

1 Agricultural rewilding: a prospect for livestock systems

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3 A. Mondière¹, M.S. Corson¹, L. Morel², H.M.G. van der Werf^{1*}

4 ¹ UMR SAS, INRAE, Institut Agro, 65 rue de Saint Briec, 35042 Rennes, France; aymeric.mondiere@inrae.fr,
5 michael.corson@inrae.fr, hayo.van-der-werf@inrae.fr

6 ² Unité BOREA (MNHN), Université de Rennes 1, Rennes, France; lois.morel@univ-rennes1.fr

7 * Corresponding author

8

9 **Abstract**

10 **CONTEXT:** Agricultural intensification is a major cause of biodiversity loss. Biodiversity conservation and
11 restoration generally involve human intervention. In comparison, rewilding, a radically different approach to
12 address the erosion of biodiversity, aims to increase the ability of ecological processes to act with little or no
13 human intervention, and thus to enhance biodiversity and the supply of ecosystem services.

14 **OBJECTIVE:** In this review and call to explore the potential of rewilding for agriculture, in particular for
15 livestock systems, we identified effects of agroecological livestock systems on biodiversity and analysed
16 similarities, differences and complementarities between the agroecological transition and the rewilding of
17 livestock systems.

18 **METHODS:** We researched literature in the Web of Science Core Collection that focussed on biodiversity,
19 livestock, agriculture, rewilding and interactions among them.

20 **RESULTS AND CONCLUSIONS:** Agricultural rewilding is an emerging form of land use that we conceptually
21 position between agroecology and rewilding. It combines restoration of ecological processes with some
22 degree of agricultural production, most often of animals. Over time, human land-use has aimed to increase
23 plant and animal output, which has degraded the ecological integrity of ecosystems. This process of dewilding
24 accelerated with the advent of agriculture. In recent decades, certain agricultural landscapes and farms have
25 evolved in the opposite direction, decreasing material human inputs and improving ecological integrity. This
26 evolution takes three forms: agroecological transition, agricultural rewilding and rewilding. Of these, the first
27 and third concern relatively large areas. A selection of 11 agricultural rewilding projects established for at
28 least 5 years in the United Kingdom had areas of 121-4402 ha. The projects targeted 48 key species/breeds,
29 23 of which were ecosystem engineers: 18 grazers, 4 pig breeds and beavers. The main actions to enhance
30 rewilding were extensive grazing and habitat restoration. The main economic activities were meat or animal
31 sales, tourism and education programmes. Agricultural rewilding may provide a multifunctional model to
32 which livestock farms may transition to respond better to societal demands.

33 SIGNIFICANCE: Agricultural rewilding offers a new and inspiring prospect for livestock systems and poses
34 research questions about its relation to agroecology and rewilding, its implementation, its potential for plant
35 production and its value for livestock farmers. The forms it can take remain to be explored, and the potential
36 influence of these forms on biodiversity, ecosystem services and environmental impacts needs to be
37 characterised. Exploring the forms that agricultural rewilding may take requires close collaboration among
38 ecologists, animal scientists and agronomists.

39 **Key words:** agroecology, agricultural rewilding, biodiversity, livestock, rewilding

40

41 1. Introduction

42 Worldwide, biodiversity (i.e. the diversity within species, between species and of ecosystems) is declining
43 faster than at any time in human history (IPBES, 2019). As agriculture occupies nearly 40% of the world's ice-
44 free land (Foley et al., 2011), the biodiversity status of agricultural landscapes is crucial. Conservation of
45 biodiversity, especially in Europe, depends largely on agroecosystems with a low level of intensity (i.e.
46 agricultural inputs per unit of farmland) (Kleijn et al., 2009). However, farming systems have intensified
47 greatly since the mid-20th century, resulting in homogenisation of agricultural landscapes and increasing use
48 of chemical inputs, which has caused a decrease in farmland biodiversity, especially populations of habitat
49 specialists (Robinson and Sutherland, 2002).

50 Livestock production, which drove 65% of land-use change (e.g. deforestation, a leading cause of biodiversity
51 loss) from 1961-2011 (Alexander et al., 2015), now requires 77% of the world's agricultural land to produce
52 its feed (Ritchie and Roser, 2019). Thus, it has strong impacts on biodiversity in agricultural landscapes.
53 Furthermore, livestock systems are increasingly criticised for their contribution to other environmental
54 impacts, such as climate change, eutrophication and water use (Poore and Nemecek, 2018), and for their
55 poor record on animal welfare (e.g. von Borell et al., 2009). The impact of overconsumption of animal
56 products on human health, especially in developed countries, further tarnishes the image of these systems
57 (Godfray et al., 2018). Consequently, livestock systems must be redesigned urgently to help solve these
58 problems.

59 Agroecology, i.e. "the application of ecological concepts and principles to the design and management of
60 sustainable agroecosystems" (Gliessman, 1998), is increasingly recommended as an approach to improve the
61 sustainability of agricultural systems. Dumont et al. (2013) propose five principles for designing sustainable
62 animal-production systems, one of which is "preserving biological diversity in agroecosystems by adapting
63 management practices". Restoring functional biodiversity in agricultural landscapes is considered a key
64 strategy for sustainable agriculture by proponents of agroecology (Altieri, 2002). Consequently, transitioning
65 to agroecological livestock systems will favour biodiversity in agricultural landscapes.

66 Biodiversity conservation and restoration often involve continued human intervention, such as habitat
67 creation or manipulation, culling of invasive species or captive-breeding programs, even in natural areas
68 (Mallon and Price, 2013). In agricultural areas, especially in Europe, agri-environment programmes are based
69 on the observation that certain forms of intervention can yield higher biodiversity and supplies of certain
70 ecosystem services than areas without these interventions (Batáry et al., 2015).

71 In contrast to biodiversity conservation based on continued human intervention, rewilding, an emerging and
72 much debated concept in the field of natural-area management, aims to restore the ability of ecological
73 processes to act with little or no human intervention (i.e. “wildness”) to systems at any spatial scale (Perino
74 et al., 2019). Rewilding can thus enhance biodiversity and the supply of ecosystem services (i.e. the
75 contributions of ecosystems to human well-being) (Haines-Young and Potschin, 2018). To date, academic
76 debate about rewilding has occurred almost exclusively among ecologists. We believe that rewilding holds
77 promise for agroecosystems, and we hope to involve those interested in agroecosystems in the debate.

78 Rethinking agroecosystem management by including rewilding processes may help reverse the current loss
79 of biodiversity, and thus restore the structure, functions and composition of ecosystems that have been
80 disturbed by farming intensification (Wade *et al.*, 2008). Ultimately, rewilding highlights the potential of
81 reducing or abstaining from human intervention in certain parts of farms and/or agricultural landscapes,
82 under the hypothesis that differing degrees of land use are complementary and have synergies with respect
83 to biodiversity (Kremen et al., 2021).

84 In this review and call to explore the potential of rewilding for agriculture, and in particular, livestock systems,
85 we identified effects of agroecological livestock systems on biodiversity and analysed similarities, differences
86 and complementarities between the agroecological transition and the rewilding of livestock systems. We
87 aimed to:

- 88 • Analyse how agroecological livestock systems influence biodiversity in agricultural landscapes and
89 may provide other benefits
- 90 • Discuss how rewilding in agricultural systems can help conserve and restore biodiversity in
91 agricultural landscapes and offer new and inspiring prospects for livestock systems, with a focus on
92 livestock as a proxy of extinct megaherbivores
- 93 • Analyse documented cases of land use that combine agricultural production and rewilding
- 94 • Identify research questions about rewilding in agricultural systems, especially concerning its degree
95 of novelty compared to those of more traditional agroecological practices

96

97 2. Methodology

98 We first considered effects of livestock practices and systems on biodiversity (in its broad sense), especially
99 positive effects. To manage the scope of this review, we considered only studies of temperate climate areas.
100 Grey literature (Dumont *et al.*, 2016) cited most articles published until 2016 that had studied effects of
101 livestock systems on biodiversity. We used the “snowball” method to identify additional key references that
102 these articles had cited. We then performed a research query for the Web of Science Core Collection (SCI-
103 EXPANDED, BKCI-S, ESCI): [TS=(biodiversity AND (livestock OR "animal production") NOT (*tropic* OR *arid
104 OR Mediterranean OR desert* OR *alpine OR *arctic OR mountain* OR Amazon* OR *Sahara*))]. The query
105 (performed in April 2021) returned 1891 articles since 1955, which we winnowed down to relevant articles
106 after sequential reading of titles, abstracts and articles. Then, to address relations between rewilding and
107 agriculture, we performed queries that focused on rewilding alone (TS=rewild* OR re-wild*), which returned
108 548 articles, and on rewilding and agriculture (TS=(rewild* OR re-wild*) AND agric*), which returned 81
109 articles. Of the 10 articles that considered integrating rewilding into agriculture, 7 mentioned rewilding of
110 livestock systems. We used the relevant articles to summarise the information that follows about effects of
111 agroecological livestock systems on biodiversity and relations between rewilding and agriculture, which
112 contributed to our reflections on rewilding in agricultural systems.

113

114 3. Agroecological livestock systems

115 Agroecological livestock systems can be considered biodiversity-based systems, which use ecosystem
116 services supplied by biological processes instead of human inputs (Therond *et al.*, 2017). As these processes
117 depend on the biodiversity in agroecosystems, transitioning to agroecology requires increasing on-farm
118 biodiversity, especially that which supports agricultural production, and managing it with a landscape
119 approach (Duru *et al.*, 2015). According to Dumont *et al.* (2013), compared to intensive livestock systems,
120 agroecological livestock systems (i) adopt more management practices that improve animal health, (ii) use
121 fewer human inputs for production, (iii) optimise their metabolic functioning (i.e. on-farm interactions) to
122 pollute less, (iv) are more diverse to increase their resilience and, as mentioned, (v) adapt management
123 practices to preserve biodiversity in the agroecosystem.

124 3.1 Agroecological livestock systems favour biodiversity

125 Applying agroecological practices to different land-use types, such as arable land, temporary and permanent
126 grasslands, and semi-natural areas (e.g. hedgerows, isolated trees, fallows, extensively grazed permanent
127 grassland), can favour a farm’s biodiversity, particularly populations of farmland specialists (Robinson and
128 Sutherland, 2002).

129 3.1.1 Effects of practices in productive areas on biodiversity

130 Livestock systems can contain two types of productive areas – grassland and arable land – each of which has
131 agroecological practices that favour biodiversity (Dumont et al., 2013) (Table 1). Farmers can manage
132 grassland to favour plant, arthropod, mammal and bird diversity by decreasing grazing and mowing intensity
133 (e.g. Huguenin-Elie et al., 2018) or by not grazing or mowing certain paddocks during flowering periods to
134 increase pollinator abundance and diversity (Ravetto Enri et al., 2017) or during nesting periods to support
135 bird populations (Sabatier et al., 2015). Nitrogen fertilisation of grasslands tends to decrease plant
136 biodiversity in the short term at rates greater than 30 kg N/ha and in the long term at even lower rates
137 (Huguenin-Elie et al., 2018). Breed management can favour grassland diversity by adapting the livestock
138 species to grassland characteristics (e.g. sheep and/or cattle, whose differing feeding strategies influence
139 grassland diversity differently) (Wang et al., 2019) or by choosing local or traditional breeds adapted to the
140 quality and quantity of grass (Wallis de Vries et al., 2007).

141 For arable land, including grassland or forage, protein or cover crops in crop rotations enhances the diversity
142 of cultivated species, habitats and the food supply for the associated biodiversity (Wezel et al., 2014),
143 especially over winter, when food is less abundant. Diversifying crop rotations may reduce pesticide use by
144 disrupting pest and/or weed cycles, and because fodder crops tend to have fewer pest and weed problems
145 (Ribeiro et al., 2016).

146 3.1.2 Effects on landscape-scale biodiversity

147 Landscape complexity favours biodiversity (Birkhofer et al., 2018). Heterogeneity of the crop mosaic and
148 smaller fields in agricultural landscapes favour biodiversity by offering a variety of habitats, particularly in
149 landscapes with a low proportion of semi-natural area (Sirami et al., 2019). Smith et al. (2019) demonstrated
150 that crop-livestock systems provided greater habitat diversity and native bird density and richness than crop-
151 only systems, due to smaller fields and more woody crops and grasslands. Maximising the heterogeneity of
152 grazing or mowing of a farm's grassland in space and time increases the diversity and heterogeneity of land
153 cover, which favours plant and arthropod diversity (Ravetto Enri et al., 2017). Semi-natural areas in
154 heterogeneous landscapes influence biodiversity restoration directly in livestock systems by supplying a
155 diversity of habitats (Sirami et al., 2019) (e.g. for natural enemies of crop pests (Bianchi et al., 2006)) and
156 food-supply areas throughout the year that are essential for several taxa, such as birds or small mammals
157 (Benton et al., 2003).

158 At low densities, domestic herbivores can create or maintain landscape heterogeneity by grazing, like the
159 now-extinct megaherbivores that kept forested landscapes more open during prehistory (Sandom et al.,
160 2014a). Vera (2000) explains that such low-intensity grazing can recreate the original European
161 forest/grassland landscape.

162 3.2 Other benefits of agroecological livestock systems

163 3.2.1 Benefits for livestock production

164 Practices that favour biodiversity can also improve production; for example, increasing a grassland's species
165 diversity can increase its yield (Weigelt et al., 2009). Semi-natural areas, such as shade trees (England et al.,
166 2020), can improve animal welfare. Agroecological livestock systems are less productive per unit area than
167 intensive systems, but this may be compensated by their lower operating costs and lower dependence on
168 human inputs (Dumont et al., 2013). Overall, diversifying feed production increases the resilience of livestock
169 systems to natural or economic disturbances (Dumont et al., 2013).

170 3.2.2 Benefits for ecosystem services

171 Favouring biodiversity in livestock systems increases the supply of regulating and cultural ecosystem services
172 (Maes et al., 2012). Practices such as not mowing paddocks (Ravetto Enri et al., 2017) and maintaining semi-
173 natural areas (Bianchi et al., 2006) support the biodiversity that supplies certain regulating ecosystem
174 services (e.g. pest control, pollination) that sustain production directly. Pasture-based livestock systems
175 support the ecosystem service of regulation of water flows, and many people appreciate the aesthetic value
176 of landscapes kept open by livestock, which is a cultural ecosystem service (Rodriguez-Ortega et al., 2014).
177 However, the relation between biodiversity and ecosystem services is not simple or linear; although it may
178 usually seem "win-win" in an agricultural context, it can also be "win-lose", especially when increasing
179 biodiversity requires decreasing provisioning ecosystem services (Reyers et al., 2012).

180

181 4 Rewilding: a multifaceted concept

182 4.1 Forms of rewilding

183 During the first 30 years of debate over definitions of "rewilding" (Jørgensen, 2015), four main forms of
184 rewilding were distinguished (Corlett, 2016): trophic (species introductions to restore top-down trophic
185 interactions), Pleistocene (restoration of a Pleistocene baseline), ecological (allowing ecological processes to
186 regain dominance) and passive (little or no human interference). While these forms of rewilding emphasise
187 little to no human intervention, forms of rewilding that include agricultural interventions have recently been
188 defined: "Rewilding Lite" (delivering wildness while producing some economic benefits, particularly animal
189 products) (Gordon et al., 2021b) and "agricultural wilding" (encouraging wild-crop production systems in
190 agricultural landscapes) (Vogt, 2021). Here, we explore the forms of rewilding and propose merging the two
191 most recent ones into a more general fifth form: "agricultural rewilding". Pettorelli et al. (2018) compared,
192 among other characteristics, the vision, aim and management interventions of the first four forms, to which
193 we added agricultural rewilding (Table 2). Agricultural rewilding as defined here differs essentially from the
194 other forms of rewilding by combining agricultural production of plants and/or animals with the restoration
195 of ecological processes. We feel that the term "agricultural rewilding" is more explicit and general than

196 “Rewilding Lite” or “agricultural wilding” and better reflects its conceptual position between agroecology and
197 rewilding, as described in subsequent sections.

198 When animals are included, agricultural rewilding involves grazers, but not carnivores, since human
199 managers fulfil the role of top predator. Management interventions include fencing in areas (if animals are
200 produced), potentially introducing species to the ecosystem, particularly in the initial phase, and then
201 harvesting plants and/or animals in order to maintain desired population levels. While the other rewilding
202 forms generally originate in landscapes where agriculture is absent, marginal or has been abandoned
203 (Navarro and Pereira, 2012), agricultural rewilding can be found on land that is either marginal or non-
204 marginal for agriculture on individual farms and/or in agricultural landscapes. Despite continued debate over
205 the utility of distinguishing “rewilding” from “restoration” (Anderson et al., 2019; Hayward et al., 2019), all
206 forms of rewilding emphasise minimal human intervention and the influence of fauna (especially large
207 mammals) on ecosystems (Gordon et al., 2021b).

208 4.2 Dewilding

209 Torres et al. (2018) developed a method to measure and monitor the progress of rewilding; it characterises
210 an ecosystem’s condition as a function of i) the intensity of human forcing of natural processes and ii) the
211 ecosystem’s ecological integrity. The former, influenced by current management, is a function of material
212 human inputs to and outputs from the ecosystem. The latter, influenced by human-legacy effects on
213 ecological composition, structure and functions, is a function of three ecological processes: i) stochastic
214 disturbances, ii) landscape connectivity and iii) trophic complexity (Perino et al., 2019). Torres et al. (2018)
215 quantified material human inputs and outputs by their human-associated energy, as recommended by
216 Anderson (1991), using a set of indicators that practitioners can assess easily. They likewise developed a set
217 of indicators to assess the three ecological processes that define ecological integrity.

218 Positioning human food systems in this framework (Fig. 1), reveals an evolution from hunting-gathering, to
219 animal-drawn agriculture, to the current industrial chemical-input-based agriculture. Over time, human land-
220 use has aimed to increase plant and animal output, mainly by increasing the use of a wide range of inputs
221 (e.g. fertilisers, pesticides, irrigation, animal feed, machines), which has degraded the ecological integrity of
222 ecosystems (Fig. 1). This evolution can be considered as a process of dewilding that started more than
223 100,000 years ago with humans driving megafauna extinctions (Sandom et al., 2014b) and accelerated with
224 the advent of agriculture, especially with its industrialisation since the mid-20th century (IPBES, 2019).

225 4.3 From dewilding to rewilding

226 Interestingly, in recent decades, certain agricultural landscapes and farms have evolved in the opposite
227 direction, decreasing material human inputs and improving ecological integrity (i.e. rewilding) (Fig. 1). This

228 evolution takes three forms: agroecology, agricultural rewilding and rewilding (section 3). Of these, the first
229 and third concern relatively large areas.

230 Rewilding occurs when humans give up control over land (e.g. agriculture, forestry) and leave the land to
231 nature (van der Zanden et al., 2017). Rewilding of abandoned farmland is an important process in many
232 regions of the world and one of the main land-use changes in Europe. It occurs primarily in remote,
233 mountainous and less productive areas, which are dominated by extensive pasture-based livestock
234 production. Using a modelling approach, van der Zanden et al. (2017) predicted that 4-11% of the agricultural
235 area in the European Union in 2000 may be abandoned by 2040.

236 The transition from industrial agriculture to agroecology can be considered as the first stage of an agricultural
237 rewilding trajectory (Fig. 1). Agroecology, as a set of practices, aims to design complex and resilient
238 agroecosystems that, by “assembling crops, animals, trees, soils and other factors in spatially and temporally
239 diversified schemes, favour natural processes and biological interactions that optimise synergies so that
240 diversified farms are able to sponsor their own soil fertility, crop protection and productivity” (Altieri, 2002).
241 Although studies have recommended a wide variety of practices for agroecological cropping and livestock
242 systems (Dumont et al., 2013), there is no definitive set of practices that can be labelled as agroecological
243 (Wezel, 2017). HLPE (2019) presents organic agriculture, agroforestry and permaculture as approaches
244 related to agroecology. As organic agriculture requires certification, it is the best-quantified form of
245 agroecology. From 1999-2019, organic agricultural land area in the world increased from 11 to 72 million ha
246 (i.e. to 1.5% of agricultural land). In the European Union, 14.6 million ha was organic in 2019, which
247 corresponded to 8.1% of its agricultural land (Willer et al., 2021).

248 4.4 Emergence of agricultural rewilding

249 The bestselling book *Wilding: the Return of Nature to a British Farm* (Tree, 2018) revealed the potential of
250 agricultural rewilding as an inspiring prospect for livestock systems to a wide audience. In it, Isabelle Tree
251 related how she and her husband transformed their economically failing dairy farm into the Knepp Wildland
252 project, a haven of rewilded biodiversity. The theoretical foundations of this rewilding were provided by
253 Vera’s (2000) influential theory of cyclical vegetation turnover, which posits that the natural vegetation of
254 lowland Europe was not closed forest but a shifting mosaic or park-like landscape in which megaherbivores
255 played an essential ecological role in slowing or preventing tree regeneration in forest clearings. The Knepp
256 Wildland project was not driven by specific goals or target species. Instead, it introduced rustic breeds of
257 domestic herbivores (i.e. longhorn cattle, Exmoor ponies) and pigs (i.e. Tamworth) and wild herbivores (i.e.
258 red, fallow and roe deer) to establish an ecosystem in which nature was given as much freedom as possible.
259 Herbivores and pigs began to be introduced gradually in 2002, and their density by 2010 was such that some
260 of them had to be relocated or harvested, which yielded premium organic meat. The absence of predators
261 of large herbivores in the project thus almost inevitably resulted in meat production.

262 According to our literature review, few articles discuss agricultural rewilding because most of them consider
263 rewilding and agriculture to be mutually exclusive. Focussing on livestock, Gordon et al. (2021b) distinguish
264 “Rewilding Max...with minimal intervention, covering large areas, with largely intact assemblages of species”
265 from “Rewilding Lite...in which carefully chosen interventions are employed to achieve as many of the
266 ecological benefits of rewilding, and with some human economic benefits...[,] to maximise the area over
267 which ecological benefits...are achieved”. They highlight that the two lie on a continuum and can be
268 complementary. As Rewilding Lite, unlike Rewilding Max, permits animal production to be harvested, it can
269 provide more income, which makes it more attractive to landowners. Indeed, where natural predators are
270 absent, there will often be no choice but to mimic their predation by harvesting and/or translocating animals.
271 Consequently, animals that have economic value, especially hardy traditional herbivore breeds, are key to
272 Rewilding Lite. Therefore, Rewilding Lite represents a subset of agricultural rewilding in which traditional
273 livestock species, but not plants, are harvested.

274 Vogt (2021) introduces the term “agricultural wilding” to describe “introducing and conserving wild crops
275 and plants for agricultural purposes, as wild productive systems”. Using the self-developed framework of
276 “Ecological Sensitivity within Human Realities”, she explores its relevance for coffee-farming landscapes,
277 stressing the value of wild crops and plants in agricultural systems and landscapes as a “significant
278 opportunity for in-situ conservation..., cultural and nutritional benefit..., and market value”. Consequently,
279 “agricultural wilding” represents a subset of agricultural rewilding in which only wild plants are included, and
280 human intervention need not be minimised.

281 4.5 What does agricultural rewilding look like?

282 The Rewilding Britain website (<http://rewildingbritain.org.uk>) lists rewilding projects in the United Kingdom.
283 To understand what form successful agricultural rewilding may take, of the 28 projects listed (as of April
284 2021), we selected those that i) had some form of agricultural output and ii) had been engaged in rewilding
285 for at least five years. This process yielded 11 projects (Table 3), with areas of 121-4402 ha and start dates of
286 1990-2016. Their main initial action was to reduce or abandon sheep grazing. The projects targeted 48 key
287 species/breeds, 23 of which were ecosystem engineers (i.e. species that influence the availability of resources
288 to other species (Jones et al., 1994)): 18 grazers, 4 pig breeds and beavers. Six actions that enhance rewilding
289 were identified: habitat restoration (10 projects), extensive grazing/grazing control (10), natural regeneration
290 (6), tree planting (5), species reintroduction (3), deer control (2) and managed realignment (1). The main way
291 to engage with people was volunteering. The main economic activities were meat or animal sales, tourism
292 and education programmes.

293 4.6 Agricultural rewilding compared

294 As defined here, agricultural rewilding goes well beyond agroecology, but not as far as rewilding (Fig. 1).
295 Comparing animal-based forms of industrial agriculture, agroecology, agricultural rewilding and rewilding

296 (Table 4) highlights that industrial agriculture emphasises specialisation, production and efficiency of human
297 input use. Agroecology, which stands for diversified production, relies on biodiversity because it replaces
298 human inputs with natural processes. Agricultural rewilding's chief aim is to restore biodiversity, with plant
299 and/or animal production as a co-benefit. Rewilding's sole focus is to restore biodiversity and improve
300 ecological integrity.

301 These four land-use forms lie along a strong gradient for several characteristics. Human input and output
302 forcing and production are highest for industrial agriculture, intermediate for agroecology, low for
303 agricultural rewilding and nil for rewilding. Gradients of environmental impacts (e.g. climate change,
304 eutrophication), although they remain to be quantified, likely display a similar order of land-use forms, as
305 impacts tend to correlate positively with human input use. Conversely, gradients of biodiversity and
306 ecosystem services (other than provisioning) likely display an inverse pattern: lowest for industrial agriculture
307 and highest for rewilding. Agroecology probably has the highest social acceptability, since industrial
308 agriculture has a poor image with the public due to high environmental impacts and poor animal welfare,
309 whereas agricultural rewilding and rewilding may suffer from a perceived lack of consideration of local
310 culture and traditions.

311 We have defined agricultural rewilding as distinct from agroecology and rewilding, but both agroecology and
312 rewilding have multiple definitions, and agroecology in particular is a fuzzy concept without clearly defined
313 boundaries (Wezel, 2017). Nevertheless, we propose agricultural rewilding as a conceptual perspective that
314 is positioned between agroecology and rewilding. Compared to agroecology, it attempts to minimise human
315 interventions, while compared to rewilding, it includes the harvest of plants and/or animals.

316

317 5 Questions for agricultural rewilding research

318 Supporting the insertion of agricultural rewilding into this conceptual niche, clarifying its definition and
319 implementing it effectively will require additional research through close collaboration among ecologists,
320 animal scientists and agronomists. Thus, here we formulate research questions about agricultural rewilding
321 and provide initial responses.

322 5.1 Can agricultural rewilding complement agroecology and rewilding?

323 Gordon et al. (2021b) suggest that, although advocates of each form of rewilding often criticise each other,
324 Rewilding Lite (i.e. agricultural rewilding) can complement Rewilding Max (i.e. rewilding) because each can
325 be applied to different parts of the landscape. Embedding wild ecosystems (i.e. rewilding) in an agriculturally
326 rewilded matrix, especially if ecological corridors are present (Torres et al., 2018), could increase the amount
327 of effective habitat for many species that otherwise might not be able to maintain viable populations in the
328 landscape. Similarly, for forestry, Morizot (2020) cites the Network for Forestry Alternatives, which

329 recommends allowing “free evolution” on 10% of all forest area in France, while implementing “non-violent”
330 forestry on the remaining 90%.

331 As mentioned, the extent to which agricultural rewilding and agroecology display synergies or antagonisms
332 also merits further investigation. Rather than relying on human inputs, agroecology relies on biodiversity,
333 which agriculturally rewilded areas may supply. However, agricultural rewilding may also conflict with
334 agroecology; for example, wild herbivores and cropped fields do not necessarily mix well.

335 5.2. What conditions (e.g. ecological, socioeconomic) are necessary to implement agricultural rewilding?

336 Attention should also be paid to potential obstacles to agricultural rewilding and how to address them. For
337 example, regulations for animal welfare, biosecurity and age at slaughter may render agricultural rewilding
338 difficult to implement. In addition, agricultural rewilding may not align with the values of many farmers (Tree,
339 2018); thus, government policies may be needed to encourage more farmers to adopt it. Currently, subsidies
340 from the European Union’s Common Agricultural Policy that provide incentives for farmers to maintain or
341 expand farmland have halted or reversed rewilding progress in certain areas of Europe (Segar et al., 2021).

342 5.3 How should agricultural rewilding be implemented/optimised?

343 Few documented examples of agricultural rewilding exist, and the most promising forms are unknown. For
344 agricultural rewilding that yields animals, several research avenues can be identified. Clearly, agricultural
345 rewilding requires animals that can thrive “in the wild”. Real-life examples of agricultural rewilding suggest
346 that traditional grazers and pigs fare best, but it is largely unknown which species combinations best meet
347 the multiple objectives that agricultural rewilding may have. As Gordon et al. (2021a) emphasise, intended
348 ecological outcomes of rewilding projects must be clearly stated from the outset.

349 Interestingly, animal science has only recently started to explore the strengths and weaknesses of multi-
350 species livestock farming for farm sustainability, as reported by Martin et al. (2020). Some of their findings
351 may be of interest for agricultural rewilding, such as the potential to combine ruminants and monogastric
352 animals (e.g. cattle and poultry) due to their complementary resource-acquisition strategies and ability to
353 reduce parasite pressure. This issue, as well as the combined use of traditional domestic animals and wild
354 animals, merits further investigation in the context of agricultural rewilding.

355 The timing of actions when initiating agricultural rewilding may be another subject worth investigating. Tree
356 (2018) reports some experiences of the Knepp Wildland project in this respect, such as the need to i) deplete
357 soil mineral nitrogen before establishing wildflower meadows on intensively farmed land and ii) give
358 vegetation a head start by rewilding it first, before gradually increasing grazer densities.

359 The spatial scale(s) for agricultural rewilding warrants investigation. Obviously, rewilding large areas is
360 attractive, as they can support more viable populations of larger species (Root-Bernstein et al., 2017). The
361 longer-term agricultural rewilding projects listed by Rewilding Britain had a mean area (1669 ha) much larger

362 than that of the average farm in the United Kingdom (86 ha). To what extent and under what circumstances
363 rewilding at smaller scales (e.g. less productive parts of farms) may be of interest remains to be investigated.

364 5.4 What potential does agricultural rewilding have for plant production?

365 Large herbivores are central to rewilding, and all 11 longer-term agricultural rewilding projects described by
366 Rewilding Britain that we selected involve extensive grazing by domestic and/or wild grazers. Pigs can
367 contribute to agricultural rewilding given their potential as ecosystem engineers and as a source of meat.
368 Plants are essential to these rewilding projects, but not as outputs. The potential of agricultural rewilding to
369 yield plant products (alone or along with animal products) remains to be explored. Vogt (2021) recommends
370 introducing wild crops and plants in agricultural landscapes as a means of in-situ conservation and
371 production, as exemplified by wild coffee systems. Fukuoka (1978) encourages a “natural farming” approach,
372 called “do-nothing farming”, whose four principles are i) no cultivation, ii) no chemical fertilisers or prepared
373 composts, iii) no weeding by tillage or herbicides and iv) no dependence on chemicals. In a somewhat similar
374 vein, Mollison (1988) defines permaculture as “the conscious design and maintenance of agriculturally
375 productive ecosystems which have the diversity, stability, and resilience of natural ecosystems. It is the
376 harmonious integration of landscape and people providing their food, energy, shelter, and other...needs in a
377 sustainable way”. Both natural farming and permaculture may inspire forms of agricultural rewilding that
378 yield plants.

379 5.5 What can agricultural rewilding do for livestock farmers?

380 Although the value and attractiveness of agricultural rewilding to society in general are obvious, one key
381 question is: what can it do for livestock farmers? Per unit area, animal production of agricultural rewilding is
382 low, so the potential of other sources of commercial income (e.g. tourism, recreation, education) and/or
383 public subsidies (e.g. payment for ecosystem services) will be crucial in determining whether farmers decide
384 to transition to agricultural rewilding. As rewilding favours carbon sequestration in soil and woody biomass
385 (van der Zanden et al., 2017), rewilding part of a farm’s land may allow carbon-neutral animal products to be
386 produced (e.g. Mayberry et al. (2019)). Depending on local soil and climate conditions, opportunities for
387 producing products or services, and the availability of subsidy schemes, farmers may position their farms
388 somewhere between agroecology and rewilding to deliver the combination of products and services that
389 suits them best.

390 5.6 How should agricultural rewilding be assessed?

391 The potential of industrial agriculture and agroecology to satisfy a range of societal demands is well
392 documented, but this is less true for rewilding, and agricultural rewilding is largely *terra incognita* in this
393 respect. Consequently, reflecting on how to assess agricultural rewilding as a form of land use, in particular
394 compared to agroecology and rewilding, is essential. In our opinion, this assessment should be results-based
395 (Herzon et al., 2018) and include a wide range of criteria, such as biodiversity; provisioning, regulating and

396 maintenance, and cultural ecosystem services; and several environmental impacts. This kind of multi-criteria
397 assessment may identify synergies and trade-offs among the criteria (Fig. 2). It should also quantify strengths
398 and weaknesses of agricultural rewilding relative to those of other land-use forms and explore the potential
399 of different forms of agricultural rewilding. To our knowledge, only one study of this type has been published:
400 Balfour et al. (2021) assessed biodiversity and ecosystem services of six sites in England, including an
401 agricultural rewilding project (i.e. Knepp Wildland). Studies that examine additional agricultural rewilding
402 projects may help assess the potential of agricultural rewilding further. Social and economic performances
403 of agricultural rewilding should also be assessed, particularly social acceptability and commercial income.

404

405 6 Conclusions

406 Agriculture, in particular livestock production, has contributed greatly to biodiversity loss and other
407 environmental impacts (e.g. climate change, water pollution) through its land use. Due to these and other
408 problems (e.g. poor animal welfare, negative effects of animal products on human health), livestock systems
409 are challenged to find new ways forward. We recommend agricultural rewilding – the promotion of largely
410 self-regulating biodiverse ecosystems compatible with harvesting, conceptually positioned between
411 agroecology and rewilding – which can take a wide range of forms. It may provide an inspiring multifunctional
412 model to which livestock farms may transition to respond better to societal demands. Transitioning from
413 industrial to agroecological livestock systems reduces environmental impacts; favours biodiversity; and
414 enhances regulating, maintenance, and cultural ecosystem services. Agricultural rewilding may allow
415 livestock systems to further reduce their impacts, restore biodiversity and deliver more ecosystem services,
416 but the degree to which it can do so remains to be quantified.

417

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596

597

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601

602 **Competing interests**

603 The authors declare no competing interests.

604

605 **Additional information**

606 Correspondence should be addressed to H.v.d.W.

607

608 Table 1. Agroecological practices that favour biodiversity on livestock farms and taxa favoured

Land use	Practices that favour biodiversity		Taxa particularly favoured	References
Grassland	Grazing	Decrease grazing intensity	Arthropods, plants, mammals, birds	Wallis De Vries et al., 2007; Rodriguez-Ortega et al., 2014; Sabatier et al., 2015; Huguenin-Elie et al., 2018
		Adapt grazing intensity to pasture characteristics and the soil and climate context	Arthropods, plants, birds	Sabatier et al., 2015; Huguenin-Elie et al., 2018
		Adapt and/or combine grazing species (e.g. sheep and cattle)	Plants	Wang et al., 2019
		Adapt the grazing calendar to flowering and nesting periods and grass diversity	Arthropods, plants, birds	Huguenin-Elie et al., 2018
		Do not graze certain paddocks	Arthropods, plants, birds	Ravetto Enri et al., 2017; Huguenin-Elie et al., 2018
		Choose a breed that is local or well adapted to low-intensity grazing	Arthropods, plants, mammals, birds	Wallis De Vries et al., 2007; Koncz et al., 2020
	Mowing	Decrease mowing frequency	Plants	Sabatier et al., 2015; Huguenin-Elie et al., 2018
		Desynchronise mowing at landscape level	Mammals, birds	Sabatier et al., 2015
		Adapt mowing dates around flowering and nesting periods	Arthropods, plants, birds	Sabatier et al., 2015; Huguenin-Elie et al., 2018
		Do not mow certain areas	Arthropods, plants, birds	Ravetto Enri et al., 2017
Arable land	Crop rotation	Add grassland or forage, protein or cover crops to crop rotations	Arthropods, plants, mammals, birds	Wezel et al., 2014
		Pesticide use	Decrease pesticide applications	Arthropods

609

610 Table 2. Approaches, associated visions, aims and management interventions of the main forms of
 611 rewilding, including agricultural rewilding, which encompasses Rewilding Lite (Gordon et al. 2021b) and
 612 agricultural wilding (Vogt, 2021) (adapted from Pettorelli et al. (2018)).

Rewilding approach	Vision	Aim	Management interventions
Pleistocene	Promote large, long-lived species; facilitate the persistence and ecological effectiveness of megafauna	Restore ecological processes lost in the late Pleistocene	Translocation (including ecological replacement)
Trophic	Promote self-regulating biodiverse ecosystems	Restore top-down trophic interactions and associated trophic cascades	Translocation (including ecological replacement)
Ecological	Promote self-regulating biodiverse ecosystems	Restore ecological processes	Translocation (including ecological replacement)
Passive	Reduce human control of landscapes	Restore ecological processes	Little to no management, although intervention may be required early in the process
Agricultural	Promote largely self-regulating biodiverse ecosystems while obtaining economic benefits from agriculture	Combine restoration of ecological processes and biodiversity with plant and/or animal production	Introduction and harvest of plant and/or animal species

613

Table 3. Agricultural rewilding projects in the United Kingdom at least five years old (initial source: Rewilding Britain website)

Project, Start year, Area	Description and County	Key species	Actions to enhance rewilding	Engaging people	Economic activities
Ingleborough 1990 400 ha	Rewilding a National Nature Reserve (Yorkshire)	Short-eared owl, Red grouse, Blue grey cattle, Belted Galloway cattle	Habitat restoration, Tree Planting, Grazing control, Natural regeneration	Volunteering, Recreation	Animal production
Purbeck Heaths 1999 3332 ha	Re-establishing natural processes on a National Nature Reserve (Dorset)	Long-horn cattle, North Devon cattle, Horses, Mangalica pigs	Extensive grazing, Habitat restoration, Species reintroduction	Volunteering, Recreation, Local business gains, Stakeholder coordination	High-quality meat production, Camping, Ecotourism, Education programme
Knepp Castle Estate 2001 962 ha	Failing farm land turned into a site of wildlife abundance (Sussex)	Eurasian beaver, Red deer, Roe deer, Fallow deer, Tamworth pigs, Exmoor ponies, Purple emperor butterfly, White stork, Long-horn cattle	Extensive grazing, Habitat restoration, Species reintroduction	Volunteering	Tourism, Recreation, Business rentals, Education and Wellness programmes, High-quality meat production
RSBP ¹ Geltsdale 2001 2157 ha	Rewilding a corner of the North Pennines (Cumbria)	Black grouse, Belted Galloway cattle, Exmoor ponies, Curlew, Hen harrier, Short-eared owl	Extensive grazing, Habitat restoration, Tree Planting, Natural regeneration	Volunteering, Recreation, Stakeholder coordination	Animal production
Wild Ennerdale 2003 4402 ha	Rewilding in the Lake District National Park (Cumbria)	Roe deer, Red deer, Red squirrel, Belted Galloway cattle, Salmon, Marsh fritillary, Arctic char, Freshwater mussels	Extensive grazing, Habitat restoration, Tree Planting, Deer control, Natural regeneration	Volunteering, Stakeholder coordination, Community hub	Animal production
Upcott Grange Farm 2005 121 ha	Changing a highly managed landscape to one of wildlife abundance (Devon)	Eurasian beaver, Exmoor ponies, Mouflon, Water buffalo, White stork, Iron Age pigs, Heck cattle	Extensive grazing, Habitat restoration, Tree Planting, Species reintroduction, Natural regeneration	Volunteering	Tourism, Education programme, Breeding animals for restoration projects
Geltsdale Farm 2009 2575 ha	Rewilding a commercial hill farm (Cumbria)	Ring ouzel, Luing cattle, Curlew, Whinchat, Hen harrier	Extensive grazing, Habitat restoration, Deer control	Volunteering, Recreation	High-quality meat production
RSPB ¹ Haweswater 2012 2264 ha	Combining upland wildlife and sustainable farming (Cumbria)	Red squirrel, Belted Galloway cattle, Fell ponies, Salmon, Ring ouzel, Mountain ringlet butterfly, Alpine plants	Extensive grazing, Habitat restoration, Tree Planting	Tourism, Stakeholder coordination, Education programme	Lamb and sheep sales
Stear Marshes 2014 468 ha	Creating a large-scale working wetland landscape (Somerset)	Otter, Avocet, Marsh harrier, Owls, Egrets, Long-horn cattle, Dexter cattle, Friesian cattle, Rutland sheep	Habitat restoration, Natural regeneration, Grazing reduction	Volunteering, Tourism, Education programme	High-quality meat production, Ecotourism
Wallasea Island 2015 853 ha	Transforming the island back into an intertidal coastal marshland (Essex)	Short-eared owl, Spoonbill, Redshank, Avocet, Black-tailed godwit, Marsh Harrier, Common seal, Mixed cattle	Habitat restoration, Managed realignment	Volunteering, Recreation	Animal production, Ecotourism
Wild Somerleyton 2016 830 ha	Rewilding lowland habitats (Norfolk)	Exmoor ponies, Welsh black cattle, Large black pigs, Mouflon, Water buffalo	Extensive grazing, Natural regeneration	Volunteering, Education and Wellness programmes	High-quality meat production, Events and weddings, Ecotourism

¹ Royal Society for the Protection of Birds

Table 4. Characteristics of four animal-based forms of land use, in order of increasing ecological integrity of ecosystems (inspired by Clay et al., 2020)

Characteristic	Industrial livestock production	Agroecological livestock system	Agricultural rewilding	Rewilding
Premise	Demand for animal food is large and increasing; increasing input-use efficiency decreases environmental impacts per unit product	Replacing human inputs with natural processes creates self-sufficient production-consumption systems that optimise local knowledge, reduce environmental impacts and enhance food sovereignty and justice	Grazers and other animal ecosystem engineers can transform marginal farmland into a biodiverse ecosystem, which allows for some harvest	Rewilding can promote self-sustaining ecosystems and enhance the conservation status of biodiversity
System characteristics	Large farms, often in regions of high animal density, using commercial breeds and globally sourced feeds to produce a single livestock species, raised indoors, for national and global markets	Diversified crop-livestock farms, using local breeds, raising several livestock species fully or largely outdoors, for local markets	Large areas where a diverse mixture of herbivores and sometimes pigs are managed to develop self-sustaining ecosystems, which protects native biodiversity and ecological processes	Large areas where a diverse mixture of herbivores and sometimes carnivores develop self-sustaining ecosystems, which protects native biodiversity and ecological processes
Management practices	Intensive use of human inputs such as feed, antibiotics and buildings. Frequent need to manage excess animal manure.	Use of natural processes and locally produced feed, fertilised with farm manure. Preservation of on-farm biodiversity.	Introduction and regular harvest of traditional livestock and wild herbivores	Introduction of functionally important communities of species, in particular large herbivores and carnivores
Strengths	High productivity per unit area	Lower environmental impacts, favourable for biodiversity, good animal welfare, superior product quality, resilient to changes	Excellent for biodiversity and provision of ecosystem services, superior product quality, resilient to changes	Best for biodiversity, ecological integrity and ecosystem services
Weaknesses	Poor for animal welfare, high environmental impact at the landscape level, poor resilience, standard product quality	Lower productivity per unit area	Lack of consideration of local culture and traditions, low productivity	Lack of consideration of local culture and traditions, conflict with agriculture
Transformation from industrial agriculture suggested or required	-	High degree of transformation, relevant mainly for small, mixed crop-livestock systems	High degree of transformation, relevant mainly for large extensive livestock systems and/or marginal farmland	Very high degree of transformation, relevant mainly for degraded or marginal farmland

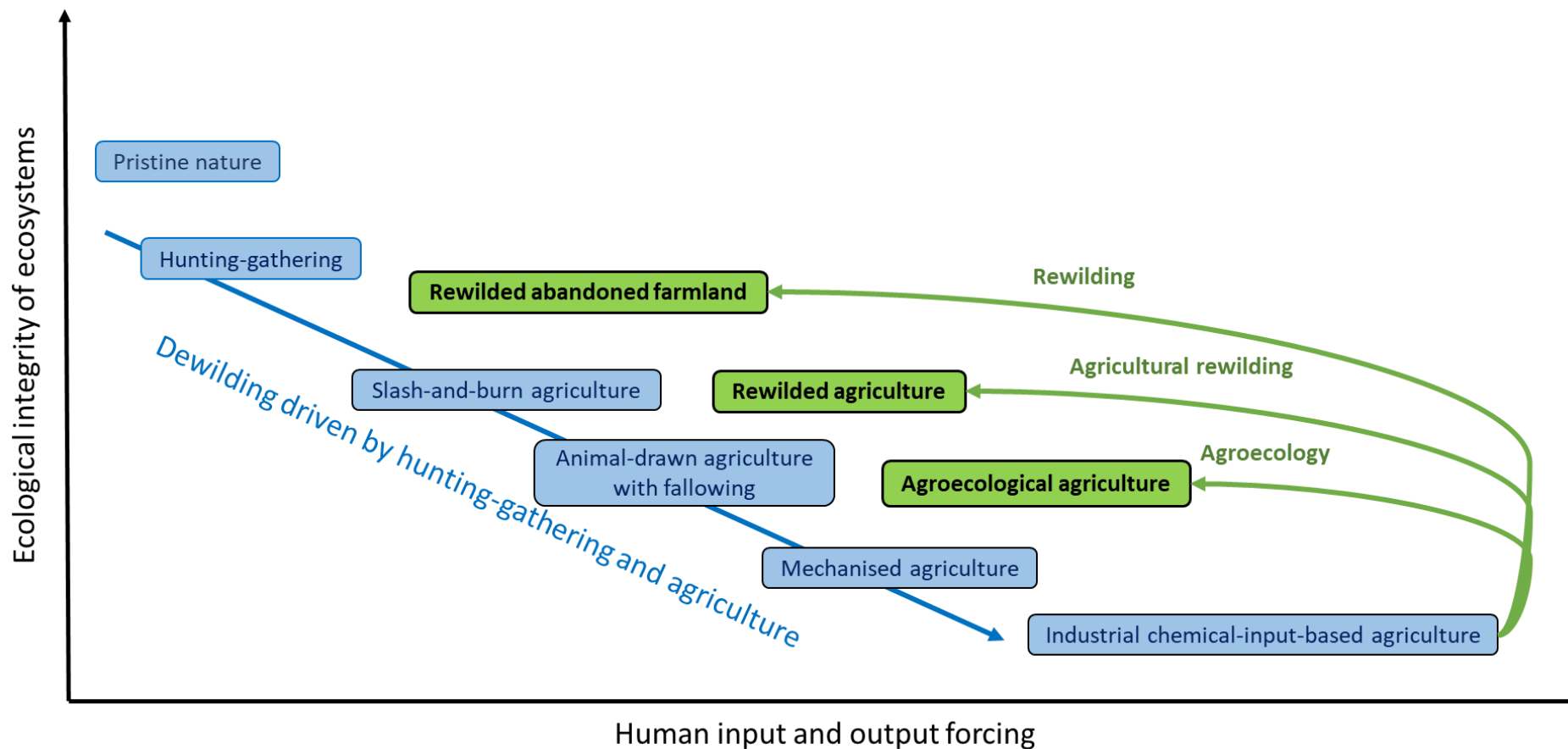


Figure 1. Over time, human food procurement has involved increased human forcing of natural processes and degraded the ecological integrity of ecosystems. This evolution can be considered as a continuous dewilding process. Recently, certain agricultural landscapes and farms have decreased human forcing of natural processes and improved the ecological integrity of ecosystems. This evolution takes three forms: rewilding, agricultural rewilding and agroecology.

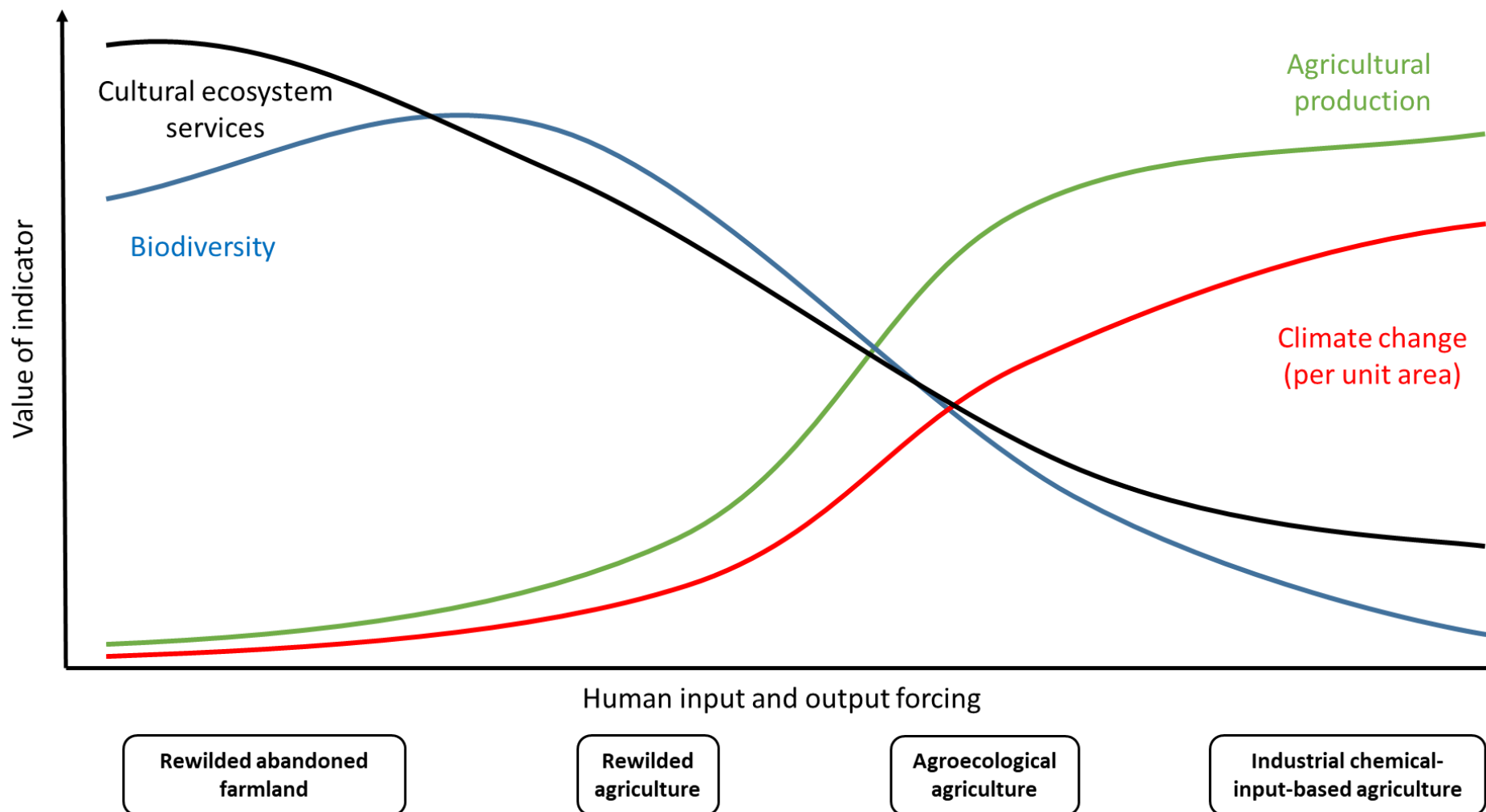


Figure 2. Conceptual representation of potential values of selected performance indicators to assess four land-use forms.