restored (Hobbs & Cramer, 2008). The specific

72   restoration goal and the availability of funding will further define the type of restoration applied

73   locally or regionally (Miller & Hobbs, 2007; Aronson and Alexander, 2013; Chazdon et al.,

74   2017). Therefore, a synthesis comparing active and passive practices will provide an analysis of

75   trends in global restoration practices, identify outcomes reported from different restoration

76   practices (Gavin, 2010), and will therefore begin to inform future restoration so as to ensure

77   limited resources are applied using evidence and, as efficiently as possible, in a given general

78   context of constraints.

79   Global agricultural intensification is likely to continue in order to meet the demands of a

80   growing human population (Tilman et al., 2011; World Health Organization, 2018). However,

81   global water scarcity particularly in dryland agricultural ecosystems – farmlands and grazing

82   lands – impacted by overexploitation, land degradation, and climate change is increasingly

83   driving retirement of those agricultural lands that are no longer productive (Benayas et al., 2007;

84   ELD Initiative, 2015). For instance, more than 200,000 acres of irrigated farmlands in California

85   are predicted to be retired in the next 10 to 20 years as part of a strategy for sustainable

86   groundwater use (Kelsey et al., 2018; Hanak et al., 2019; Bryant et al., 2020). This general

87   sociopolitical and ecological context provides the opportunity to re-claim some of these lands for

88   native plants and animals through habitat restoration (Queiroz et al., 2014; Kelsey et al., 2018).

89 Limitations in lands as set asides for plant and animal species has been proposed as a critical

90 issue in all systems globally (Diamond, 1975; Gotelli & McCabe, 2002) and evidence-informed

91 decisions for habitat restoration can contribute to the recovery of plant and animal species

92 worldwide. Restoration of agricultural drylands back to habitat for plants and animals will

93 provide capacity for reductions in species loss in these biodiversity hotspots (Durant et al., 2012;

94 Lortie et al., 2018) and contribute to more secure water and food resources for a rapidly

95 expanding human population (Tilman et al., 2011; Kelsey et al., 2018).

96   The main purpose of this global synthesis was to examine the extent of research on specific

97 restoration practices in agricultural dryland ecosystems and to identify any general trends in the

98 success of these practices for restoring native habitat. The following three goals were specifically

99 examined: whether a classification of restoration practices into active and passive is a

100 meaningful simplification of the complexity of restoration research for dryland agricultural

101 ecosystems; the overall effectiveness of active versus passive restoration practices; and the

102 outcomes identified by the restoration practices reported. The outcomes of a synthesis on

103 drylands restoration practices can be used as a mechanism to structure evidence-based

104 discussions and planning by researchers and stakeholders, and to yield insight into the

105 interventionist efforts carried out for agricultural dryland restoration.

106

107 **Survey methodology**

108 *Literature search and eligibility criteria*

109   PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) guidelines

110 were used to structure this meta-analysis (Fig. 1) (Moher et al., 2009). We systematically

111 searched Scopus and The Web of Science using the following term combinations: [restoration*

112 desert* vegetation*] OR [restoration* grassland* desert*] OR [restoration desert* plant*] OR

113 [restoration "agricultural lands"] OR ["restoration techniques" desert*] OR ["passive restoration"

114 desert* plant*] OR ["active restoration" desert* plant*] OR [revegetation abandoned desert*] OR

115 [restoration "agricult*land*" desert* plant*] OR [restoration dryland* vegetation] OR

116 [restoration semiarid* plant*] OR [restoration arid* plant*]. The searches were done in

117 September 2018 and then updated in January 2020 and returned 2077 published articles. We

118 collected data from studies that met the following inclusion criteria: (1) research articles that

119 included numerical results; review and theoretical articles were not included; (2) agriculture

120 (farmlands and grazing lands – we grouped these agricultural practices within our analysis even

121 though there may be reasons to conduct synthesis or meta-analysis for these land uses separately,

122 including potentially large differences in the extent of disturbance and type and intensity of

123 restoration required to return the site to a natural state) as the main disturbance reported; (3)

124 studies demonstrating a clear comparison of restoration practices and reference groups (i.e. intact

125 or minimally disturbed condition) (Wortley, Hero & Howes, 2013); (4) reported statistical

126 analysis and significance of treatments. We categorized all the reported terms that referred to

127 agricultural land uses into a single term entitled "agricultural dryland ecosystems" (Fig. 2 for

128 details on terminology for the land uses included in this meta-analysis). Agricultural land uses

129 prior to the implementation of restoration practices included a variety of crop species and grazing

130 systems globally (Table 1).

131   After the application of PRISMA guidelines and the above inclusion criteria, a total of 42

132 peer-reviewed articles (Fig. 1; Table S1) and 1,427 independent observations, from 16 different

133 countries (Fig. 3; Table 2), were included in the meta-analysis. We defined an independent

134   observation as a repeated, separate test in a different location listed within the 42 articles

135   (Koricheva, Gurevitch & Mengersen, 2013).

136

137   *Data extraction*

138   We extracted the following three primary elements from each article: (1) the specific

139   restoration practice implemented (e.g. natural recovery of vegetation); (2) the restoration goal

140   (hereafter restoration outcome) reported by the study researchers that was explicitly linked to a

141   clearly described restoration practice (e.g. vegetation restoration); and 3) the reported response

142   variables listed for each independent observation (Table 3).

143   Each of the 19 restoration practices was further categorized as active or passive to facilitate

144   factor analysis and partition heterogeneity between studies in a transparent, a priori designation

145   (Ioannidis, Patsopoulos & Evangelou, 2007; Koricheva & Gurevitch, 2014). Passive restoration

146   practices included those that focused on natural regeneration with minimal to no human

147   interventions (DellaSala et al., 2003; Hobbs & Cramer, 2008), such as the cessation of

148   disturbance from cattle or livestock grazing (Filazzola et al., 2020). Active restoration practices

149   included those that involved direct human interventions (Holl & Aide, 2011), such as

150   remediating soil (e.g. nutrient addition) and adding vegetation back to the system (e.g. planting

151   and seeding).

152   Specific restoration practices were rarely replicated globally. Consequently, we classified

153   passive restoration practices into the following categories based on their primary focus: soil,

154   vegetation, and grazing exclusion. Passive restoration practices focused on soils restoration, such

155   as mycorrhizal recovery, or on vegetation restoration, such as plant facilitation, and were

156   classified within soil and vegetation categories respectively (Table 3). Grazing exclusion was

157   classified as a passive restoration practice because grazing was removed, and no other

158   interventions were applied. We grouped active restoration practices into the following categories

159   based on their primary focus: soil, vegetation, and water supplementation. Active restoration

160   practices focused on soils restoration, such as mycorrhizal inoculation, or on vegetation

161   restoration, such as seeding, and were classified within soil and vegetation categories,

162   respectively. Water supplementation included practices such as irrigation (Table 3).

163   Restoration outcomes for active and passive practices were grouped into the following

164   categories: soil, vegetation, animals, and habitat. The response variables related to soil measures

165   (e.g. nutrient content) were included within the soil category. The vegetation category included

166   plant measures such as plant cover and abundance. The animal category included measures of

167   invertebrate abundance, diversity, and richness. The studies that met the above inclusion criteria

168   and were related to the restoration of animal populations, were focused exclusively on

169   invertebrates. This could be a limitation when trying to generalize about animal restoration

170   practices and outcomes. For the vegetation and animal studies, we did not record species

171   composition or species provenance. The habitat category included measures of both soil and

172   vegetation restoration reported together, or measures of general community structure, such as

173   plant productivity and species evenness (Table 3).

174   For each reported response variable, we extracted the mean and standard deviation, the

175   number of replicates, and the target taxa for restoration. These quantitative data were extracted

176   for the two groups evaluated at each study including the treatment and reference groups. When

177   these data were provided in figures within an article, we used WebPlotDigitizer (Rohatgi, 2019)

178   to extract values. In addition, we collected mean annual temperature and annual precipitation

179   data from each study site to calculate an aridity index (Martonne, 1927), and then recorded the

180   reported duration of each study. When climatic data were not provided in the studies, we used

181   the latitude and longitude listed to look up the means from WorldClim (www.worldclim.org).

182   The aridity index and duration of studies were used as covariates in our statistical models. We

183   also reviewed the spatial grain size (i.e. minimum size of units of observation) (Gustafson, 1998)

184   of each study.

185

186   *Statistical analysis*

187   To estimate the effect of active and passive restoration practices, we calculated the log

188   response ratio (*lrr*) (Hedges et al., 1999). This index measures the effect size of a treatment over

189   a control group (Lajeunesse, 2015); in this work, *lrr* represents the effect size of the restoration

190   practice as the log-proportional change between the means of the treatment and reference groups.

191   Thus, a positive *lrr* value indicates the effect of the restoration practice was higher than that of

192   the reference group (i.e. the restoration practice has a positive impact on restoration outcomes)

193   while a negative *lrr* value indicates the effect of the reference or control group was higher than

194   that of the restoration practice. A *lrr* value of zero represents no net effect of the restoration

195   practice on restoration outcomes (Pustejovsky, 2018).

196   We used random effects models to account for the variability between studies (e.g.

197   different restoration practices implemented, response outcomes pursued, and response variables

198   measured) (Schwarzer, Carpenter & Rücker, 2015). Post hoc meta-regressions were then used to

199   test the influence of aridity (Martonne, 1927) and time from onset of study. Statistical

200   significance of active and passive restoration practices was tested with t-tests against a value of

201   0. Restoration practices and outcomes were considered significant if their estimated 95%

202   confidence intervals did not overlap 0 (Cote & Jennions, 2013). All analyses were done in R

203   version 3.4.4 (R Core Team, 2018). The meta and metaphor packages were used for the meta-

204   analysis (Schwarzer, 2007; Viechtbauer, 2010).

205

206   **Results**

207   This meta-analysis included 42 peer-reviewed articles covering 16 countries in dryland

208   agricultural ecosystems (Fig. 3; Table 2). The meta-analysis included the evaluation of 19

209   different restoration practices, categorized into three active and three passive practices, on

210   restoration outcomes (Table 3). There were a total 1,427 independent observations (or data

211   entries) from the 42 articles that were analyzed in the meta-analysis (Miguel, Butterfield &

212   Lortie, 2020). The mean spatial grain size for the studies was 2,320.1 m^2 for active and 814.15

213   m^2 for passive restoration practices (Table S2).

214   Active restoration practices consistently led to positive restoration outcomes (Table 4).

215   All three categories of active restoration, including soil, vegetation, and water supplementation,

216   had net positive responses. Water supplementation was the most effective restoration practice,

217   followed by soil and vegetation restoration practices (Table 4A, Fig. 4). When analyzing

218   restoration outcomes, we found that soils, vegetation, and habitat are likely to be restored

219   through active restoration practices, but that invertebrate animal communities were not (Table

220   4B).

221   Passive restoration practices had lower and more variable effect sizes when compared to

222   active restoration practices (Table 4A). Passive restoration of vegetation and grazing exclusion

223   had positive effects on restoration outcomes (Table 4A, Fig. 4). However, passive soil restoration

224   practices led to negative restoration outcomes (Table 4A, Fig. 4). Soils did not passively recover

225   in agricultural drylands, but plants and habitat did passively recover in some instances (Table

226   4B).

227   Aridity had a weak negative impact on active restoration practices suggesting that water

228   limitations can mediate the positive results of these practices on restoration outcomes (*lrr* aridity

229   = -0.02, 95% CI = -0.03 to -0.02). For active restoration practices, increasing the duration of the

230   study had a significant, but small positive impact on restoration (*lrr* time = 0.003, 95% CI =

231   0.002 to 0.0034), suggesting longer studies be considered when evaluating the impact of active

232   restoration practices on restoration outcomes. For passive restoration practices, the duration of

233   the study negatively influenced restoration outcomes, but variation in aridity had no effect (*lrr*

234   time = -0.003, 95% CI = -0.003 to -0.002; *lrr* aridity = -0.003, 95% CI = -0.006 to 0.005).

235

236   **Discussion**

237   ***The need for a meta-analysis of restoration practices in dryland agricultural ecosystems***

238   Active versus passive restoration strategies is a critical decision in the management of

239   agricultural drylands globally, and the aggregated evidence confirmed that there are consistent

240   and crucial differences between this simple grouping of practices. The opportunity to restore

241   agricultural systems is increasing globally particularly in farmlands in dryland ecosystems that

242   are experiencing intensifying water shortages and resulting land retirement (Benayas et al., 2007;

243   Kelsey et al., 2018). Unfortunately, ecological restoration is neither a simple concept nor "one

244   size fits all" group of practices with known outcomes (Higgs, 1997). Instead, there are numerous

245   potential combinations of restoration practices across most systems, including in drylands, which

246   are infrequently replicated globally. The low replicability of individual restoration practices is a

247   potential limitation for using the results of this synthesis to inform global decision making for

248   restoration. However, synthesis of practices helps to simplify and aggregate the global evidence

249   to explore generality and to advance theory in this field.

250   Ecological restoration is a broad set of interventions that comprise practices conducted in a

251   wide range of ecosystems globally (Hobbs & Cramer, 2008). In tropical and temperate rain

252   forests, previous meta-analyses have shown that passive restoration including natural succession

253   processes can lead to positive, desired plant and animal restoration outcomes (Crouzeilles et al.,

254   2017; Meli et al., 2017). Nevertheless, for drylands, this meta-analysis showed that active

255   restoration practices more consistently led to positive restoration outcomes. The likelihood of

256   efficacy between active and passive restoration practices can be explained by the physical

257   constraints of these ecosystems that experience relatively severe limitations in rainfall, soil

258   fertility, and productivity (Millennium Ecosystems Assessment (MEA), 2005). To this end,

259   aridity was a significantly limiting factor in the models for active restoration outcomes

260   suggesting that drylands pose unique challenges and considerations for effective application of

261   interventions. Moreover, the extent of land transformation and the type of prior land use can also

262   contribute to the requirement of increased efforts and investments (Holl & Aide, 2011) to

263   achieve agricultural dryland restoration. Collectively, this evidence supports previous research

264   and highlights the need for consideration of environmental limitations in drylands.

265

266   ***The outcome of active versus passive restoration practices***

267   Importantly, active restoration practices are required to achieve soil-based outcomes in

268   farmlands in agricultural drylands, while passive practices lead to negative soil restoration

269   outcomes. Because soils constitute the foundation for long-term ecosystem recovery (Costantini

270   et al., 2016), it is likely that any successful effort would require some form of active restoration.

271   For instance, mycorrhizal inoculation contributes to the restoration of soil microorganisms and

272   the subsequent successful establishment and growth of the desired shrub species (e.g. Caravaca

273   et al., 2003); and carbon addition increases the availability of soil nutrients for plants and moss

274   cover in former agricultural drylands (e.g. Török et al., 2014). This result is consistent with

275   previous work from the San Joaquin Desert of California that recommends any restoration

276   project on formerly farmed lands start with soil nutrient remediation (Laymon et al., 2010).

277   Despite the fact that we did not separately evaluate restoration outcomes for farmlands and

278   grazing lands in this study, soil restoration efforts are much more likely to be required in

279   farmlands (versus grazing lands) because of the extent of the damage – including from tilling and

280   synthetic inputs to increase crop productivity – in these intensively managed systems (Garibaldi

281   et al., 2019; Kleijn et al., 2019). Although resources can be limiting for restoration, particularly

282   for large-scale projects that will have the most significant impacts on ecosystem services and

283   biodiversity, active restoration may be necessary in order to overcome the legacies of soil

284   disturbances, nutrient additions, and pesticide usage (Kleijn et al., 2019) in agricultural drylands.

285   Once soil restoration is achieved, plant restoration can proceed, actively or passively. The

286   passive restoration of plant species is an emerging strategy for restoring native communities with

287   minimal costs (Hobbs & Cramer, 2008; Tabeni et al., 2017). Moreover, the removal of grazing

288   was an effective strategy for passive restoration in drylands, similar to the findings from a recent

289   global grazing meta-analysis (Filazzola et al., 2020). Nevertheless, in some more mesic grazing

290   systems, like in the coastal and northern interior portions of California, removing grazing can

291   lead to greater dominance of non-native plant species and overall lower levels of native plant and

292   animal biodiversity (Hayes & Holl, 2003; Marty, 2005). Active plant restoration such as seeding

293   and planting also led to positive outcomes and likely requires water supplementation. However,

294   as the species origin of the restored plant communities was not evaluated in this meta-analysis,

295   the decision for active or passive plant restoration practices will depend on the biotic context of

296   the site and the species-specific restoration goals of the project. Future studies can examine this

297   limitation by specifically assessing species diversity of restored agricultural drylands under

298   different restoration practices.

299   Although some passive restoration practices led to positive restoration outcomes, these

300   results were more variable and at lower levels than the ones found by active restoration practices.

301   The aridity of sites and the duration of treatments had contrasting influence on the restoration

302   outcomes of different practices reflecting the dependence on context for the outcomes of

303   restoration projects (Gravuer et al., 2018) and the influence of physical constraints to the success

304   of restoration practices (Miller & Hobbs, 2007). However, a focus on intensively (farmlands) and

305   extensively (grazing lands) managed agricultural drylands and their restoration outcomes

306   contributes to a more general understanding of the restoration practices because of the relatively

307   high variety of intervention tested. Finally, data on animal restoration outcomes was limited to

308   invertebrate community-based studies, a taxa that is known to be severely impacted by

309   agricultural practices (Potts et al., 2010; Garibaldi et al., 2011; Sánchez-Bayo and Wyckhuys,

310   2019). This research gap highlights the difficulties in restoring animal community targets even if

311   soil and plant restoration is successful at a specific site. More comprehensive studies of

312   restoration outcomes and extended biodiversity analyses in agricultural drylands are necessary to

313   better assess the extent of intervention needed.

314

315   **Conclusions**

316   Meta-analysis is a synthesis tool particularly valuable to identify large-scale patterns and

317   to inform evidence-based decision making for stakeholders (Gavin, 2010). Considering the

318   opportunity to restore agricultural dryland ecosystems globally, meta-analysis can reveal broad

319   trends in data that inform decision-making about the restoration practices most likely to achieve

320   certain restoration outcomes. This meta-analysis revealed that you can get some restoration

321   outcomes for "free" but, as we noted, these outcomes may be more variable in these systems.

322   Nevertheless, with limited resources, active restoration practices are required to achieve positive

323   restoration outcomes, likely because of severe anthropogenic pressures and concurrent

324   environmental stressors – both past and present – in dryland agricultural ecosystems. Facing the

325   opportunity of reclaiming drylands formerly used for agricultural practices, soils will require

326   active restoration interventions; and when resources for restoration do exist, we may focus

327   efforts on native plant species restoration and potentially more specifically those that serve a

328   foundational or keystone role (e.g. shrubs) (Lortie et al., 2016) within the ecosystem.

329

330

331   **Acknowledgments**

332   We acknowledge The Nature Conservancy and York University for their support to this

333   synthesis. C.J.L. is thankful for a Senior Research Fellow at NCEAS. M.F.M. thanks CONICET

334   for a postdoctoral fellowship at the Argentine Dryland Research Institute.

335

336

337

338

339

340

341

342

343

344

345

346

347

348

349

350

351 **References**

352

353 Aronson J, Alexander S. 2013. Ecosystem restoration is now a global priority: Time to roll up

354   our sleeves. *Restoration Ecology* 21:293–296. DOI: 10.1111/rec.12011.

355 Benayas JMR, Martins A, Nicolau JM, Schulz JJ. 2007. Abandonment of agricultural land: An

356   overview of drivers and consequences. *CAB Reviews: Perspectives in Agriculture,*

357   *Veterinary Science, Nutrition and Natural Resources* 2. DOI:

358   10.1079/PAVSNNR20072057.

359 Bonkoungou EG. 2001. Biodiversity in drylands: challenges and opportunities for conservation

360   and sustainable use. :1–20.

361 Bryant BP, Kelsey TR, Vogl AL, Wolny SA, Selmants P, Biswas, Tanushree Butterfield HS.

362   2020. Shaping land use change and ecosystem restoration in a water stressed agricultural

363   landscape to achieve multiple benefits. Frontiers in Sustainable Food Systems. *In revision*.

364 Caravaca F, Figueroa D, Azcón-Aguilar C, Barea JM, Roldán A. 2003. Medium-term effects of

365   mycorrhizal inoculation and composted municipal waste addition on the establishment of

366   two Mediterranean shrub species under semiarid field conditions. *Agriculture, Ecosystems*

367   *and Environment* 97:95–105. DOI: 10.1016/S0167-8809(03)00126-9.

368 Castro AJ, Quintas-Soriano C, Egoh BN. 2018. Ecosystem services in dryland systems of the

369   world. *Journal of Arid Environments* 159:1–3. DOI: 10.1016/j.jaridenv.2018.09.006.

370 Chazdon RL, Brancalion PHS, Lamb D, Laestadius L, Calmon M, Kumar C. 2017. A Policy-

371   Driven Knowledge Agenda for Global Forest and Landscape Restoration. *Conservation*

372   *Letters* 10:125–132. DOI: 10.1111/conl.12220.

373 Clewell AF, Aronson J. 2006. Motivations for the restoration of ecosystems. *Conservation*

374   *Biology* 20:420–428. DOI: 10.1111/j.1523-1739.2006.00340.x.

375 Cote, I. M., Jennions MD. 2013. The procedure of meta-analysis in a nutshell. In: *Handbook of*

376   *Meta-analysis in Ecology and Evolution*. 14–26.

377 Crouzeilles R, Ferreira MS, Chazdon RL, Lindenmayer DB, Sansevero JBB, Monteiro L,

378   Iribarrem A, Latawiec AE, Strassburg BBN. 2017. Ecological restoration success is higher

379   for natural regeneration than for active restoration in tropical forests. *Science Advances*

380   3:e1701345.

381 DellaSala DA, Martin A, Spivak R, Schulke T, Bird B, Criley M, van Daalen C, Kreilick J,

382   Brown R, Aplet G. 2003. A Citizen's Call for Ecological Forest Restoration: Forest

383   Restoration Principles and Criteria. *Ecological Restoration* 21:14–23.

384 Diamond JM. 1975. Assembly of species communities. In: Cody, M. L. Diamond JM ed.

385   *Ecology and evolution of communities.* Harvard University Press, Cambridge,

386   Massachusetts, USA., 342–444.

387   Díaz S, Pascual U, Stenseke M, Martín-López B, Watson RT, Molnár Z, Hill R, Chan KMA,

388   Baste IA, Brauman KA, Polasky S, Church A, Lonsdale M, Larigauderie A, Leadley PW,

389   van Oudenhoven APE, van der Plaat F, Schröter M, Lavorel S, Aumeeruddy-Thomas Y,

390   Bukvareva E, Davies K, Demissew S, Erpul G, Failler P, Guerra CA, Hewitt CL, Keune H,

391   Lindley S, Shirayama Y. 2018. Assessing nature's contributions to people. *Science*

392   359:270–272. DOI: 10.1126/science.aap8826.

393   Durant SM, Pettorelli N, Bashir S, Woodroffe R, Wacher T, De Ornellas P, Ransom C, Abaigar

394   T, Abdelgadir M, El Alqamy H, Beddiaf M, Belbachir F, Belbachir-Bazi A, Berbash AA,

395   Beudels-Jamar R, Boitani L, Breitenmoser C, Cano M, Chardonnet P, Collen B, Cornforth

396   WA, Cuzin F, Gerngross P, Haddane B, Hadjeloum M, Jacobson A, Jebali A, Lamarque F,

397   Mallon D, Minkowski K, Monfort S, Ndoassal B, Newby J, Ngakoutou BE, Niagate B,

398   Purchase G, Samaila S, Samna AK, Sillero-Zubiri C, Soultan AE, Stanley Price MR, Baillie

399   JEM. 2012. Forgotten Biodiversity in Desert Ecosystems. *Science* 336:1379–1380. DOI:

400   10.1126/science.336.6087.1379.

401   ELD Initiative. 2015. *Report for policy and decision makers: Reaping economic and*

402   *environmental benefits from sustainable land management.*

403   Filazzola A, Brown C, Dettlaff MA, Batbaatar A, Grenke J, Bao T, Peetoom Heida I, Cahill JF.

404   2020. The effects of livestock grazing on biodiversity are multi-trophic: a meta-analysis.

405   *Ecology Letters.*

406   Garibaldi LA, Pérez-Méndez N, Garratt MPD, Gemmill-Herren B, Miguez FE, Dicks L V. 2019.

407   Policies for Ecological Intensification of Crop Production. *Trends in Ecology and Evolution*

408   34:282–286. DOI: 10.1016/j.tree.2019.01.003.

409   Gavin S. 2010. Meta-analysis in applied ecology. *Biology Letters* 6:78–81. DOI:

410   10.1098/rsbl.2009.0546.

411   Gotelli NJ, McCabe DJ. 2002. Species co-occurrence: A meta-analysis of J. M. Diamond's

412   assembly rules model. *Ecology* 83:2091–2096. DOI: 10.1890/0012-

413   9658(2002)083[2091:SCOAMA]2.0.CO;2.

414   De Groot RS, Blignaut J, Van Der Ploeg S, Aronson J, Elmqvist T, Farley J. 2013. Benefits of

415   Investing in Ecosystem Restoration. *Conservation Biology* 27:1286–1293. DOI:

416   10.1111/cobi.12158.

417   Gustafson EJ. 1998. Quantifying Landscape Spatial Pattern: What Is the State of the Art?

418   *Ecosystems* 1:143–156.

419   Hanak E, Escriva-Bou A, Gray B, Green S, Harter T, Jezdimirovic J, Lund J, Medellín-Azuara J,

420   Moyle P, Seavy N. 2019. *Water and the Future of the San Joaquin Valley*. DOI:

421   10.13140/RG.2.2.24360.83208.

422   Hayes GF, Holl KD. 2003. Cattle Grazing Impacts on Annual Forbs and Vegetation Composition

423   of Mesic Grasslands in California. *Conservation Biology* 17:1694–1702. DOI:

424   10.1111/j.1523-1739.2003.00281.x.

425   Hedges, L. V, Gurevitch J, Curtis P. 1999. The Meta-Analysis of Response Ratios in

426   Experimental Ecology. *Ecology* 80:1150–1156.

427   Hobbs RJ, Cramer VA. 2008. Restoration Ecology: Interventionist Approaches for Restoring and

428   Maintaining Ecosystem Function in the Face of Rapid Environmental Change. *Annual*

429   *Review of Environment and Resources* 33:39–61. DOI:

430   10.1146/annurev.energy.33.020107.113631.

431   Holl KD, Aide TM. 2011. When and where to actively restore ecosystems? *Forest Ecology and*

432   *Management* 261:1558–1563.

433   Ioannidis JPA, Patsopoulos NA, Evangelou E. 2007. Uncertainty in heterogeneity estimates in

434   meta-analyses. *British Medical Journal* 335:914–916.

435   James JJ, Sheley RL, Erickson T, Rollins KS, Taylor MH, Dixon KW. 2013. A systems

436   approach to restoring degraded drylands. *Journal of Applied Ecology* 50:730–739. DOI:

437   10.1111/1365-2664.12090.

438   Kelsey R, Hart A, Scott Butterfield H, Vink D. 2018. Groundwater sustainability in the San

439   Joaquin Valley: Multiple benefits if agricultural lands are retired and restored strategically.

440   *California Agriculture* 72:151–154.

441   Kennedy CM, Oakleaf JR, Theobald DM, Baruch-Mordo S, Kiesecker J. 2019. Managing the

442   middle: A shift in conservation priorities based on the global human modification gradient.

443   *Global Change Biology*:811–826. DOI: 10.1111/gcb.14549.

444   Kleijn D, Bommarco R, Fijen TPM, Garibaldi LA, Potts SG, van der Putten WH. 2019.

445   Ecological Intensification: Bridging the Gap between Science and Practice. *Trends in*

446   *Ecology and Evolution* 34:154–166. DOI: 10.1016/j.tree.2018.11.002.

447   Koricheva J, Gurevitch J. 2014. Uses and misuses of meta-analysis in plant ecology. *Journal of*

448   *Ecology* 102:828–844.

449   Koricheva J, Gurevitch J, Mengersen K. 2013. *Handbook of Meta-Analysis In Ecology and*

450   *Evolution*. Princeton University Press.

451   Lajeunesse MJ. 2015. Bias and correction for the log response ratio in ecological meta-analysis.

452   *Ecology* 96:2056–2063.

453   Lortie CJ, Filazzola A, Kelsey R, Hart AK, Butterfield HS. 2018. Better late than never: a

454   synthesis of strategic land retirement and restoration in California. *Ecosphere* 9:e02367.

455   DOI: 10.1002/ecs2.2367.

456   Martonne E De. 1927. Regions of Interior-Basin Drainage. *Geographical Review* 17:397–414.

457   Marty JT. 2005. Effects of cattle grazing on diversity in ephemeral wetlands. *Conservation*

458   *Biology* 19:1626–1632. DOI: 10.1111/j.1523-1739.2005.00198.x.

459   Meli P, Holl KD, Benayas JMR, Jones HP, Jones PC, Montoya D, Mateos DM. 2017. A global

460   review of past land use, climate, and active vs. passive restoration effects on forest

461   recovery. *PLoS ONE* 12:1–17.

462   Miguel FM, Butterfield SH, Lortie C. 2020. A synthesis dataset describing dryland agricultural

463   restoration practices. *figshare. Dataset*.

464   Millennium Ecosystems Assessment (MEA). 2005. Dryland Systems. In: *Ecosystems and*

465   *Human well-being: Current State and Trends*. 1–40. DOI: 10.1196/annals.1439.003.

466   Miller RJ, Hobbs JR. 2007. Habitat restoration - do we know what we're doing? *Restoration*

467   *Ecology* 15:382–390.

468   Moher D, Liberati A, Tetzlaff J, Altman DG, Altman D, Antes G, Atkins D, Barbour V,

469   Barrowman N, Berlin JA, Clark J, Clarke M, Cook D, D'Amico R, Deeks JJ, Devereaux PJ,

470   Dickersin K, Egger M, Ernst E, Gøtzsche PC, Grimshaw J, Guyatt G, Higgins J, Ioannidis

471   JPA, Kleijnen J, Lang T, Magrini N, McNamee D, Moja L, Mulrow C, Napoli M, Oxman

472   A, Pham B, Rennie D, Sampson M, Schulz KF, Shekelle PG, Tovey D, Tugwell P. 2009.

473   Preferred reporting items for systematic reviews and meta-analyses: The PRISMA

474   statement. *PLoS Medicine* 7:889–896. DOI: 10.3736/jcim20090918.

475   Perino A, Pereira HM, Navarro LM, Fernández N, Bullock JM, Ceauşu S, Cortés-Avizanda A,

476   van Klink R, Kuemmerle T, Lomba A, Pe'er G, Plieninger T, Rey Benayas JM, Sandom CJ,

477   Svenning J-C, Wheeler HC. 2019. Rewilding complex ecosystems. *Science* 364:eaav5570.

478   DOI: 10.1126/science.aav5570.

479 Pustejovsky JE. 2018. Using response ratios for meta-analyzing single-case designs with

480   behavioral outcomes. *Journal of School Psychology* 68:99–112.

481 Queiroz C, Beilin R, Folke C, Lindborg R. 2014. Farmland abandonment: Threat or opportunity

482   for biodiversity conservation? A global review. *Frontiers in Ecology and the Environment*

483   12:288–296. DOI: 10.1890/120348.

484 R Core Team. 2018. R: A language and environment for statistical computing. *R Foundation for*

485   *Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.*

486 Ramankutty N, Evan AT, Monfreda C, Foley JA. 2008. Farming the planet: 1. Geographic

487   distribution of global agricultural lands in the year 2000. *Global Biogeochemical Cycles*

488   22:1–19. DOI: 10.1029/2007GB002952.

489 Reid W V, Mooney HA, Cropper A, Capistrano D, Carpenter SR, Chopra K, Dasgupta P, Dietz

490   T. 2005. *Ecosystems and Human Well-being: Synthesis*. DOI: 10.1196/annals.1439.003.

491 Reynolds JF, Smith DMS, Lambin EF, Turner BL, Mortimore M, Batterbury SPJ, Downing TE,

492   Dowlatabadi H, Fernandez RJ, Herrick JE, Huber-Sannwald E, Jiang H, Leemans R, Lynam

493   T, Maestre FT, Ayarza M, Walker B. 2007. Global Desertification: Building a Science for

494   Dryland Development. *Science* 316:847–851. DOI: 10.1126/science.1131634.

495 Rohatgi A. 2019.WebPlotDigitizer

496 Schwarzer G. 2007. meta: An R package for meta-analysis. *R news* 7:40–45.

497 Schwarzer G, Carpenter JR, Rücker G. 2015. *Meta- Analysis with R*. New York: Springer.

498 Tilman D, Balzer C, Hill J, Befort BL. 2011. Global food demand and the sustainable

499   intensification of agriculture. *Proceedings of the National Academy of Sciences of the*

500   *United States of America* 108:20260–20264. DOI: 10.1073/pnas.1116437108.

501   Török K, Szitár K, Halassy M, Szabó R, Szili-Kovács T, Baráth N, Paschke MW. 2014. Long-

502   term outcome of nitrogen immobilization to restore endemic sand grassland in Hungary.

503   *Journal of Applied Ecology* 51:756–765. DOI: 10.1111/1365-2664.12220.

504   Viechtbauer W. 2010. Conducting meta-analyses in R with the metafor package. *Journal of*

505   *Statistical Software* 36:1–48.

506   Webb NP, Marshall NA, Stringer LC, Reed MS, Chappell A, Herrick JE. 2017. Land

507   degradation and climate change : building climate resilience in agriculture. *Frontiers in*

508   *Ecology and the Environment* 15:450–459. DOI: 10.1002/fee.1530.

509   White RP, Nackoney J. 2003. Drylands, people, and ecosystem goods and services: A Web-

510   Based Geospatial Analysis. In: *World Resources Institute, Washington, D.C., USA.*

511   World Health Organization. 2018. *The state of food security and nutrition in the world 2018:*

512   *building climate resilience for food security and nutrition.*

513   Wortley L, Hero JM, Howes M. 2013. Evaluating ecological restoration success: A review of the

514   literature. *Restoration Ecology* 21:537–543.

515

Table 1. List of crop and animal grazer species in farmlands and grazing lands prior to the implementation of active and passive restoration practices in dryland agricultural ecosystems globally.

Each restoration practice was categorized as active or passive. Different practices were grouped into general categories based on their primary focus, for example those related with plant interventions such as planting or seeding, were included within the vegetation category.

1 **Table 1.** List of crop and animal grazer species in farmlands and grazing lands prior to the

2 implementation of active and passive restoration practices in dryland agricultural ecosystems

3 globally.

4 Each restoration practice was categorized as active or passive. Different practices were grouped

5 into general categories based on their primary focus, for example those related with plant

6 interventions such as planting or seeding, were included within the vegetation category.

Farmlands	Grazing lands	Restoration	Category of practices	Practices
Avena chinensis *Brassica nigra* *Erigeron canadensis* *Fagopyrum sagittatum* *Kochia scoparia* *Lactuca scariola* *Linum usitatissimum* *Medicago sativa* *Pisum sativum* *Salsola iberica* *Schismus spp* *Sesamum indicum* *Solanum tuberosum* *Triticum aestivum* cotton corn mellon pecans watermelon	cattle livestock	Active	vegetation	seeding seeding, mowing and herbicide, mulching seeding, mulching, weeding seeding, irrigation seeding and ripping mechanical disturbance and seeding seeding, safe sites for seeds and fencing planting
			water supplementation	water supplementation seeding and irrigation
not listed in studies			soil	carbon addition mycorrhizal inoculation
Medicago spp *Melilotus albus* *Mentha spp* *Triticum aestivum* *Zea mays* fruits-vegetables forage crops	sheep and goat cattle livestock	Passive	vegetation	natural recovery grazing exclusion facilitation
-	livestock cattle sheep livestock		grazing exclusion	grazing exclusion facilitation natural recovery
Solanum tuberosum cereal crops-fallow chinese onion peanut sorghum	-		soil	natural recovery mycorrhizal recovery

Table 2. Distribution of studies evaluating restoration practices in dryland agricultural ecosystems.

List of countries (n= 16) included in the meta-analysis, their active or passive restoration focus and the restoration practice implemented. Different restoration practices were grouped into general categories based on their primary focus, for example those related with plant interventions such as planting or seeding, were included within the vegetation category.

1   **Table 2.** Distribution of studies evaluating restoration practices in dryland agricultural

2   ecosystems (n = 42 and 1,427 data entries).

3   List of countries (n= 16) included in the meta-analysis, their active or passive restoration focus

4   and the restoration practice implemented. Different restoration practices were grouped into

5   general categories based on their primary focus, for example those related with plant

6   interventions such as planting or seeding, were included within the vegetation category.

Country	Restoration	Category of practices	Data entries
Argentina	Active	vegetation	13
	Passive	vegetation	10
Australia	Active	vegetation	12
Canada	Active	vegetation	30
China	Active	vegetation	622
		water supplementation	12
		grazing exclusion	30
	Passive	soil	204
		vegetation	42
Egypt	Passive	vegetation	21
Ethiopia	Passive	grazing exclusion	5
Hungary	Active	soil	27
Iran	Passive	vegetation	15
Kenya	Active	vegetation	7
Kuwait	Passive	vegetation	10
Mongolia	Active	vegetation	24
	Passive	vegetation	37
Portugal	Passive	grazing exclusion	21
Russia	Passive	soil	4
South Africa	Active	vegetation	9
Spain	Active	soil	128
United States of America	Active	vegetation	57
		water supplementation	63
	Passive	vegetation	24

Table 3. List of restoration practices, desired restoration goals (i.e. outcomes) and original response variables included in the meta-analysis.

Data was used to compare active versus passive restoration practices in dryland agricultural ecosystems globally (n = 42 and 1,427 independent observations or data entries). Different practices were grouped into general categories based on their primary focus, for example those related with plant interventions such as planting or seeding, were included within the vegetation category. The outcomes listed describe restoration goals from each restoration practice; the habitat classification includes studies that reported measures of both soil and vegetation recovery or of vegetation community structure.

1   **Table 3.** List of restoration practices, desired restoration goals (i.e. outcomes) and original

2   response variables included in the meta-analysis.

3   Data was used to compare active versus passive restoration practices in dryland agricultural

4   ecosystems globally (n = 42 and 1,427 independent observations or data entries). Different

5   practices were grouped into general categories based on their primary focus, for example those

6   related with plant interventions such as planting or seeding, were included within the vegetation

7   category. The outcomes listed describe restoration goals from each restoration practice; the

8   habitat classification includes studies that reported measures of both soil and vegetation recovery

9   or of vegetation community structure.

Restoration	Category of Practices	Practices	Outcomes	Response variables	Data entries
Active	soil	carbon amendment	soil	moss cover; soil nutrient content	27
		mycorrhizal inoculation	vegetation	plant biomass; nutrient	128
	vegetation	burning, mowing	habitat	soil nutrient content and soil properties	24
		mechanical disturbance, seeding	vegetation	plant cover and density	4
		planting	habitat	plant biomass, density, cover, diversity and richness; soil nutrient	369
		planting	vegetation	plant height and cover; invertebrate and lizard abundance, diversity, dominance, evenness and richness	26
		planting	soil	soil nutrient content and soil properties	84
		planting	animals	invertebrate abundance, diversity and richness	6
		planting, grazing exclusion	animals	arthropod abundance, richness and diversity; soil properties; plant cover, density, height and richness	24
		seeding	vegetation	plant cover and density; seedling emergence and establishment	53
		seeding	soil	soil nutrient content and soil properties	117
		seeding and ripping	vegetation	plant cover and abundance	12
		seeding, gypsum and organic mulch	habitat	soil properties; seedling emergence and surviving plants	9
		seeding, irrigation	vegetation	seedling emergence	7
		seeding, mowing and herbicide, mulching	habitat	plant cover and richness; soil nutrient content and soil properties	18
		seeding, mulching, weeding	vegetation	plant cover	6
		seeding, safe sites for seeds, fencing	vegetation	plant cover and biomass	8
		seeding, soil tilling, fertilization	vegetation	plant biomass	7
	water supplementation	irrigation, seeding	vegetation	plant cover, abundance, biomass, density and survival	63
		water supply	habitat	plant biomass, density, cover, evenness, productivity and richness; soil nutrient content	12
Passive	grazing exclusion	fencing	vegetation	plant height, cover and diversity	21
		grazing exclusion	vegetation	plant height, cover, diversity, biomass and	8

				richness	
		natural recovery	vegetation	plant biomass, cover, density, height	27
	soil	mycorrhizal recovery	soil	microbial richness and density	6
		natural recovery	soil	soil nutrient content and soil properties	202
	vegetation	facilitation	habitat	soil nutrient content and soil properties; plant survival, biomass, height, width, abundance, and richness	60
		natural recovery	habitat	soil nutrient content and soil properties; plant richness	40
		natural recovery	animals	arthropod density, diversity and richness	3
		natural recovery	soil	soil properties	18
		fencing	habitat	plant biomass, evenness, cover, density, diversity, height and richness; soil nutrient content and soil properties	15
		grazing exclusion	vegetation	plant cover, density, height, biomass and richness	23

Table 4. The effect of active and passive restoration practices and restoration outcomes evaluated in dryland agricultural – here, defined as farmlands and grazing lands – ecosystems globally.

The log response ratio (effect size) and 95% confidence interval (CI) were calculated from random effects models (Lortie, C.J. and Miguel, M.F. 2019. R code, DOI: 10.5281/zenodo.3907012). Effect of active and passive restoration practices 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. Outcomes describe target goals from each restoration practice; the habitat category includes studies that reported measures of both soil and vegetation restoration or general community structure.

1   **Table 4.** The effect of active and passive restoration practices and restoration outcomes

2   evaluated in dryland agricultural – here, defined as farmlands and grazing lands – ecosystems

3   globally.

4   The log response ratio (effect size) and 95% confidence interval (CI) were calculated from

5   random effects models (Lortie, C.J. and Miguel, M.F. 2019. R code, DOI:

6   10.5281/zenodo.3907012). Effect of active and passive restoration practices was tested by t-test

7   against a value of 0, and restoration practices and outcomes were considered significant if their

8   estimated 95% confidence intervals did not overlap 0. (A) Random effects model results

9   comparing restoration practices. (B) Random effects model results comparing restoration

10   outcomes. Outcomes describe target goals from each restoration practice; the habitat category

11   includes studies that reported measures of both soil and vegetation restoration or general

12   community structure.

Restoration	Log Response Ratio	95% CI
(A)		
Active practices	0.34	0.27, 0.42
Water supplementation	0.64	0.55, 0.73
Soil	0.56	0.54, 0.57
Vegetation	0.19	0.18, 0.21
Passive practices	-0.29	-0.36, -0.21
Soil	-0.74	-0.81, -0.68
Vegetation	0.23	0.18, 0.28
Grazing exclusion	0.13	0.06, 0.20
(B)		
Active restoration outcomes		

Vegetation	0.50	0.49, 0.52
Soil	0.28	0.21, 0.35
Habitat	0.10	0.09, 0.12
Animals	-0.11	-0.113, -0.112
Passive restoration outcomes		
Soil	-0.68	-0.74, -0.62
Vegetation	0.29	0.23, 0.35
Habitat	0.13	0.07, 0.19
Animals	1.05	-0.21, 2.31

Figure 1

Figure 1. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flowchart. PRISMA report of a meta-analysis comparing active versus passive restoration practices in dryland agricultural ecosystems globally.

Records identified through
database searching
(n = 2077)

Additional records identified
through other sources
(n = 5)

Records after duplicates removed
(n = 1441)

Records screened
(n = 1441)

Records excluded
(n = 1251)

Full-text articles assessed
for eligibility
(n = 190)

Full-text articles excluded,
with reasons
(n = 148)

Studies included in qualitative synthesis
(n = 42)

Studies included in
quantitative synthesis
(meta-analysis)
(n = 42)
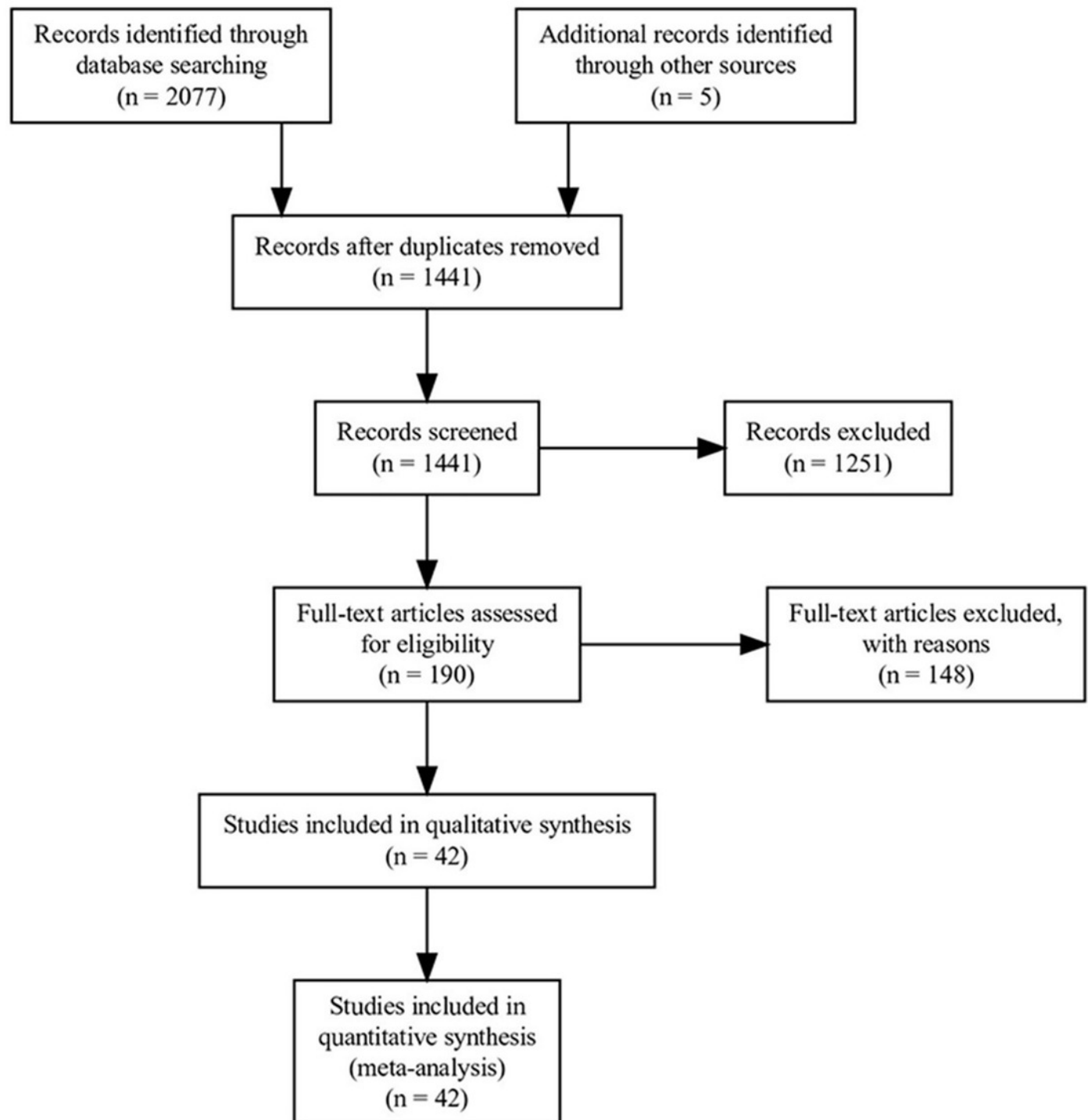
Figure 2

Figure 2. Frequency of terminologies referring to agricultural land uses in dryland ecosystems.

Different terms were applied in studies included in the meta-analysis comparing active and passive restoration practices in agricultural dryland ecosystems globally. These terminologies were grouped into a single term – "agricultural dryland ecosystems", including farmlands (cultivation, farmland, agricultural land, cropland, agriculture, and agricultural field) and grazing lands (grazing and overgrazing terms).
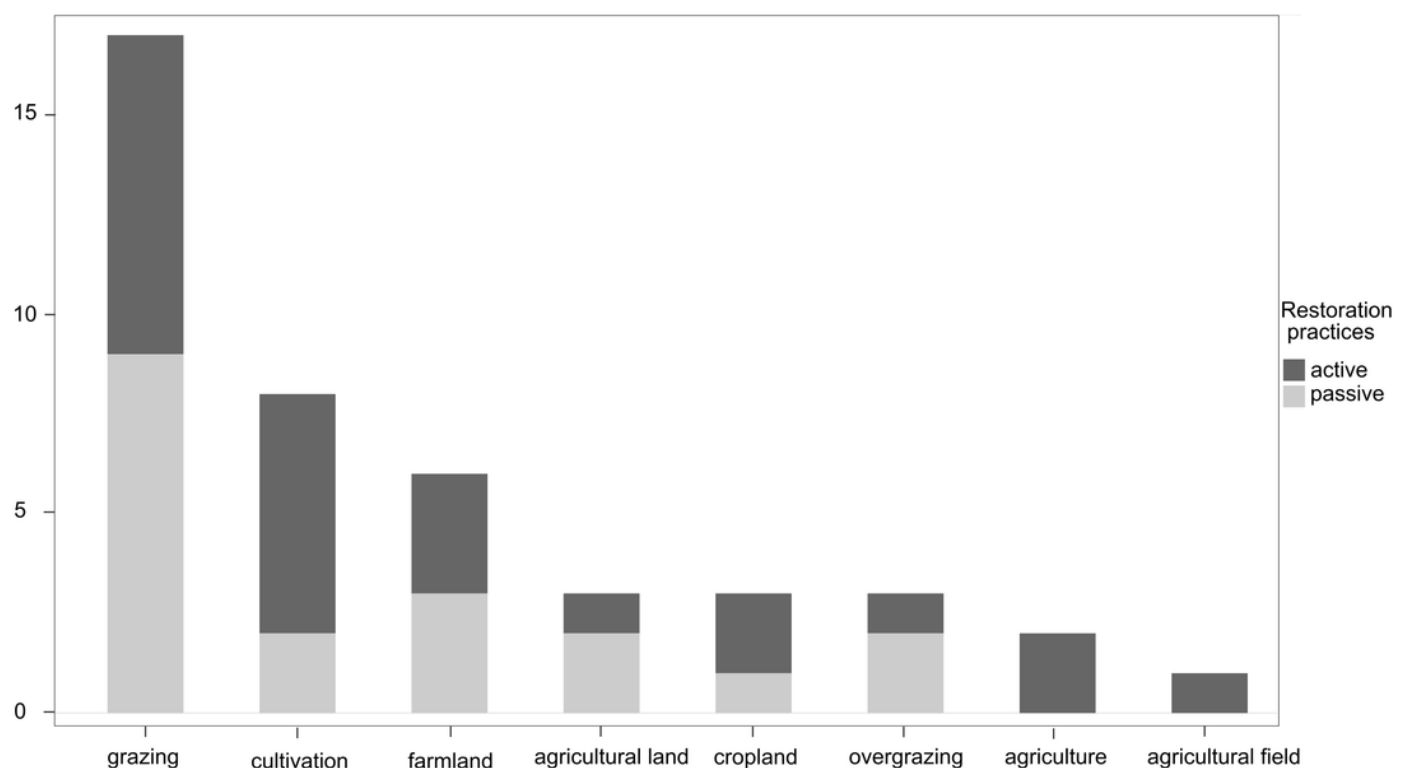
Figure 3

Figure 3. Global distribution of studies evaluating restoration practices in dryland agricultural ecosystems (n = 42).

Restoration practices included in the meta-analysis were classified into active or passive. Dark gray points represent the location of studies that used active restoration practices. Lighter gray points represent the location of studies that used passive restoration practices.
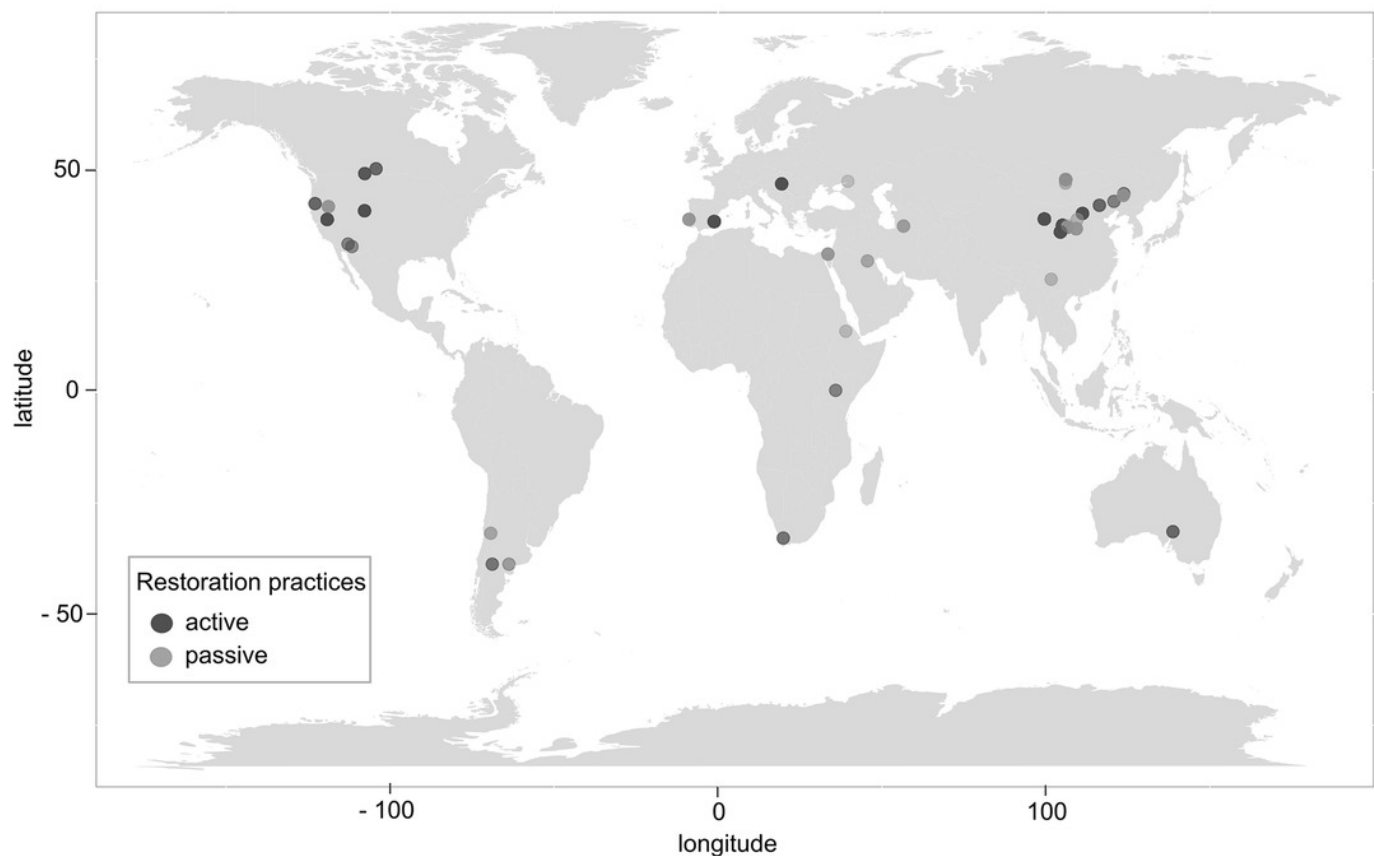
Figure 4

Figure 4. Log response ratio (effect size) and 95% confidence intervals for active and passive restoration practices in agricultural dryland ecosystems.

The dashed vertical line denotes no effect of restoration practices, or a mean of zero. A positive log response ratio value indicates the mean of the restoration practice was higher than that of the reference condition and a negative value indicates the mean of the reference condition was higher than that of the restoration practice. The *p*-values are from random effect models comparing subgroups differences among restoration practices.