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1 **Quantifying the impacts of ecological restoration on biodiversity and ecosystem**
2 **services in agroecosystems: a global meta-analysis**

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15

16 **ABSTRACT**

17 Landscape transformation due to agriculture affects more than 40% of the planet's land
18 area and is the most important driver of losses of biodiversity and ecosystem services
19 (ES) worldwide. Ecological restoration may significantly reduce these losses, but its
20 effectiveness has not been systematically assessed in agroecosystems at the global level.
21 We quantitatively meta-analyzed the results of 54 studies of how restoration actions
22 reflecting the two contrasting strategies of land **sparing** and land sharing affect levels of
23 biodiversity and ES in a wide variety of agroecosystems in 20 countries. Restoration
24 increased overall biodiversity of all organism types by an average of 68%. It also
25 increased the supply of many ES, in particular the levels of supporting ES by an average
26 of 42% and levels of regulating ES by an average of 120% relative to levels in the pre-
27 restoration agroecosystem. In fact, restored agroecosystems showed levels of
28 biodiversity and supporting and regulating ES similar to those of reference ecosystems.
29 Recovery levels did not correlate with the time since the last restoration action.
30 Comparison of land **sparing** and land sharing as restoration strategies showed that while
31 both were associated with similar biodiversity recovery, land **sparing** led to higher
32 median ES response ratios. Passive and active restoration actions did not differ
33 significantly in the levels of biodiversity or ES recovery. Biodiversity recovery
34 positively correlated with ES recovery. We conclude that ecological restoration of
35 agroecosystems is generally effective and can be recommended as a way to enhance
36 biodiversity and supply of supporting and regulating ES in agricultural landscapes.
37 Whether a land sharing or land **sparing** strategy is preferable remains an open question,
38 and **might be case dependent. Moreover,** it is unclear whether crop production on
39 restored land can meet future food production needs.

40

41 **Keywords:** agriculture, land sharing, land **sparing**, land use planning.

42

43 **1. Introduction**

44 Croplands and pastures occupy approximately 40% of the Earth's terrestrial surface,
45 making **them** the largest land use **types** on the planet (Foley et al., 2011). Agricultural
46 expansion and intensification **result in** loss of biodiversity (Tscharntke et al., 2012) and
47 **reduction of** the variety and levels of ecosystem services (ES), which are benefits that
48 people obtain from ecosystems (Millennium Ecosystem Assessment [MEA], 2005).
49 Converting land for agricultural use leaves some provisioning ES unaffected and
50 improves other provisioning ES (e.g., food and fiber) (Rey Benayas and Bullock, 2012),
51 while at the same time reducing land available to supply other supporting, regulating
52 and cultural ES (Bullock et al., 2011; Pilgrim et al., 2010; Raudsepp-Hearne et al.,
53 2010a, 2010b). Thus, the MEA (2005) found that, over the last 50 years, the supply of
54 15 of the 24 ES analyzed have decreased, including biological pest control and
55 pollination. Growth in global income and population are projected to continue in the
56 next decade, leading to predictions of continued growth in demand for agricultural
57 products around the world. Growth in **food requirement** may be as high as 70% by 2050
58 (Bruinsma, 2009), though other authors have estimated that future demand can be met
59 with no further increase in **agricultural land** (Foley et al., 2011).

60

61 This highlights the importance of finding **management** alternatives to reconcile
62 agricultural production with the maintenance or enhancement of levels of biodiversity
63 and ES in agricultural landscapes. Ecological restoration seems well-suited to
64 accomplish this goal (Wade et al., 2008). Restoration efforts aim to recover the
65 characteristics of an ecosystem, such as biodiversity and supply of ES, that have been

66 degraded, **damaged**, or destroyed, usually as a result of human activity (**SER, 2004; see**
67 **this source for definition of concepts**). Evidence suggests that ecological restoration
68 works: for instance, a meta-analysis of 89 studies assessing the effects of restoration of
69 a broad range of ecosystem types around the world found that it increased biodiversity
70 by an average of 44% and ES levels by an average of 25% (Rey Benayas et al., 2009).
71 Similarly, other ecological restoration meta-analyses in more specific ecosystem types
72 such as forests (e.g., Felton et al., 2010; Ilstedt et al., 2007) and wetlands (Meli et al.,
73 2014) have reported increases in biodiversity and/or supply of ES. Two examples of
74 large-scale ecological restoration programs are the Atlantic Forest Restoration Pact,
75 which aims to restore 15 million hectares of degraded lands in the Brazilian Atlantic
76 Forest by 2050 (Calmon et al., 2011), and the Sloping Land Conversion Program in
77 China, in which steeply sloping and marginal land has been retired from agricultural
78 production since 1999 in order to promote forest and grassland cover (Yin and Zhao,
79 2012). These initiatives align with international agreements such as the Action Plan for
80 2020 published by the Convention on Biological Diversity (CBD), which aims to
81 restore at least 15% of the world's degraded ecosystems (CBD, 2012).

82

83 Given that a large proportion of degraded, **damaged, or destroyed** ecosystems are
84 agricultural land, some studies have sought to assess whether ecological restoration can
85 increase biodiversity and supply of ES specifically in agroecosystems (e.g., Aviron et
86 al., 2011; Pöyry et al., 2004; Pykala, 2003; Wade et al., 2008; Wang et al., 2011). Each
87 of these studies, however, has been limited to specific ecosystems, leaving open the
88 question of whether ecological restoration is effective for agroecosystems on a global
89 scale. Therefore, it is necessary to analyze case studies across a broad range of
90 agroecosystems in order to identify global trends in ecological restoration outcomes.

91

92 This issue is particularly important because two contrasting strategies are widely used to
93 enhance biodiversity and supply of ES in agroecosystems (Rey Benayas and Bullock,
94 2012). Land sharing, often called wildlife-friendly farming, advocates conserving and
95 improving the levels of biodiversity and ES of the farmed environment; in contrast, land
96 **sparing** advocates dividing the land area into separate areas for farming and for
97 maximizing biodiversity and supply of ES other than agricultural production (Green et
98 al., 2005; Phalan et al., 2011). While the restoration actions implemented under a land
99 sharing or land **sparing** strategy seem to differ more in scale or extent than in type, the
100 two strategies can have profoundly different implications for land use planning,
101 particularly for defining restoration targets, indicators of restoration success, the site of
102 restoration actions, and specific actions that should be taken (**Fig. 1**).

103

104 The two strategies are typically implemented through either passive or active
105 restoration. Passive restoration implies the removal of degrading factors and most
106 frequently involves secondary succession following abandonment of agricultural land in
107 areas formerly used for crop or livestock farming. Active restoration involves actions
108 such as adding in desired plant species and amending the soil, which also drive
109 secondary succession. While previous studies have evaluated one or more of these
110 measures for specific agroecosystem restoration projects, such as forests (Rey Benayas
111 et al., 2008), species-rich grasslands (Pywell et al., 2002), and heathlands (Pywell et al.,
112 2011), we are unaware of studies systematically assessing their effectiveness across a
113 range of ecosystems.

114

115 The aim of the present study was to quantitatively assess how ecological restoration
116 affects biodiversity and supply of ES in a broad range of agroecosystems around the
117 world through meta-analysis of individual case studies from the peer-reviewed
118 literature. Our goal was to examine (1) to what extent restoration efforts can recover
119 biodiversity and ES levels in degraded agroecosystems; (2) whether restoration
120 outcomes are affected by factors such as restoration strategy (land **sparing** vs. land
121 sharing), type of restoration actions (passive vs. active), the time since the last
122 restoration action (restoration age), or climate type (temperate vs. tropical); and (3)
123 whether biodiversity recovery correlates with ES recovery. We hypothesized that
124 restoration of agroecosystems results in the recovery of biodiversity and ES supply, and
125 that this recovery increases with restoration age. We also expected biodiversity recovery
126 to positively correlate with ES recovery based on the biodiversity-ecosystem function
127 theory (Cardinale, 2012; Hector and Bagchi, 2007; Isbell et al., 2011). The results of
128 this study may help guide land use planning in agricultural activities and the
129 achievement of the CBD's targets for 2020.

130

131 **2. Methods**

132 **2.1. Literature search**

133 We systematically searched the ISI Web of Knowledge database, which provides access
134 to peer-reviewed studies, on 17 April 2012. We searched without any restriction on
135 publication year using the following combination of terms: [((ecosystem OR
136 environment*) AND (biodiversity OR good* OR service* OR function*) AND (restor*
137 OR re-creat* OR rehabilitat* OR enhance*) AND (farm* OR crop* OR agro* OR
138 pasture* OR grass*))]. We refined the search to include only the subject areas
139 “environmental sciences ecology”, “agriculture”, “plant sciences”, “biodiversity

140 conservation”, “forestry”, “water resources”, “biotechnology and applied
141 microbiology”, “entomology”, “zoology”, “food science and technology” and
142 “microbiology”, which resulted in 1590 articles. We examined the title and abstract of
143 each of these articles to identify those likely to report the information necessary to meet
144 all inclusion criteria for our analysis. To be included in our meta-analysis, studies had to
145 focus on an agroecosystem (cropland or pasture) or agricultural landscape and report the
146 following information:

- 147 1) quantitative assessment of passive restoration (natural regeneration) or active
148 restoration in terms of variables related to biodiversity and/or the supply of one
149 or more major types of ES, defined as supporting, provisioning, regulating, and
150 cultural (MEA, 2005);
- 151 2) one or more comparisons involving different states of the agroecosystem, such
152 as the reference ecosystem (prior to conversion into an agroecosystem),
153 converted ecosystem (after agricultural activity or intensive grazing and before
154 restoration), and restored ecosystem (after restoration); and
- 155 3) sample size and variance estimates.

156

157 **2.2. Data extraction and database building**

158 **Fifty-four studies were identified** that met the criteria listed above, **yielding 141**
159 **comparisons used in our meta-analysis** (see below; **Table A1, Supplementary data**).

160 We constructed a database in which rows contained observations and columns
161 contained the properties of those observations (**Table A1, Supplementary data**). For
162 each study, we extracted data that were available in the text, tables or graphics on the
163 variables used to measure the impacts of restoration (response variables). Each
164 measurement was recorded as a separate row in the database, even when the

165 measurements came from the same study. To avoid possible problems of non-
166 independence of within-study data, measurements were recorded separately only when
167 the original study assumed spatially independent conditions within the same study site.
168
169 We extracted data on the country where the study took place, type of agroecosystem, the
170 main degradation factors, the time since completion of the last restoration action
171 (restoration age), overall climate (temperate or tropical), and the specific restoration
172 action(s) implemented. We categorized the restoration actions according to whether
173 they reflected a land sharing or land **sparing** strategy. We considered a restoration action
174 to reflect a land sharing strategy when it did not exclude agricultural production (e.g.,
175 conversion to organic farming or creating hedgerows that affected a small portion of the
176 agroecosystem). We considered a restoration action to reflect a land **sparing** strategy
177 when it impeded agricultural production at the field level and involved a relatively large
178 area (e.g., abandonment of farmed fields; Rey Benayas and Bullock, 2012). We further
179 categorized the restoration actions as passive or active. Passive actions were those
180 involving only the removal or reduction of degrading factor(s), such as organic farming
181 and secondary succession following farmland abandonment. Active actions were actions
182 going beyond removal of degrading factors.
183
184 Measures of biodiversity assessed species abundance, richness or diversity, as well as
185 growth or biomass of organisms in the agroecosystems. Different biodiversity variables
186 were used for different types of organisms (**Table A2, Supplementary data**). For ES,
187 we used measured variables that are proxies or indicators of ES supply. ES variables
188 were classified according to the main groups defined by the MEA (2005). Studies in our
189 meta-analysis reported data on regulating and supporting ES. Regulating ES are benefits

190 obtained from the regulation of ecosystem processes, while supporting ES are necessary
191 for the production of other ES (Table A3, Supplementary data). Very few studies
192 reported on provisioning ES (see below), while none reported on cultural ES.

193

194 From the 54 selected studies, we extracted 153 observations; however, the following six
195 ES were represented by very few observations and so were not included in the analysis:
196 nutrient mineralization (two observations from one study), primary productivity (three
197 observations from two studies), nutrient retention (one observation from one study), soil
198 biological quality (two observations from one study), crop production (three
199 observations from three studies) and water regulation (one observation from one study).
200 Finally, 141 observations were included in the meta-analysis and assigned as coming
201 from either a temperate climate (131 observations, 50 studies) or a tropical climate (10
202 observations, four studies), as reflecting either a land sparing strategy (31 observations,
203 13 studies) or a land sharing strategy (110 observations, 41 studies), and as involving
204 either passive restoration (60 observations, 23 studies) or active restoration (81
205 observations, 31 studies). Restoration age was reported by 39 studies for 109
206 observations.

207

208 **2.3. Statistical analysis**

209 In meta-analysis, effect sizes are extracted from individual studies and pooled to
210 calculate an overall effect size with associated statistical significance (Hedges et al.,
211 1999). The studies in our meta-analysis varied substantially in what ecosystem states
212 they compared as well as in what response variables they used or how they measured
213 them. Therefore we used response ratios (RRs) to quantify the effects of restoration on
214 levels of biodiversity and ES relative to a control. We calculated RRs of the restored

215 agroecosystems relative to reference ecosystems [$\ln(\text{Rest}/\text{Ref})$] and relative to converted
216 ecosystems [$\ln(\text{Rest}/\text{Con})$] for each measure of biodiversity and ES extracted from the
217 studies.

218

219 We expected most response variables to correlate positively with biodiversity or with
220 supply of a particular ES; for example, we predicted greater biomass to be associated
221 with a higher level of the supporting ES "primary productivity". However, we expected
222 some response variables to correlate negatively with supply of ES; for example, we
223 predicted that greater concentration of a soil contaminant or nutrient would be
224 associated with lower levels of supporting ES. In these cases we inverted the sign of the
225 RR (**Table A1, Supplementary data**).

226

227 We performed separate analyses to compare restored and converted ecosystems and to
228 compare restored and reference ecosystems (Rey Benayas et al., 2009; Meli et al.,
229 2014). A categorical, random-effect meta-analysis model was used to calculate mean
230 effect sizes assuming random variation among observations; 95% confidence intervals
231 were calculated around the mean effect sizes using bootstrapping with 999 iterations
232 (Rosenberg et al., 2000). Effect size estimates were considered significantly different
233 from zero if their 95% confidence intervals did not include zero.

234

235 To check for publication bias, we calculated Rosenthal's fail-safe number (Rothstein et
236 al., 2005), which indicates how many studies reporting zero effect size would need to be
237 added to the meta-analysis to render the observed effect statistically insignificant. We
238 obtained a fail-safe number of 968,268, suggesting no publication bias in our meta-
239 analysis. We also checked for publication bias using funnel plots (**Fig. A1,**

240 **Supplementary data**) (Ellis, 2010). RR calculations and statistical analyses were
241 performed using MetaWin 2.0 (Rosenberg et al., 2000).
242
243 To examine whether restoration outcomes are affected by factors such as restoration
244 strategy and type of restoration action and restoration age, we performed non-
245 parametric Kruskal-Wallis tests to compare RRs relating restored ecosystems to
246 converted ones for different restoration strategies (land **sparing** vs. land sharing) and
247 types of restoration actions (passive vs. active). We also performed Spearman's rank
248 correlation to compare RRs for different restoration ages; for this analysis, we
249 aggregated biodiversity and ES observations before calculating RRs for different
250 restoration ages in order to ensure adequate sample size. Since our sample included only
251 four studies in tropical areas, we decided not to examine whether restoration outcomes
252 are affected by climate.
253
254 To examine whether biodiversity recovery correlates with ES recovery, we used the
255 Spearman rank coefficient to quantify the correlation between biodiversity RRs and ES
256 RRs in comparisons of restored and converted ecosystems. We used only RRs from the
257 16 studies that evaluated both biodiversity and supply of ES, and we treated each of
258 these studies as an independent sample. When the same study measured biodiversity or
259 supply of ES using multiple variables, the related RRs were averaged to generate an
260 overall RR for biodiversity and an overall RR for supply of ES for each study, thereby
261 minimizing the risk of pseudo-replication. We also pooled data for all the major ES
262 types into the same overall RR for supply of ES, thereby ensuring adequate sample size
263 (Rey Benayas et al., 2009; Meli et al., 2014). We could not examine the correlation
264 between biodiversity RRs and ES RRs in comparisons of restored and reference

265 ecosystems since the relevant data came from only three studies. Correlation analyses
266 and Kruskal-Wallis tests were performed using R 3.0.2 (R, 2012).

267

268 To evaluate possible pseudo-replication effects, we used an approach similar to that in
269 other ecology meta-analyses (Vilá et al. 2011; Meli et al. 2014): we calculated the mean
270 RR for each of the three largest categories (e.g., supporting ES, regulating ES and
271 biodiversity) using only one randomly selected effect size from each study. These mean
272 RRs were similar to the mean RRs obtained when all effect sizes from each study were
273 included (i.e., the differences were not statistically significant; **Table A4,**
274 **Supplementary data**), as the bias-corrected 95% bootstrap confidence interval of the
275 reduced dataset overlapped with that of the complete dataset. Therefore we retained our
276 full dataset.

277

278 **3. Results**

279 **3.1. Overview of analyzed studies**

280 The 54 studies included were conducted in 20 countries: 39 in Europe, five in America,
281 four in Africa, four in Oceania and two in Asia. The studies included a variety of
282 cropland and pasture systems: herbaceous crops (28 studies), woody crops (8 studies)
283 and grassland (18 studies). The main degradation factors were agricultural
284 intensification, such as increased use of agrochemicals, crop monocultures, irrigation
285 and high-yielding crop varieties; and agricultural expansion, with the concomitant
286 fragmentation of natural and semi-natural habitats. The mean restoration age was 10
287 years (sd, 8 years; min, 1 year; max, 61 years).

288

289 Approximately 80% of studies in our meta-analysis were based on a land sharing
290 strategy and the remainder on a land sparing strategy (**Fig. 1**). While both types of
291 studies employed a variety of restoration actions, they favored active restoration to
292 passive restoration. Restoration based on land sharing focused on modifying field and
293 water margins and on generating small conservation areas at the expense of small
294 production areas. Restoration based on land sparing relied mostly on creating new
295 wilderness areas through revegetation with native species (**Fig. 1**).

296

297 **3.2. Effects of restoration on biodiversity and supply of ES**

298 Overall, biodiversity and levels of both supporting and regulating ES were 73% higher
299 in the restored state of agroecosystems than in the converted state (**Fig. 2**). Restoration
300 enhanced overall biodiversity of all organism types by 68%, ranging from 54% for
301 vertebrates to 79% for invertebrates; the recovery levels for soil microfauna and
302 vascular plants fell within the same range (**Fig. 2**). Restoration actions associated with
303 the greatest increases in biodiversity were creating patches/strips of wildflowers,
304 creating habitats on riparian margins and on the edges of crop fields, organic farming,
305 and revegetating with native species (detailed results not shown).

306

307 Restoration also increased the supply of supporting and regulating ES (**Fig. 2**). Supply
308 of supporting ES increased by an average of 42%, with the following increases for
309 individual ES: soil physical quality (57%) and soil chemical quality (30%). Supply of
310 regulating ES was 120% higher in restored agroecosystems than in converted ones, with
311 the difference between restored and converted areas greatest for pollination (228%),
312 followed by carbon sequestration (62%) and biological control (49%). Restoration
313 actions associated with the greatest increases in ES levels were creating habitats on the

314 edges of crop fields, organic farming and revegetating with native species (detailed
315 results not shown). Biodiversity and levels of supporting and regulating ES as measured
316 by RRs were not significantly different between restored agroecosystems and reference
317 ecosystems assessed across the primary studies (**Fig. 3**).

318

319 **3.3. Effects of restoration strategy, type of restoration action and restoration age** 320 **on restoration outcomes**

321 Analyses to determine the effect of restoration strategy, type of restoration action and
322 restoration age on the effectiveness of ecological restoration were inconclusive.

323 Kruskal-Wallis analysis showed that land **sparing** and land sharing strategies were
324 associated with significantly different ES RRs relating restored agroecosystems to
325 converted ones (**Table 1**). In fact, the median associated with the **sparing** strategy was
326 more than 2-fold higher than the median associated with sharing. On the other hand, the
327 means were not so different and the standard deviations were relatively large. In the
328 case of biodiversity RRs, the differences between strategies were not significant (**Table**
329 **1**).

330

331 The two types of restoration actions were not associated with significant differences in
332 supply of ES or in biodiversity (**Table 1**). Contrary to what we expected, restoration age
333 did not correlate with either biodiversity or ES RRs ($r = -0.12$, $p = 0.267$, $n = 78$).

334

335 **3.4. Relationship between biodiversity and ES recovery**

336 Only 16 of the 54 studies measured the effects of ecological restoration on levels of
337 both biodiversity and ES. These studies involved primarily habitat creation and organic
338 farming. Biodiversity recovery positively correlated with ES recovery in comparisons of

339 restored and converted ecosystems (**Fig. 4**), meaning that restoration of agroecosystems
340 was associated with simultaneous recovery of biodiversity and supply of supporting and
341 regulating ES.

342

343 **4. Discussion**

344 **4.1. Recovery of biodiversity and ES levels**

345 Our meta-analysis of a wide variety of agroecosystems across the globe suggests that
346 agroecosystem restoration is usually successful for enhancing biodiversity and supply of
347 ES other than agricultural production and may be an effective approach for achieving
348 CBD goals for 2020. However, the available evidence leaves open the question of
349 whether the increased use of restoration actions will support adequate crop production
350 for global needs, especially since restoration practices often give lower agricultural
351 yields than more intensive methods (Azadi et al., 2011; Foley et al., 2011).

352

353 Restoration improved biodiversity to roughly the same extent for all organism types
354 examined. An increase in diversity, though by itself insufficient for ensuring high
355 ecosystem functioning (Callaway, 2005), is usually interpreted as an indication that the
356 structure and resilience of the agroecosystem are recovering (Holt-Giménez, 2002;
357 Swift et al., 2004). However, further studies are needed to clarify whether and how such
358 biodiversity enhancement indicates that the compositions of flora and fauna have fully
359 recovered. The complexity of analyzing biodiversity enhancement is well illustrated by
360 the case of organic farming. Nearly half (47%) of the studies in our meta-analysis
361 evaluated the effects of organic farming on biodiversity. Several reviews and meta-
362 analyses of these effects have concluded, consistent with our findings, that organic
363 farming has overall positive effects on biodiversity (Bengtsson et al., 2005; Gomiero et

364 al., 2011; Hole et al., 2005; Tuck et al., 2014), and that these effects can interact with
365 landscape characteristics such as heterogeneity and scale (e.g. field level vs. landscape
366 level) effects (Bengtsson et al., 2005; Rundlöf et al., 2010; Winqvist et al., 2011). At the
367 same time, in contrast to our findings, some of these existing reviews have concluded
368 that organic farming increases the population size of some taxa more than others (Hole
369 et al., 2005; Tuck et al., 2014), and that it may even reduce the population size of certain
370 taxa (Birkhofer et al., 2014).

371

372 Restoration increased the levels of all supporting and regulating ES. Very few studies
373 reporting levels of provisioning ES after agroecosystem restoration (e.g., crop
374 production) met our inclusion criteria, so they were not part of our meta-analysis.
375 Agroecosystems typically seek to maximize the supply of this type of ES (e.g.,
376 providing grains, meat, and fiber). Therefore analyzing the trade-offs and synergies
377 among levels of provisioning, supporting and regulating ES is crucial for selecting the
378 most appropriate indicators to quantify restoration outcomes (Latterra et al., 2012;
379 Naidoo et al., 2008). Indeed, assessing how restoration affects levels of provisioning ES
380 is key to assessing how well it can reconcile farmland production with biodiversity and
381 supply of ES in agricultural landscapes (Wade et al., 2008).

382

383 The cost of agroecosystem restoration is another important factor to take into account
384 when assessing its effectiveness (Aronson et al., 2010; de Groot et al., 2013), yet we
385 found that only three of the 54 studies addressed this issue. Demonstrating a positive
386 cost-benefit relationship for restoring levels of biodiversity and ES in agroecosystems
387 may help support worldwide efforts to accomplish CBD's targets for 2020.

388

389 **4.2. Context dependence of restoration effectiveness**

390 We found that, based on non-parametric analysis, a restoration strategy of land sparing
391 led to a significantly greater recovery of ES levels than a strategy of land sharing.
392 However, the two contrasting strategies led to similar increases in biodiversity, though a
393 trend was observed in which land sparing was associated with higher biodiversity.
394 These findings should be interpreted with caution because the statistical inference is
395 based on medians, whereas the means for the two strategies are rather similar and their
396 deviations are large, particularly for the sharing strategy. In addition, the studies
397 examining land sparing systematically differed in several respects from those examining
398 land sharing. In our meta-analysis, most sites that were restored using a land sparing
399 strategy, which ranged in size from 5 ha to > 1000 ha, were much larger than the sites
400 restored through land sharing, which usually measured < 0.5 ha (e.g., a field-level
401 scale). Furthermore, most restorations based on land sparing in our meta-analysis relied
402 primarily on active or passive revegetation, and outcomes were assessed using
403 exclusively soil-related response variables (e.g., carbon sequestration). In contrast to our
404 finding of similar biodiversity recovery for both restoration strategies, Phalan et al.
405 (2011) found land sparing to be more effective for restoring densities of bird and tree
406 species in Ghana and India in the face of habitat degradation due to food production.
407 The trend in our data supports this, but a much larger sample is needed to gain a reliable
408 global picture.
409
410 The fact that we failed to obtain unambiguous results for the comparison of land sharing
411 and land sparing strategies despite including a relatively large number of studies
412 highlights the difficulties in assessing ecological restoration of agroecosystems. It also
413 underscores the practical and philosophical benefits of seeing the two strategies not as

414 mutually exclusive alternatives but as complementary approaches that can be combined
415 to maximize biodiversity and supply of ES (Rey Benayas and Bullock, 2012). For
416 example, while it may be necessary to choose between these strategies at each
417 individual site, both can be applied at various sites within the same degraded landscape
418 according to an integrated land management strategy.

419

420 Our comparison of active and passive types of restoration actions suggests that both
421 types may lead to similar increases in biodiversity and ES supply in agroecosystems.
422 This result is consistent with that obtained by Morrison and Lindell (2011) for bird
423 habitat quality following active and passive restoration in Costa Rica. Since passive
424 restoration is generally less costly than active restoration, the former may be a feasible
425 alternative to enhance biodiversity and ES other than crop production in
426 agroecosystems.

427

428 We were unable to compare the effects of specific restoration actions on recovery of
429 biodiversity and ES levels because we identified only a small number of studies using
430 the land **sparing** strategy. Nevertheless, our meta-analysis identified at least five
431 restoration actions that seem particularly effective. One of these actions is creating
432 habitats in field margins, which seems quite successful and costs little to implement
433 (Pywell et al., 2006). Most of these five effective actions follow the land sharing
434 strategy and have already been widely implemented in large-scale environmental
435 programs, such as agri-environment schemes in Europe (Kohler et al., 2008). This
436 suggests the feasibility of implementing these restoration actions in real-world situations
437 governed by political considerations, beyond the simplicity of scientific experiments.
438 On the other hand, the effectiveness of agri-environment schemes for biodiversity

439 conservation in Europe remains controversial (Kleijn and Sutherland, 2003; Kleijn et
440 al., 2006) and so should be the focus of future research.

441

442 As 70% of the studies in our meta-analysis and 132 out of 142 observations
443 corresponded to temperate areas, we were unable to compare the recovery of
444 biodiversity and supply of ES in temperate versus tropical agroecosystems. Rey
445 Benayas et al. (2009) found that restoration of terrestrial biomes led to 10-fold greater
446 biodiversity and 100-fold greater levels of ES in tropical climates than in temperate
447 ones, but these differences may not apply to agroecosystems. Like the present study,
448 other global meta-analyses contained a preponderance of data from temperate regions
449 (Meli et al., 2014). This highlights the need for more ecological restoration research in
450 tropical regions, such as the study by De Beenhouwer et al. (2013), who assessed the
451 impact of cacao and coffee agroforestry management on biodiversity and supply of ES.

452

453 Recovery of biodiversity and ES levels did not correlate with restoration age, similar to
454 other findings (Meli et al., 2014; JM RB, unpublished data). While this may reflect the
455 limited variation in the average restoration age (10 years) in the studies that we
456 analyzed, it may also suggest that successful agroecosystem restoration requires less
457 time than in other ecosystems such as wetlands, where full recovery takes several
458 decades (Moreno-Mateos et al., 2012). Further research should examine this issue.

459

460 **4.3. Correlation of biodiversity recovery and ES recovery**

461 We found that levels of biodiversity and ES recovery after restoration of degraded
462 agroecosystems positively correlated, similar to findings in a meta-analysis of a wide
463 range of ecosystems around the world (Rey Benayas et al., 2009). This result may at

464 least partially reflect the fact that our analysis did not include measurements of primary
465 productivity variables and the fact that, particularly in agroecosystems, lower
466 productivity is usually associated with higher levels of biodiversity (e.g., Verhulst et al.,
467 2004). Understanding this correlation has important consequences not only for
468 restoration science but also for economics, government policy and social welfare
469 (Naidoo et al., 2008). Thus further research is urgently needed into the poorly
470 understood relationship between biodiversity and ES supply (de Groot et al., 2010). For
471 example, future studies should explore how to optimize the synergy between
472 biodiversity and ES supply when designing management and conservation programs
473 involving restoration (Meli et al., 2014).

474

475 **5. Conclusions**

476 Our study is the first global, quantitative meta-analysis to show that ecological
477 restoration of agroecosystems improves biodiversity and levels of supporting and
478 regulating ES by an average of 73%. In fact, biodiversity recovery positively correlated
479 with recovery of ES supply. The available evidence therefore strongly supports using
480 agroecosystem restoration in sustainable land use planning. However, our study does
481 not provide clear answers to the questions of whether restoration outcomes are better
482 with a land sharing or land **sparing** strategy, whether outcomes are better with active or
483 passive restoration actions, or how much such restoration reduces food production. Our
484 results suggest that the answers to these questions may be strongly case-dependent. A
485 wide range of specific restoration actions appears to be effective, and they can be
486 combined as required by the socioeconomic and political context of the ecological
487 restoration. Understanding the optimal mix of actions will require as diverse an
488 evidence base as possible, pointing to the need for more studies in regions like South

489 America, where we did not identify any agroecosystem restoration studies. Restoration
490 effects did not differ significantly as a function of restoration age, and the
491 preponderance of studies in temperate climates highlights the need for more restoration
492 research in tropical areas. Our meta-analysis supports the ability of ecological
493 restoration to enhance biodiversity and ES supply in agricultural landscapes, and
494 highlights important directions for future research to explain and optimize restoration
495 outcomes.

496

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503 Nacional de Mar del Plata (Argentina).

504

505 **Supplementary data**

506 Supplementary data associated with this article can be found, in the online version, at ...

507

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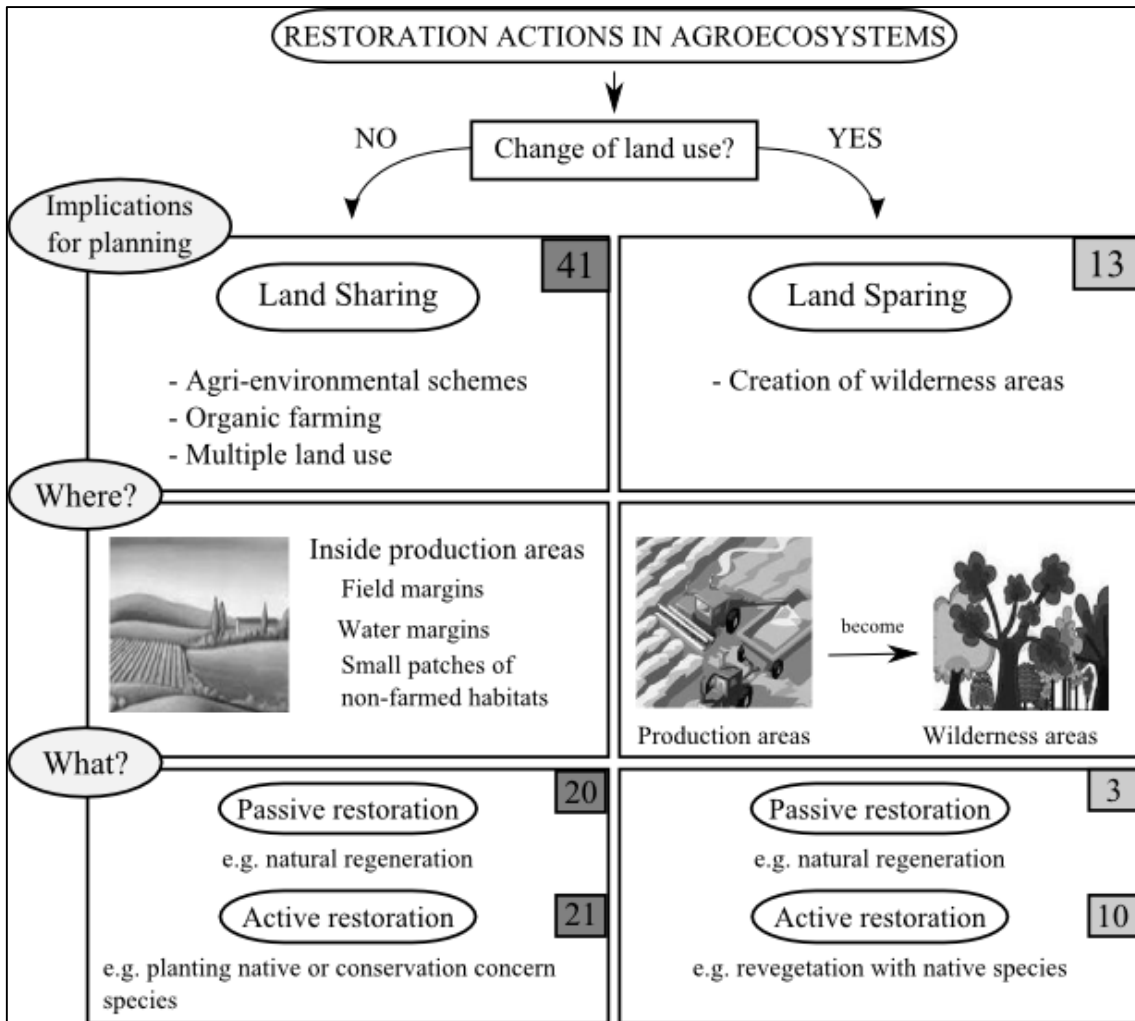


Figure 1. Framework of restoration strategies (land sharing or land separation) and specific restoration actions (passive or active) identified in the agroecosystems in our meta-analysis. Numbers in boxes indicate how many articles for each strategy and action were included.

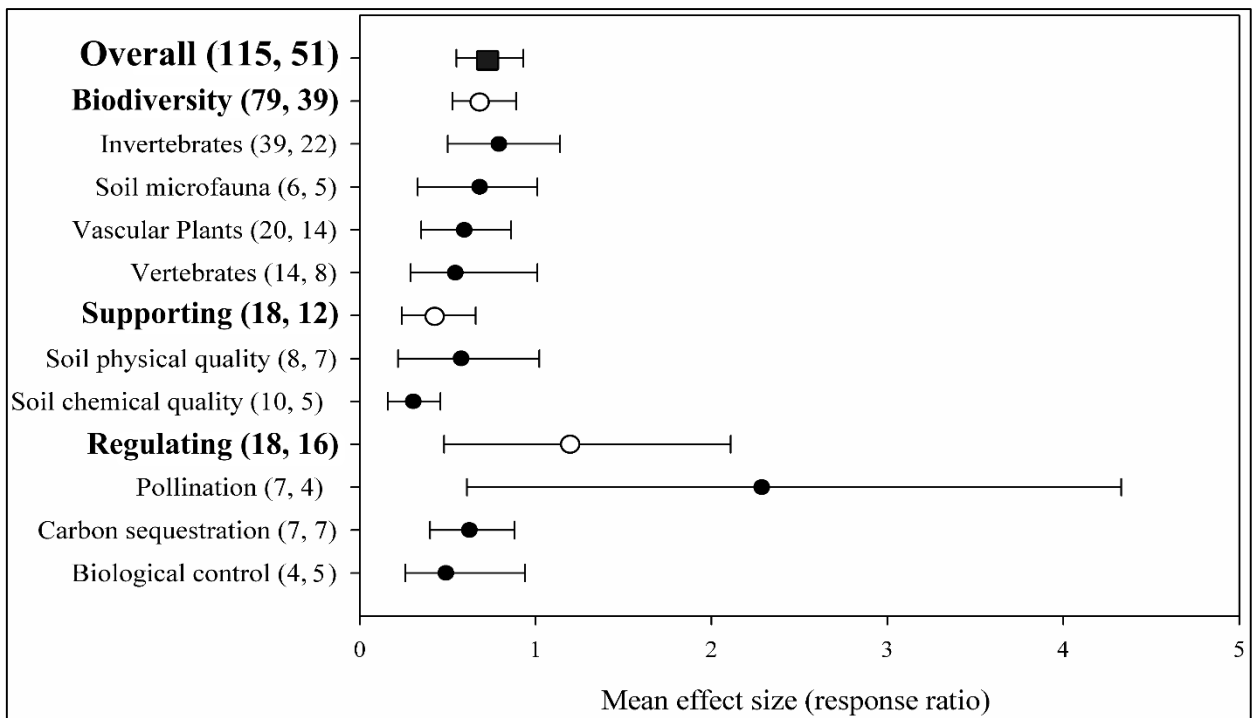


Figure 2. Mean effect size (response ratio) for levels of biodiversity and of supporting and regulating ES in restored agroecosystems relative to converted ones assessed across the primary studies. Bars around the means denote bias-corrected bootstrap 95% confidence intervals. Mean effect size is significantly different from zero if the 95% confidence interval does not include zero. The first and second numbers in parentheses indicate, respectively, how many comparisons and how many studies were included in each calculation.

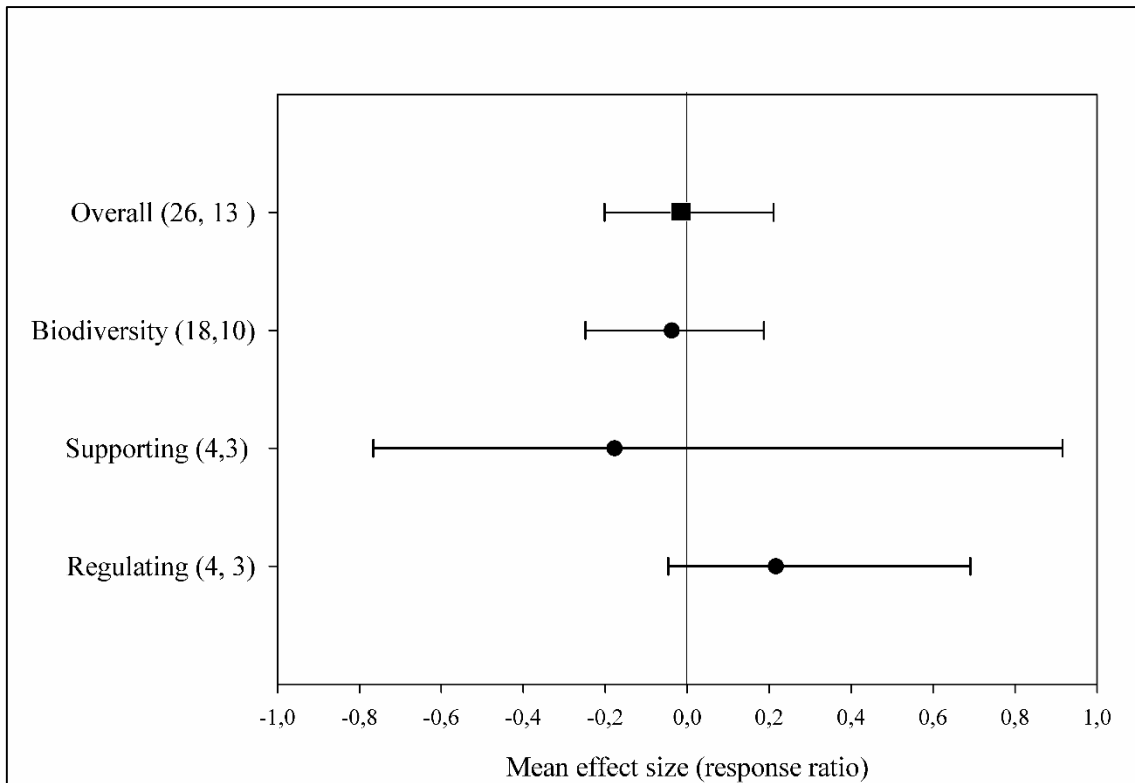


Figure 3. Mean effect size (response ratio) for levels of biodiversity and of supporting and regulating ES in restored agroecosystems relative to reference ecosystems (i.e. prior to conversion to agroecosystem) assessed across the primary studies. Bars around the means denote bias-corrected bootstrap 95% confidence intervals. Mean effect size is significantly different from zero if the 95% confidence interval does not include zero. The first and second numbers in parentheses indicate, respectively, how many comparisons and how many studies were included in each calculation. Data on biodiversity for specific organism types and on different types of ES were pooled due to small sample size.

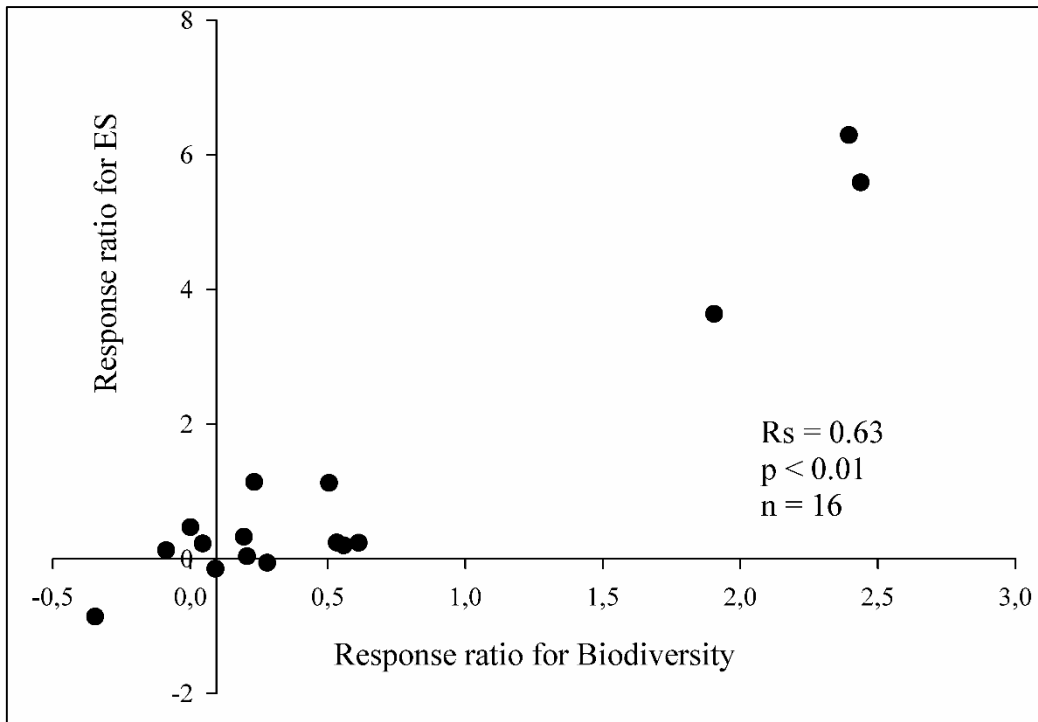


Figure 4. Spearman rank (R_s) correlation between response ratios for biodiversity and ES levels in restored agroecosystems relative to converted ones.

Statistics	Ecosystem services				Biodiversity			
	Land sharing	Land sparing	Active restoration	Passive restoration	Land sharing	Land sparing	Active restoration	Passive restoration
Chi-squared	4.61		1.36		1.49		2.88	
p	0.03		0.24		0.22		0.08	
n	16	16	19	13	79	5	45	39
Median RR	0.20	0.50	0.36	0.24	0.41	1.09	0.41	0.36
Mean RR	1.10	0.66	1.17	0.46	0.68	0.84	0.90	0.41
sd of RR	2.08	0.44	1.86	0.51	0.87	0.48	1.06	0.31

Table 1. Effects of restoration strategy and type of restoration action on response ratios (RR) of ecosystem services and biodiversity relating restored agroecosystems to converted ones.

APPENDIX. Supplementary data.

TABLE A1. Database used for this meta-analysis and citations for the 54 studies included. The last column indicates whether the response variable positively or negatively correlated with biodiversity or with supply of a particular ES.

Reference*	Agroecosystem type	Restoration activity	Type of restoration actions	Age of restoration (yr)	Land use strategy	Country	Climate type	Comparison of restored system	ES/ Biodiversity	Units of measurements	RR	Variance	Correlation
Pywell et al. 2006	Rainfed herbaceous crops	Providing foraging habitats on arable field margins	Active	7	Land sharing	United Kingdom	Temperate	Converted	Pollination	Number of visits	6.29	0.01	+
Pywell et al. 2006	Rainfed herbaceous crops	Providing foraging habitats on arable field margins	Active	7	Land sharing	United Kingdom	Temperate	Converted	Pollination	Number of visits	5.59	0.01	+
Pywell et al. 2006	Rainfed herbaceous crops	Providing foraging habitats on arable field margins	Active	7	Land sharing	United Kingdom	Temperate	Converted	Invertebrates	Number of species	4.02	0.04	+
Pywell et al. 2006	Rainfed herbaceous crops	Providing foraging habitats on arable field margins	Active	7	Land sharing	United Kingdom	Temperate	Converted	Invertebrates	Number of species	3.94	0.04	+
Pywell et al. 2006	Rainfed herbaceous crops	Providing foraging habitats on arable field margins	Active	7	Land sharing	United Kingdom	Temperate	Converted	Pollination	Number of visits	3.63	0.01	+
Pywell et al. 2006	Rainfed herbaceous crops	Providing foraging habitats on arable field margins	Active	7	Land sharing	United Kingdom	Temperate	Converted	Invertebrates	Number of species	3.18	0.04	+
Arlettaz et al. 2010	Rainfed herbaceous crops	Ecological compensation areas - wildflower area	Active	2	Land sharing	Switzerland	Temperate	Converted	Vertebrates	Number of individuals/ha	2.72	0.00	+
Smith et al. 2008	Rainfed herbaceous crops	Establishment of grassy strips at the edges of arable fields	Active	5	Land sharing	United Kingdom	Temperate	Converted	Invertebrates	Number of individuals	2.40	0.00	+
Kohler et al. 2008	Rainfed herbaceous crops	Creation of flower-rich patches	Active	1	Land sharing	Netherlands	Temperate	Converted	Vascular Plants	Number of individuals	2.27	0.01	+
Aviron et al. 2011	Woody crops	Creation of wildflower strips	Active	10	Land sharing	Switzerland	Temperate	Converted	Invertebrates	Number of individuals	2.16	0.00	+

Gaigher et al. 2010	Woody crops	Organic farming	Passive	4	Land sharing	South Africa	Temperate	Converted	Vascular Plants	Plant species richness	1.69	0.00	+
Pywell et al. 2011	Rainfed herbaceous crops	Field margin management: wildflowers	Active	3	Land sharing	United Kingdom	Temperate	Converted	Invertebrates	Number of individuals	1.61	0.01	+
Colloff et al. 2010	Rainfed grassland	Revegetation with deep-rooted perennial native plants	Active	15.5	Land separation	Australia	Temperate	Converted	Soil physical quality	Density of macropores	1.58	0.00	+
Kohler et al. 2008	Rainfed herbaceous crops	Creating flower-rich patches	Active	1	Land sharing	Netherlands	Temperate	Converted	Invertebrates	Species density	1.53	0.02	+
Albrecht et al. 2010	Rainfed grassland	Ecological compensation areas - wildflower area	Active	5	Land sharing	Switzerland	Temperate	Converted	Vascular Plants	Number of species	1.45	0.00	+
Aviron et al. 2011	Woody crops	Creating wildflower strips	Active	10	Land sharing	Switzerland	Temperate	Converted	Invertebrates	Number of species	1.39	0.00	+
Pywell et al. 2011	Rainfed herbaceous crops	Field margin management: tall grass	Active	3	Land sharing	United Kingdom	Temperate	Converted	Invertebrates	Number of individuals	1.34	0.04	+
Gormsen et al. 2006	Rainfed grassland	Soil inoculation - natural colonization	Active	1	Land separation	Netherlands	Temperate	Converted	Soil microfauna	Number of mites/m ²	1.31	0.05	+
Mills and Cowling 2006	Woody crops	Planting <i>P. afra</i> cuttings	Active	22	Land separation	South Africa	Temperate	Converted	Carbon sequestration	kg C/m ²	1.21	0.09	+
Kone et al. 2012	Rainfed herbaceous crops	Introducing legumes	Active	1	Land sharing	Guinea	Tropical	Reference	Soil chemical quality	g/kg	1.20	0.05	+
Mills and Cowling 2006	Woody crops	Planting <i>P. afra</i> cuttings	Active	22	Land separation	South Africa	Temperate	Converted	Soil physical quality	g/kg	1.20	0.01	+
Lomov et al. 2009	Rainfed grassland	Revegetation of pastures with native trees and shrubs	Active	10	Land separation	Australia	Temperate	Converted	Biological control	Number of seeds removed	1.14	0.06	+
Gormsen et al. 2006	Rainfed grassland	Soil inoculation - natural colonization	Active	1	Land separation	Netherlands	Temperate	Converted	Soil microfauna	Number of mites/m ²	1.10	0.10	+
Mekuria et al. 2011	Rainfed grassland	Passive restoration – exclosure	Passive	20	Land separation	Ethiopia	Tropical	Converted	Carbon sequestration	Mg C/ha	1.06	0.00	+
Kone et al.	Rainfed	Introducing legumes	Active	1	Land	Guinea	Tropical	Reference	Carbon	g/kg	1.00	0.04	

2012	herbaceous crops				sharing				sequestration				+
Mekuria et al. 2011	Rainfed grassland	Passive restoration – enclosure	Passive	20	Land separation	Ethiopia	Tropical	Converted	Soil physical quality	Mg C/ha	1.00	0.00	+
Kardol et al. 2009	Rainfed herbaceous crops	Passive restoration - abandoned agricultural sites	Passive	22	Land separation	Netherlands	Temperate	Reference	Invertebrates	Individual/m	0.99	0.00	+
Maes et al. 2008	Rainfed grassland	Agri-environment scheme – ditches	Active	8	Land sharing	Netherlands	Temperate	Converted	Vertebrates	Number of species	0.95	0.12	+
Pywell et al. 2006	Rainfed herbaceous crops	Providing foraging habitats on arable field margins	Active	7	Land sharing	United Kingdom	Temperate	Converted	Vascular Plants	Number of species	0.93	0.00	+
Kohler et al. 2008	Rainfed herbaceous crops	Creating flower-rich patches	Active	1	Land sharing	Netherlands	Temperate	Reference	Invertebrates	Species density	0.84	0.02	+
Kohler et al. 2008	Rainfed herbaceous crops	Creating flower-rich patches	Active	1	Land sharing	Netherlands	Temperate	Converted	Invertebrates	Species density	0.84	0.01	+
Winqvist et al. 2011	Rainfed herbaceous crops	Organic farming	Passive	Undetermined	Land sharing	Europe	Temperate	Converted	Vascular Plants	Number of species	0.83	0.00	+
Mekuria et al. 2011	Rainfed grassland	Passive restoration - enclosure	Passive	20	Land separation	Ethiopia	Tropical	Converted	Soil chemical quality	Mg/ha	0.81	0.00	+
Pywell et al. 2011	Rainfed herbaceous crops	Field margin management: natural revegetation	Passive	3	Land sharing	United Kingdom	Temperate	Converted	Soil microfauna	Number of individuals	0.81	0.04	+
Pywell et al. 2006	Rainfed herbaceous crops	Providing foraging habitats on arable field margins	Active	7	Land sharing	United Kingdom	Temperate	Converted	Vascular Plants	Number of species	0.77	0.00	+
Llorente et al. 2010	Rainfed herbaceous crops	Reforestation with <i>Pinus halepensis</i>	Active	40	Land separation	Spain	Temperate	Converted	Carbon sequestration	Percentage of nitrogen	0.75	0.03	+
Aviron et al. 2011	Woody crops	Creating wildflower strips	Active	10	Land sharing	Switzerland	Temperate	Reference	Invertebrates	Number of individuals	0.69	0.00	+
Batary et al. 2010	Rainfed herbaceous crops	Organic farming	Passive	Undetermined	Land sharing	Germany	Temperate	Converted	Vertebrates	Number of individuals	0.69	0.00	+
Batary et al. 2012	Rainfed herbaceous crops	Organic farming	Passive	Undetermined	Land sharing	Germany	Temperate	Converted	Invertebrates	Number of individuals	0.68	0.02	+

Berges et al. 2010	Rainfed herbaceous crops	Riparian buffers	Active	14	Land sharing	USA	Temperate	Converted	Vertebrates	Number of species	0.67	0.00	+
Batary et al. 2012	Rainfed herbaceous crops	Organic farming	Passive	Undetermined	Land sharing	Germany	Temperate	Converted	Invertebrates	Number of individuals	0.67	0.00	+
Pywell et al. 2006	Rainfed herbaceous crops	Providing foraging habitats on arable field margins	Active	7	Land sharing	United Kingdom	Temperate	Converted	Vascular Plants	Number of species	0.63	0.00	+
Feber et al. 2007	Rainfed herbaceous crops	Organic farming	Passive	3	Land sharing	United Kingdom	Temperate	Converted	Invertebrates	Number of individuals/km	0.63	0.03	+
Birkhofer et al. 2008a	Rainfed herbaceous crops	Organic farming	Passive	Undetermined	Land sharing	Switzerland	Temperate	Converted	Invertebrates	Individuals/gram soil	0.61	0.01	+
Rundlof et al. 2010	Rainfed herbaceous crops	Organic farming	Passive	Undetermined	Land sharing	Sweden	Temperate	Converted	Vascular Plants	Number of species	0.61	0.00	+
Roschewitz et al. 2005	Rainfed herbaceous crops	Organic farming	Passive	Undetermined	Land sharing	Germany	Temperate	Converted	Vascular Plants	Number of species	0.56	0.24	+
Birkhofer et al. 2008a	Rainfed herbaceous crops	Organic farming	Passive	Undetermined	Land sharing	Switzerland	Temperate	Converted	Invertebrates	Individuals/g soil	0.56	0.00	+
Mekuria et al. 2011	Rainfed grassland	Passive restoration - exclosure	Passive	20	Land separation	Ethiopia	Tropical	Converted	Soil chemical quality	Mg/ha	0.54	0.00	+
Verbruggen et al. 2012	Rainfed herbaceous crops	Organic farming	Passive	8	Land sharing	Netherlands	Temperate	Converted	Soil microfauna	Average root colonization rates by arbuscular mycorrhizal fungi (AMF) (%)	0.53	0.02	+
Batary et al. 2012	Rainfed herbaceous crops	Organic farming	Passive	Undetermined	Land sharing	Germany	Temperate	Converted	Invertebrates	Number of individuals	0.51	0.01	+
Diekotter et al. 2010	Rainfed herbaceous crops	Organic farming	Passive	9	Land sharing	Germany	Temperate	Converted	Invertebrates	Number of species	0.51	0.01	+
Verbreggen et al.	Rainfed herbaceous	Organic farming	Passive	Undetermined	Land sharing	Netherlands	Temperate	Converted	Soil microfauna	AMF richness	0.50	0.00	+

2010	crops			d						average			
Aviron et al. 2011	Woody crops	Creating wildflower strips	Active	10	Land sharing	Switzerland	Temperate	Reference	Invertebrates	Number of species	0.47	0.00	+
Bach et al. 2010	Rainfed grassland	Conversion of cropland to grassland	Active	19	Land sharing	USA	Temperate	Converted	Soil physical quality	Millimeters	0.47	0.01	+
Brittain et al. 2010	Woody crops	Organic farming	Passive	Undetermined	Land sharing	Italy	Temperate	Converted	Invertebrates	Number of individuals	0.45	0.01	+
Llorente et al. 2010	Rainfed herbaceous crops	Reforestation with <i>Pinus halepensis</i>	Active	40	Land separation	Spain	Temperate	Converted	Soil chemical quality	Percentage of organic carbon	0.45	0.08	+
Berges et al. 2010	Rainfed herbaceous crops	Riparian buffers	Active	14	Land sharing	USA	Temperate	Converted	Vertebrates	Number of individuals	0.44	0.00	+
Schekkerman et al. 2008	Rainfed grassland	Delayed and staggered mowing of fields. Refuge strips and active nest protection	Active	Undetermined	Land sharing	Netherlands	Temperate	Converted	Biological control	Clutch survival	0.42	0.00	+
Manhoudt et al. 2007	Rainfed herbaceous crops	Organic farming	Passive	5	Land sharing	Netherlands	Temperate	Converted	Vascular Plants	Number of species	0.41	0.01	+
Wang et al. 2011	Woody crops	Conversion of cropland to forest	Active	25	Land separation	China	Temperate	Converted	Carbon sequestration	kg C/m ²	0.41	0.00	+
Bell et al. 2008	Rainfed herbaceous crops	Compost - spent mushroom compost	Active	3	Land sharing	United Kingdom	Temperate	Converted	Biological control	Back-transformed means (number of prey)	0.41	0.03	-
Batary et al. 2010	Rainfed herbaceous crops	Organic farming	Passive	Undetermined	Land sharing	Germany	Temperate	Converted	Vertebrates	Number of species	0.41	0.00	+
Winqvist et al. 2011	Rainfed herbaceous crops	Organic farming	Passive	Undetermined	Land sharing	Europe	Temperate	Converted	Vertebrates	Number of species	0.41	0.00	+
MacGregor et al. 2010	Woody crops	Hillside restoration with native trees and use of a nitrogen-fixing nurse plant	Active	5	Land separation	Mexico	Tropical	Converted	Vertebrates	Number of species	0.40	0.04	+
Gaigher et al. 2010	Woody crops	Organic farming	Passive	4	Land sharing	South Africa	Temperate	Converted	Vascular Plants	Plant species richness	0.37	0.00	+

Kohler et al. 2007	Rainfed grassland	Agri-environment schemes	Active	6.5	Land sharing	Switzerland	Temperate	Converted	Invertebrates	Number of species	0.37	0.01	+
Pywell et al. 2011	Rainfed herbaceous crops	Field margin management: split margin	Active	3	Land sharing	United Kingdom	Temperate	Converted	Invertebrates	Number of individuals	0.36	0.02	+
Kucharik 2007	Rainfed herbaceous crops and Rainfed grassland	Removal of highly erodible land from agricultural production: introduction of permanent grasses and legumes / establishment of permanent native grasses	Active	4	Land separation	USA	Temperate	Converted	Carbon sequestration	kg C/m ²	0.36	0.00	+
Kucharik 2007	Rainfed herbaceous crops and Rainfed grassland	Remove highly erodible land from agricultural production: introduction of permanent grasses and legumes / establishment of permanent native grasses	Active	4	Land separation	USA	Temperate	Converted	Soil chemical quality	kg N/m ²	0.36	0.01	+
Silver et al. 2004	Rainfed grassland	Conversion of abandoned cattle pastures to secondary forest	Active	61	Land separation	Puerto Rico	Tropical	Converted	Carbon sequestration	Mg C/ha	0.35	0.00	+
Batary et al. 2012	Rainfed herbaceous crops	Organic farming	Passive	Undetermined	Land sharing	Germany	Temperate	Converted	Invertebrates	Number of individuals	0.34	0.02	+
Kone et al. 2012	Rainfed herbaceous crops	Introducing legumes	Active	1	Land sharing	Guinea	Tropical	Reference	Soil chemical quality	mg/kg	0.34	0.22	+
Power and Stout 2011	Rainfed grassland	Organic farming	Passive	11.5	Land sharing	Ireland	Temperate	Converted	Vascular Plants	Number of species	0.34	0.00	+
Wen-Jie et al. 2011	Woody crops	Conversion of cropland to forest or grassland	Active	8	Land separation	China	Temperate	Converted	Carbon sequestration	g C /kg soil	0.34	0.00	+
Holzschunh et al. 2010	Rainfed herbaceous crops	Organic farming	Passive	Undetermined	Land sharing	Germany	Temperate	Converted	Invertebrates	Number of species	0.33	0.00	+
Power and Stout 2011	Rainfed grassland	Organic farming	Passive	11.5	Land sharing	Ireland	Temperate	Converted	Pollination	Number of interactions	0.33	0.00	+
Brennan et al. 2006	Rainfed herbaceous	Conservation tillage	Passive	3	Land sharing	Ireland	Temperate	Converted	Invertebrates	Mean abundance	0.33	0.00	+

	crops									log ₁₀ (n+1)			
Araj et al. 2009	irrigated herbaceous crops	Addition of floral nectar resources	Active	Undetermined	Land sharing	New Zealand	Temperate	Converted	Biological control	Mean percentage of aphids parasitized	0.31	0.00	+
Berges et al. 2010	Rainfed herbaceous crops	Riparian buffers	Active	14	Land sharing	USA	Temperate	Converted	Vertebrates	H index	0.31	0.00	+
Manhoudt et al. 2007	Rainfed herbaceous crops	Organic farming	Passive	5	Land sharing	Netherlands	Temperate	Converted	Vascular Plants	Number of species	0.31	0.01	+
Birkhofer et al. 2008b	Rainfed grassland	Organic farming	Passive	26	Land sharing	Switzerland	Temperate	Converted	Invertebrates	Log activity-density (individual/m ²)	0.28	0.02	+
Roth et al. 2008	Rainfed herbaceous crops	Ecological compensation areas	Active	5	Land sharing	Switzerland	Temperate	Converted	Vascular Plants	Number of species	0.27	0.01	+
Roth et al. 2008	Rainfed herbaceous crops	Ecological compensation areas	Active	5	Land sharing	Switzerland	Temperate	Converted	Invertebrates	Number of species	0.27	0.01	+
Kohler et al. 2008	Rainfed herbaceous crops	Creation of flower-rich patches	Active	1	Land sharing	Netherlands	Temperate	Reference	Invertebrates	Species density	0.25	0.00	+
Birkhofer et al. 2008a	Rainfed herbaceous crops	Organic farming	Passive	Undetermined	Land sharing	Switzerland	Temperate	Converted	Soil chemical quality	Percentage of nitrogen content	0.25	0.00	+
Albrecht et al. 2010	Rainfed grassland	Ecological compensation areas	Active	5	Land sharing	Switzerland	Temperate	Converted	Invertebrates	Number of species	0.24	0.00	+
Lomov et al. 2009	Rainfed grassland	Revegetation of pastures with native trees and shrubs	Active	10	Land separation	Australia	Temperate	Converted	Invertebrates	Ant species richness	0.23	0.01	+
Roth et al. 2008	Rainfed herbaceous crops	Ecological compensation areas	Active	5	Land sharing	Switzerland	Temperate	Converted	Vertebrates	Number of species	0.23	0.01	+
Kohler et al. 2007	Rainfed grassland	Agri-environment schemes	Active	6.5	Land sharing	Switzerland	Temperate	Converted	Pollination	Number of species	0.22	0.00	+
Albrecht et al. 2007	Rainfed grassland	Ecological compensation areas	Active	Undetermined	Land sharing	Switzerland	Temperate	Converted	Biological control	Mean number of host species/natu	0.22	0.00	+

										ral enemy species			
Batary et al. 2010	Rainfed herbaceous crops	Organic farming	Passive	Undetermined	Land sharing	Germany	Temperate	Converted	Vertebrates	Number of species	0.22	0.01	+
Feber et al. 2007	Rainfed herbaceous crops	Organic farming	Passive	3	Land sharing	United Kingdom	Temperate	Converted	Invertebrates	Number of species/km	0.22	0.00	+
Roth et al. 2008	Rainfed herbaceous crops	Ecological compensation areas	Active	5	Land sharing	Switzerland	Temperate	Converted	Invertebrates	Number of species	0.22	0.03	+
Birkhofer et al. 2008a	Rainfed herbaceous crops	Organic farming	Passive	Undetermined	Land sharing	Switzerland	Temperate	Converted	Soil chemical quality	Percentage of organic carbon content	0.21	0.00	+
De Deyn et al. 2011	Rainfed grassland	Long-term seed addition	Active	16	Land sharing	United Kingdom	Temperate	Converted	Vascular Plants	Number of species	0.21	0.00	+
Holzschunh et al. 2010	Rainfed herbaceous crops	Organic farming	Passive	Undetermined	Land sharing	Germany	Temperate	Converted	Invertebrates	Number of species	0.19	0.00	+
De Deyn et al. 2011	Rainfed grassland	Long-term seed addition	Active	16	Land sharing	United Kingdom	Temperate	Converted	Soil chemical quality	C:N ratio	0.19	0.01	+
Langridge 2010	Woody crops	Riparian forest restoration	Active	3	Land sharing	USA	Temperate	Converted	Vascular Plants	Log seed abundance	0.17	0.00	+
Wang et al. 2011	Woody crops	Conversion of cropland to forest	Active	25	Land separation	China	Temperate	Converted	Soil physical quality	g /cm ³	0.17	0.00	-
Rundlof et al. 2007	Rainfed herbaceous crops	Organic farming	Passive	Undetermined	Land sharing	Sweden	Temperate	Converted	Invertebrates	Number of species	0.17	0.00	+
De Deyn et al. 2011	Rainfed grassland	Long-term seed addition	Active	16	Land sharing	United Kingdom	Temperate	Converted	Soil physical quality	Percentage of loss on ignition (LOI)	0.17	0.00	+
Birkhofer et al. 2008a	Rainfed herbaceous crops	Organic farming	Passive	Undetermined	Land sharing	Switzerland	Temperate	Converted	Soil chemical quality	Percentage of nitrogen content	0.16	0.00	+
Birkhofer et al. 2008a	Rainfed herbaceous crops	Organic farming	Passive	Undetermined	Land sharing	Switzerland	Temperate	Converted	Soil chemical quality	Percentage of organic carbon content	0.15	0.13	+
Smith et al.	Rainfed	Organic farming	Passive	Undet	Land	Sweden	Temperate	Converted	Vertebrates	Log of	0.15	0.01	

2010	herbaceous crops			ermined	sharing					number of species			-
Gaigher et al. 2010	Woody crops	Organic farming	Passive	4	Land sharing	South Africa	Temperate	Converted	Vascular Plants	Plant species richness	0.14	0.00	+
Kohler et al. 2007	Rainfed grassland	Agri-environment schemes	Active	6.5	Land sharing	Netherlands	Temperate	Converted	Pollination	Number of species	0.13	0.00	+
Lomov et al. 2010	Rainfed grassland	Revegetation of pastures with native trees and shrubs	Active	10	Land separation	Australia	Temperate	Reference	Pollination	Percentage of stigmas with germinated pollen	0.13	0.00	+
Hodgson et al. 2010	Rainfed herbaceous crops	Organic farming	Passive	Undetermined	Land sharing	United Kingdom	Temperate	Converted	Invertebrates	Individuals/15 min	0.12	0.35	+
Langridge 2010	Woody crops	Riparian forest restoration	Active	3	Land sharing	USA	Temperate	Reference	Vascular Plants	Log seed abundance	0.12	0.00	+
Brittain et al. 2010	Woody crops	Organic farming	Passive	Undetermined	Land sharing	Italy	Temperate	Converted	Invertebrates	Number of species	0.11	0.00	+
Winqvist et al. 2011	Rainfed herbaceous crops	Organic farming	Passive	Undetermined	Land sharing	Europe	Temperate	Converted	Invertebrates	Number of species	0.10	0.00	+
Leng et al. 2009	Rainfed grassland	Ditch banks as part of agri-environment scheme	Active	9	Land sharing	Netherlands	Temperate	Converted	Vascular Plants	Number of species	0.10	0.01	+
De Deyn et al. 2011	Rainfed grassland	Cessation of fertilizer application	Passive	16	Land sharing	United Kingdom	Temperate	Converted	Vascular Plants	Number of species	0.09	0.00	+
Batary et al. 2010	Rainfed herbaceous crops	Organic farming	Passive	Undetermined	Land sharing	Germany	Temperate	Converted	Vertebrates	Number of individuals	0.07	0.00	+
Kohler et al. 2007	Rainfed grassland	Agri-environment schemes	Active	6.5	Land sharing	Netherlands	Temperate	Converted	Invertebrates	Number of individuals	0.06	0.01	+
Power and Stout 2011	Rainfed grassland	Organic farming	Passive	11.5	Land sharing	Ireland	Temperate	Converted	Invertebrates	Number of species	0.05	0.00	+
De Deyn et al. 2011	Rainfed grassland	Cessation of fertilizer application	Passive	16	Land sharing	United Kingdom	Temperate	Converted	Soil physical quality	Percentage of LOI	0.02	0.00	+
Kucharik 2007	Rainfed herbaceous crops and	Removal of highly erodible land from agricultural production:	Active	4	Land separation	USA	Temperate	Converted	Soil physical quality	g/m ³	0.02	0.00	-

	Rainfed grassland	introduction of permanent grasses and legumes / establishment of permanent native grasses											
Bach et al. 2010	Rainfed grassland	Conversion of cropland to grassland	Active	19	Land sharing	USA	Temperate	Converted	Soil microfauna	Number of phospholipid fatty acids (PLFA)	0.00	0.00	+
Smith et al. 2010	Rainfed herbaceous crops	Organic farming	Passive	Undetermined	Land sharing	Sweden	Temperate	Converted	Vertebrates	Log of number of species	-0.01	0.00	+
Lomov et al. 2009	Rainfed grassland	Revegetation of pastures with native trees and shrubs	Active	10	Land separation	Australia	Temperate	Reference	Seed dispersal	Number of removed seeds	-0.02	0.00	+
Kardol et al. 2009	Rainfed herbaceous crops	Passive restoration - abandoned agricultural sites	Passive	22	Land separation	Netherlands	Temperate	Reference	Invertebrates	Number of species	-0.06	0.00	+
Brittain et al. 2010	Woody crops	Organic farming	Passive	Undetermined	Land sharing	Italy	Temperate	Converted	Pollination	Visits by potential pollinators	-0.06	0.00	+
Mills and Cowling 2006	Woody crops	Planting <i>P. afra</i> cuttings	Active	15	Land separation	South Africa	Temperate	Reference	Carbon sequestration	kg C/m ²	-0.08	0.01	+
De Deyn et al. 2011	Rainfed grassland	Cessation of fertilizer application	Passive	16	Land sharing	United Kingdom	Temperate	Converted	Soil chemical quality	C:N ratio	-0.09	0.00	+
Bach et al. 2010	Rainfed grassland	Conversion of cropland to grassland	Active	19	Land sharing	USA	Temperate	Reference	Soil microfauna	Number of PLFAs	-0.12	0.00	+
Poyry et al. 2004	Rainfed grassland	Reinitiation of grazing	Active	5	Land sharing	Finland	Temperate	Reference	Vascular Plants	Number of species	-0.14	0.01	+
Poyry et al. 2004	Rainfed grassland	Reinitiation of grazing	Active	5	Land sharing	Finland	Temperate	Reference	Invertebrates	Number of species	-0.15	0.01	+
Gaigher et al. 2010	Woody crops	Organic farming	Passive	4	Land sharing	South Africa	Temperate	Reference	Vascular Plants	Plant species richness	-0.17	0.00	+
Kohler et al. 2007	Rainfed grassland	Agri-environment schemes	Active	6.5	Land sharing	Netherlands	Temperate	Converted	Invertebrates	Number of species	-0.24	0.32	+
MacGregor et al. 2010	Woody crops	Hillside restoration with native trees and use of a nitrogen-fixing nurse plant	Active	5	Land separation	Mexico	Tropical	Reference	Vertebrates	Number of species	-0.27	0.01	+

Kohler et al. 2007	Rainfed grassland	Agri-environment schemes	Active	6.5	Land sharing	Switzerland	Temperate	Converted	Invertebrates	Number of individuals	-0.28	0.75	+
Poyry et al. 2004	Rainfed grassland	Reinitiation of grazing	Active	5	Land sharing	Finland	Temperate	Converted	Vascular Plants	Number of species	-0.29	0.00	+
Verbruggen et al. 2010	Rainfed herbaceous crops	Organic farming	Passive	Undetermined	Land sharing	Netherlands	Temperate	Reference	Soil microfauna	AMF richness average	-0.32	0.00	+
Gaigher et al. 2010	Woody crops	Organic farming	Passive	4	Land sharing	South Africa	Temperate	Reference	Vascular Plants	Plant species richness	-0.34	0.00	+
Poyry et al. 2004	Rainfed grassland	Reinitiation of grazing	Active	5	Land sharing	Finland	Temperate	Converted	Invertebrates	Number of species	-0.40	0.01	+
Gaigher et al. 2010	Woody crops	Organic farming	Passive	4	Land sharing	South Africa	Temperate	Reference	Vascular Plants	Plant species richness	-0.51	0.00	+
Kardol et al. 2009	Rainfed herbaceous crops	Passive restoration - abandoned agricultural sites	Passive	22	Land separation	Netherlands	Temperate	Reference	Invertebrates	Individuals/m	-0.54	0.03	+
Kardol et al. 2009	Rainfed herbaceous crops	Passive restoration - abandoned agricultural sites	Passive	22	Land separation	Netherlands	Temperate	Reference	Invertebrates	Number of species	-0.73	0.00	+
Lomov et al. 2009	Rainfed grassland	Revegetation of pastures with native trees and shrubs	Active	10	Land separation	Australia	Temperate	Reference	Invertebrates	Number of species	-0.74	0.01	+
Bach et al. 2010	Rainfed grassland	Conversion of cropland to grassland	Active	19	Land sharing	USA	Temperate	Reference	Soil physical quality	Millimeters	-0.75	0.00	+
Mills and Cowling 2006	Woody crops	Planting <i>P. afra</i> cuttings	Active	15	Land separation	South Africa	Temperate	Reference	Soil physical quality	g/kg	-0.78	0.00	+

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Table A2. Classification and illustrative examples of the biodiversity measures used in this meta-analysis.

Group	Subgroup	Examples	Unit of measure
Invertebrates	Arthropods	Butterfly richness	Number of species
		Spider abundance	Total number of spiders per trap
	Nematodes	Abundance of bacterivorous nematodes	Individuals/g of soil
Vertebrates	Mammals	Small mammal density	Number of individuals/ha
	Birds	Bird abundance	Number of individuals
Vascular Plants	Herbaceous	Plant richness	Number of species
	Seed	Abundance	Log seed abundance
Soil microfauna	Bacteria	Diversity of soil bacterial communities	Shannon-Wiener index
	Fungi	Diversity of arbuscular mycorrhizal fungi (AMF)	Percentage of root length colonized by AMF

Table A3. Classification of ecosystem service (ES) indicators used in this meta-analysis.

Main ES group*	ES	Indicator/proxy of ES
Supporting	Soil chemical quality	Total nitrogen
		Total phosphorous
		Carbon:nitrogen ratio
		Available phosphorous
	Soil physical quality	Soil organic matter
		Soil aggregates
		Bulk density
		Soil organic carbon
		Macropore density
Regulating	Carbon sequestration	Soil organic carbon
		Rate of carbon sequestration
	Pollination	Number of visits by pollinators
	Biological control	Weed seeds removed
		Parasitism rates

Table A4. Sample sizes (N), effect sizes (RR) and bias-corrected 95% bootstrapping confidence intervals (Bias CI) of RRs calculated for three main categories of data (biodiversity, supporting ES, and regulating ES) after taking into account all effect sizes (complete dataset) or only one effect size per study (reduced dataset).

		<i>Restored vs. Degraded Agroecosystems</i>		
	Dataset	N	RR	Bias CI
Biodiversity				
	Reduced	35	0.61	0.4184 to 0.8491
	Complete	79	0.68	0.5271 to 0.8892
Supporting ES				
	Reduced	5	0.72	0.2954 to 1.2846
	Complete	18	0.42	0.2474 to 0.6688
Regulating ES				
	Reduced	12	1.11	0.3928 to 2.1843
	Complete	19	1.20	0.4836 to 2.1141

Figure A1. Funnel plot for effect sizes (y-axis) and their variance (x-axis) in restored agroecosystems relative to converted ones assessed across the primary studies.

