Agricultural rewilding: a prospect for livestock systems

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Abstract

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

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

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

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

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

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

1. Introduction

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

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

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

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

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

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

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

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

2. Methodology

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

3. Agroecological livestock systems

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

3.1 Agroecological livestock systems favour biodiversity

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

3.1.1 Effects of practices in productive areas on biodiversity

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

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

3.1.2 Effects on landscape-scale biodiversity

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

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

3.2 Other benefits of agroecological livestock systems

3.2.1 Benefits for livestock production

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

3.2.2 Benefits for ecosystem services

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

4 Rewilding: a multifaceted concept

4.1 Forms of rewilding

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

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

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

4.2 Dewilding

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

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

4.3 From dewilding to rewilding

Interestingly, in recent decades, certain agricultural landscapes and farms have evolved in the opposite direction, decreasing material human inputs and improving ecological integrity (i.e. rewilding) (Fig. 1). This evolution takes three forms: agroecology, agricultural rewilding and rewilding (section 3). Of these, the first and third concern relatively large areas.

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

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

4.4 Emergence of agricultural rewilding

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

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

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

4.5 What does agricultural rewilding look like?

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

4.6 Agricultural rewilding compared

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

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

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

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

5 Questions for agricultural rewilding research

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

5.1 Can agricultural rewilding complement agroecology and rewilding?

Gordon et al. (2021b) suggest that, although advocates of each form of rewilding often criticise each other, Rewilding Lite (i.e. agricultural rewilding) can complement Rewilding Max (i.e. rewilding) because each can be applied to different parts of the landscape. Embedding wild ecosystems (i.e. rewilding) in an agriculturally rewilded matrix, especially if ecological corridors are present (Torres et al., 2018), could increase the amount of effective habitat for many species that otherwise might not be able to maintain viable populations in the landscape. Similarly, for forestry, Morizot (2020) cites the Network for Forestry Alternatives, which recommends allowing "free evolution" on 10% of all forest area in France, while implementing "non-violent" forestry on the remaining 90%.

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

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

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

5.3 How should agricultural rewilding be implemented/optimised?

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

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

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

The spatial scale(s) for agricultural rewilding warrants investigation. Obviously, rewilding large areas is attractive, as they can support more viable populations of larger species (Root-Bernstein et al., 2017). The longer-term agricultural rewilding projects listed by Rewilding Britain had a mean area (1669 ha) much larger than that of the average farm in the United Kingdom (86 ha). To what extent and under what circumstances rewilding at smaller scales (e.g. less productive parts of farms) may be of interest remains to be investigated.

5.4 What potential does agricultural rewilding have for plant production?

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

5.5 What can agricultural rewilding do for livestock farmers?

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

5.6 How should agricultural rewilding be assessed?

The potential of industrial agriculture and agroecology to satisfy a range of societal demands is well documented, but this is less true for rewilding, and agricultural rewilding is largely *terra incognita* in this respect. Consequently, reflecting on how to assess agricultural rewilding as a form of land use, in particular compared to agroecology and rewilding, is essential. In our opinion, this assessment should be results-based (Herzon et al., 2018) and include a wide range of criteria, such as biodiversity; provisioning, regulating and maintenance, and cultural ecosystem services; and several environmental impacts. This kind of multi-criteria assessment may identify synergies and trade-offs among the criteria (Fig. 2). It should also quantify strengths and weaknesses of agricultural rewilding relative to those of other land-use forms and explore the potential of different forms of agricultural rewilding. To our knowledge, only one study of this type has been published: Balfour et al. (2021) assessed biodiversity and ecosystem services of six sites in England, including an agricultural rewilding project (i.e. Knepp Wildland). Studies that examine additional agricultural rewilding projects may help assess the potential of agricultural rewilding further. Social and economic performances of agricultural rewilding should also be assessed, particularly social acceptability and commercial income.

6 Conclusions

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

References

Alexander, P., Rounsevell, M.D.A., Dislich, C. Dodson, J.R., Engström, K., Moran, D, 2015. Drivers for global agricultural land use change: The nexus of diet, population, yield and bioenergy. Global Environ. Chang. 35 138-147.

Altieri, M.A. 2002. Agroecology: the science of natural resource management for poor farmers in marginal environments. Agric. Ecosyst. Environ. 93, 1–24.

Anderson, J.E., 1991 A conceptual framework for evaluating and quantifying naturalness. Conserv. Biol. 5, 347–352.

Anderson, R.M., Buitenwerf, R., Driessen, C., Genes, L., Lorimer, J., Svenning, J.-C., 2019. Introducing rewilding to restoration to expand the conservation effort: a response to Hayward et al. Biodivers. Conserv. 28, 3691-3693.

Balfour, N.J., Durrant, R., Ely, A., Sandom, C.J., 2021. People, nature and large herbivores in a shared landscape: A mixed-method study of the ecological and social outcomes from agriculture and conservation. People Nat. 3, 418-430.

Batáry, P, Dicks, L.V., Kleijn, D., Sutherland, W.J., 2015. The role of agri-environment schemes in conservation and environmental management. Conserv. Biol. 29, 1006-1016.

Benton, T.G., Vickery, J.A., Wilson, J.D., 2003. Farmland biodiversity: is habitat heterogeneity the key? Trends Ecol. Evol. 18, 182-188.

Bianchi, F.J.J.A., Booij, C.J.H., Tscharntke, T., 2006. Sustainable pest regulation in agricultural landscapes: a review on landscape composition, biodiversity and natural pest control. Proc. R. Soc. Lond. [Biol] 273, 1715-1727.

Birkhofer, K., Andersson, G.K.S., Bengtsson, J., Bommarco, R., Dänhardt, J., Ekbom, B., Ekroos, J., Hahn, T., Hedlund, K., Jönsson, A.M., Lindborg, R., Olsson, O., Rader, R., Rusch, A., Stjernman, M., Williams, A., Smith, H.G., 2018. Relationships between multiple biodiversity components and ecosystem services along a landscape complexity gradient. Biol. Conserv. 218, 247–253.

Clay, N., Garnett, T., Lorimer, J., 2020. Dairy intensification: drivers, impacts and alternatives. Ambio 49, 35-48.

Corlett R.T., 2016. Restoration, reintroduction, and rewilding in a changing world. Trends Ecol. Evol., 31, 453–462.

Dumont, B., Dupraz, P., Aubin, J., Batka, M., Beldame, D., Boixadera, J., Bousquet-Melou, A., Benoit, M., Bouamra-Mechemache, Z., Chatellier, V., Corson, M., Delaby, L., Delfosse, C., Donnars, C., Dourmad, J.Y., Duru, M., Edouard, N., Fourat, E., Frappier, L., Friant-Perrot, M., Gaigné, C., Girard, A., Guichet, J.L., Haddad, N., Havlik, P., Hercule, J., Hostiou, N., Huguenin-Elie, O., Klumpp, K., Langlais, A., Lemauviel-Lavenant, S., Le Perchec, S., Lepiller, O., Letort, E., Levert, F., Martin, B., Méda, B., Mognard, E.L., Mougin, C., Ortiz, C., Piet, L., Pineau, T., Ryschawy, J., Sabatier, R., Turolla, S., Veissier, I., Verrier, E., Vollet, D., van der Werf, H., Wilfart, A., 2016. Rôles, impacts et services issus des élevages en Europe, 1032 pp.

Dumont, B., Fortun-Lamothe, L., Jouven, M., Thomas, M., Tichit, M., 2013. Prospects from agroecology and industrial ecology for animal production in the 21st century. Animal 7, 1028-1043.

Duru, M., Therond, O., Martin, G., Martin-Clouaire, R., Magne, M.A., Justes, E., Journet, E.P., Aubertot, J.N., Savary, S., Bergez, J.E., Sarthou, J.P., 2015. How to implement biodiversity-based agriculture to enhance ecosystem services: a review. Agron. Sustain. Dev. 35, 1259-1281.

England, J.R., O'Grady, A.P., Fleming, A., Marais, Z., Mendham, D., 2020. Trees on farms to support natural capital: An evidence-based review for grazed dairy systems. Sci. Total Environ. 704, 135345.

Foley, J. A., Ramankutty, N., Brauman, K. A., Cassidy, E. S., Gerber, J. S., Johnston, M., Mueller, N.D., O'Connell, C., Ray, D.K., West, P.C., Balzer, C., Bennett, E.M., Carpenter, S.R., Hill, J., Monfreda, C., Polasky, S., Rockström, J., Sheehan, J., Siebert, S., Tilman, D., Zaks, D.P.M., 2011. Solutions for a cultivated planet. Nature 478, 337-342.

Fukuoka, M., 1978. The One-Straw Revolution – An Introduction to Natural Farming. Rodale Press, Emmaus, USA, 146 pp.

Gliessman, S.R., 1998. Agroecology: Ecological Processes in Sustainable Agriculture. Ann Arbor Press, Chelsea, Michigan, USA, 384 pp.

Godfray, H.C.J., Aveyard, P., Garnett, T., Hall, J.W., Key, T.J., Lorimer, J., Pierrehumbert, R.T., Scarborough, P., Springmann, M., Jebb, S.A., 2018. Meat consumption, health, and the environment. Science 361, 243.

Gordon, I.J., Manning, A.D., Navarro, L.M., Rouet-Leduc, J., 2021a. Domestic livestock and rewilding: are they mutually exclusive? Front Sustainable Food Syst. 5, 550410.

Gordon, I.J., Pérez-Barbería, F.J., Manning, A.D., 2021b. Rewilding Lite: using traditional domestic livestock to achieve rewilding outcomes. Sustainability 13, 3347.

Haines-Young, R., Potschin, M., 2018. Common International Classification of Ecosystem Services (CICES) V5.1 Guidance on the Application of the Revised Structure. Available from www.cices.eu.

Hayward, M.W., Scanlon, R.J., Callen, A., Howell, L.G., Klop-Toker, K.L., Di Blanco, Y., Balkenhol, N., Bugir, C.K., Campbell, L., Caravaggi, A., Chalmers, A.C., Clulow, J., Clulow, S., Cross, P., Gould, J.A., Griffin, A.S., Heurich, M., Howe, B.K., Jachowski, D.S., Jhala, Y.V., Krishnamurthy, R., Kowalczyk, R., Lenga, D.J., Linnell, J.D.C., Marnewick, K.A., Moehrenschlager, A., Montgomery, R.A., Osipova, L., Peneaux, C., Rodger, J.C., Sales, L.P., Seeto, R.G.Y., Shuttleworth, C.M., Somers, M.J., Tamessar, C.T., Upton, R.M.O., Weise, F.J., 2019. Reintroducing rewilding to restoration – rejecting the search for novelty. Biol. Conserv. 233, 255-259.

Herzon, I., Birge, T., Allen, B., Povellato, A., Vanni, F., Hart, K., Radley, G., Tucker, G., Keenleyside, C., Oppermann, R., Underwood, E., Poux, X., Beaufoy, G., Pražan, J., 2018. Time to look for evidence: Results-based approach to biodiversity conservation on farmland in Europe. Land Use Policy, 71, 347-354.

HLPE, 2019. Agroecological and other innovative approaches for sustainable agriculture and food systems that enhance food security and nutrition. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security, Rome.

Huguenin-Elie, O., Delaby, L., Klumpp, K. Lemauviel-Lavenant, S., Ryschawy, J., Sabatier, R., 2018. The role of grasslands in biogeochemical cycles and biodiversity conservation. In: Marshall, A. and Collins, R. (ed.), Improving Grassland and Pasture Management in Temperate Agriculture, Burleigh Dodds Science Publishing, Cambridge, UK.

Humbert, J.Y., Dwyer, J.M., Andrey, A., Arlettaz, R., 2016. Impacts of nitrogen addition on plant biodiversity in mountain grasslands depend on dose, application duration and climate: a systematic review. Glob Chang Biol 22, 110-120.

IPBES, 2019. Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. S. Díaz, J. Settele, E. S. Brondízio E.S., H. T. Ngo, M. Guèze, J. Agard, A. Arneth, P. Balvanera, K. A. Brauman, S. H. M. Butchart, K. M. A. Chan, L. A. Garibaldi, K. Ichii, J. Liu, S. M. Subramanian, G. F. Midgley, P. Miloslavich, Z. Molnár, D. Obura, A. Pfaff, S. Polasky, A. Purvis, J. Razzaque, B. Reyers, R. Roy Chowdhury, Y. J. Shin, I. J. Visseren-Hamakers, K. J. Willis, and C. N. Zayas (eds.). IPBES secretariat, Bonn, Germany, 56 pp.

Jones, C.G., Lawton G.H., Shackak, M., 1994. Organisms as ecosystem engineers. Oikos 69, 373-386.

Jørgensen, D. Rethinking rewilding. Geoforum 65, 482-488.

Kleijn, D., Kohler, F., Baldi, A., Batary, P., Concepcion, E.D., Clough, Y., Diaz, M., Gabriel, D., Holzschuh, A., Knop, E., Kovacs, A., Marshall, E.J., Tscharntke, T., Verhulst, J., 2009. On the relationship between farmland biodiversity and land-use intensity in Europe. Proc. Biol. Sci. 276, 903-909.

Koncz, N.K., Béri, B., Deák, B., Kelemen, A., Tóth, K., Kiss, R., Radócz, S., Miglécz, T., Tóthmérész, B., Valkó, O., 2020. Meat production and maintaining biodiversity: Grazing by traditional breeds and crossbred beef cattle in marshes and grasslands. Applied Vegetation Science 23, 139-148.

Kremen, C., Kelsey, T.R., Gennet, S., 2021. The role of diversifying farmland management in rewilding the San Joaquin Valley. Chapter 10 in: Butterfield, H.S., Kelsey, T.R., Hart, A.K. (eds.), Rewilding Agricultural Landscapes: a California Study in Rebalancing the Needs of People and Nature. Island Press, Washington, DC. pp. 149-166.

Maes, J., Paracchini, M.L., Zulian, G., Dunbar, M.B., Alkemade, R., 2012. Synergies and trade-offs between ecosystem service supply, biodiversity, and habitat conservation status in Europe. Biol. Conserv. 155, 1-12.

Mallon, D.P., Price, M.R.S., 2013. The fall of the wild. Oryx 47, 467-468.

Martin, G., Barth, K., Benoit, M., Brock, C. Destruel, M, Dumont, B., Grillot, M. Hübner, S. Magne, M.A., Moerman, M., Mosnier, C. Parsons, D., Ronchi, B., Schanz, L., Steinmetz, L., Werne, S., Winckler, C., Primi, R., 2020. Potential of multi-species livestock farming to improve the sustainability of livestock farms: A review. Agric. Syst. 181, 102821.

Mayberry, D., Bartlett, H., Moss, J., Davison, T., Herrero, M., 2019. Pathways to carbon-neutrality for the Australian red meat sector. Agric. Syst. 175, 13-21.

Mollison, B., 1988. Permaculture: A Designer's Manual. Tagari, Tasmania, Australia, 574 pp.

Morizot, B., 2020. Rekindle the embers of life – A common front. [In French: Raviver les braises du vivant – Un front commun]. Actes Sud, Arles, France.

Navarro, L.M., Pereira H.M., 2012. Rewilding abandoned landscapes in Europe. Ecosyst. 15, 900-912.

Perino, A., Pereira, H.M., Navarro, L.M., Fernandez, N., Bullock, J.M., Ceausu, S., Cortes-Avizanda, A., van Klink, R., Kuemmerle, T., Lomba, A., Pe'er, G., Plieninger, T., Rey Benayas, J.M., Sandom, C.J., Svenning, J.C., Wheeler, H.C., 2019. Rewilding complex ecosystems. Science 364, eaav5570.

Pettorelli, N. Barlow, J., Stephens, P.A. Durant, S.M., Connor, B., Schulte to Bühne, H., Sandom, C.J., Wentworth, J., du Toit, J.T., 2018. Making rewilding fit for policy. J. Appl. Ecol. 55, 1114-1125.

Poore, J., Nemecek, T., 2018. Reducing food's environmental impacts through producers and consumers. Science 360, 987-992.

Ravetto Enri, S., Probo, M., Farruggia, A., Lanore, L., Blanchetete, A., Dumont, B., 2017. A biodiversity-friendly rotational grazing system enhancing flower-visiting insect assemblages while maintaining animal and grassland productivity. Agric. Ecosyst. Environ. 241, 1-10.

Reyers, B., Polasky, S., Tallis, H., Mooney, H.A., Larigauderie, A., 2012. Finding common ground for biodiversity and ecosystem services. BioScience 62, 503-507.

Ribeiro, P.F., Santos, J.L., Santana, J., Reino, L., Beja, P., Moreira, F., 2016. An applied farming systems approach to infer conservation-relevant agricultural practices for agri-environment policy design. Land Use Policy 58, 165-172.

Ritchie, H., Roser, M., 2019. "Land Use", Our World in Data, September 2019, https://ourworldindata.org/land-use (accessed 14 April 2021).

Robinson, R.A., Sutherland, W.J., 2002. Post-war changes in arable farming and biodiversity in Great Britain. J. Appl. Ecol. 39, 157-176.

Rodriguez-Ortega, T., Oteros-Rozas, E., Ripoll-Bosch, R., Tichit, M., Martin-Lopez, B., Bernues, A., 2014. Applying the ecosystem services framework to pasture-based livestock farming systems in Europe. Animal 8, 1361-1372.

Root-Bernstein M., Galetti, M., Ladle, R.J., 2017. Rewilding South America: ten key questions. Perspect. Ecol. Conserv. 15, 271-281.

Sabatier, R., Durant, D., Hazard, L., Lauvie, A., Lecrivain, E., Magda, D., Martel, G., Roche, B., de Sainte Marie, C., Teillard, F., Tichit, M., 2015. Towards biodiversity-based livestock systems: review of evidence and options for improvement. CAB Rev.: Perspect. Agric. Vet. Sci. Nutr. Nat. Resour. 10, 20.

Sandom, C.J., Ejrnæs, R., Hansen, M.D.D., Svenning, J.C., 2014a. High herbivore density associated with vegetation diversity in interglacial ecosystems. Proc. Natl. Acad. Sci. USA 111, 4162-4167.

Sandom, C., Faurby, S., Sandel, B., Svenning, J.C., 2014b. Global late Quaternary megafauna extinctions linked to humans, not climate change. Proc. R. Soc. Lond. [Biol] 281: 20133254.

Segar, J., Pereira, H.M., Filgueiras, R., Karamanlidis, A.A., Saavedra, D., Fernández, N., 2021. Expert-based assessment of rewilding indicates progress at site-level, yet challenges for upscaling. Ecography 44, 1–10.

Sirami, C. et al., 2019. Increasing crop heterogeneity enhances multitrophic diversity across agricultural regions. Proc. Natl Acad. Sci. USA 116, 16442-16447.

Smith, O.M., Kennedy, C.M., Owen, J.P., Northfield, T.D., Latimer, C.E., Snyder, W.E., 2019. Highly diversified crop–livestock farming systems reshape wild bird communities. Ecol. Appl. 30, e02031.

Therond, O., Duru, M., Roger-Estrade, J., Richard, G., 2017. A new analytical framework of farming system and agriculture model diversities. A review. Agron. Sustain. Dev. 37, 21.

Torres, A., Fernandez, N., zu Ermgassen, S., Helmer, W., Revilla, E., Saavedra, D., Perino, A., Mimet, A., Rey-Benayas, J.M., Selva, N., Schepers, F., Svenning, J.C., Pereira, H.M., 2018. Measuring rewilding progress. Phil. Trans. R. Soc. B 373: 20170433.

Tree, I., 2018. Wilding: The Return of Nature to a British Farm. Picador, London, UK, 362 pp.

van der Zanden, E.H., Verburg, P.H., Schulp, C.J.E., Verkerk, P.J., 2017. Trade-offs of European agricultural abandonment. Land Use Policy 62, 290-301.

Vera, F.W.M., 2000. Grazing Ecology and Forest History. CABI Publishing, Wallingford, UK, 506 pp.

Vogt, M.A.B., 2021. Agricultural wilding: rewilding for agricultural landscapes through an increase in wild productive systems. J Env. Manag. 284, 112050.

Von Borell, E., Baumgartner, J., Giersing, M., Jäggin, N., Prunier, A., Tuyttens, F.A.M., Edwards, S.A., 2009. Animal welfare implications of surgical castration and its alternatives in pigs. Animal 3, 1488-1496.

Wade, M.R., Gurr, G.M., Wratten, S.D., 2008. Ecological restoration of farmland: progress and prospects. Philos. Trans. R. Soc. B 363, 831-847.

Wallis De Vries, M.F., Parkinson, A.E., Dulphy, J.P., Sayer, M., Diana, E., 2007. Effects of livestock breed and grazing intensity on biodiversity and production in grazing systems. 4. Effects on animal diversity. Grass Forage Sci. 62, 185-197.

Wang, L., Delgado-Baquerizo, M.D.Wang, D., Isbell, F., Liu, J., Feng, C., Liu, J., Zhong, Z., Zhu, H., Yuan, X., Chang, Q., Liu, C., 2019. Diversifying livestock promotes multidiversity and multifunctionality in managed grasslands. Proc. Natl. Acad. Sci. USA 116, 6187-6192.

Weigelt, A., Weisser, W.W., Buchmann, N., Scherer-Lorenzen, M., 2009. Biodiversity for multifunctional grasslands: equal productivity in high-diversity low-input and low-diversity high-input systems. Biogeosci. 6, 1695-1706.

Wezel, A., Casagrande, M., Celette, F., Vian, J.F., Ferrer, A., Peigné, J., 2014. Agroecological practices for sustainable agriculture. A review. Agron. Sustain. Dev. 34, 1-20.

Wezel, A. 2017. Agroecological Practices for Sustainable Agriculture: Principles, Applications, and Making the Transition. World Scientific Publishing, Hackensack, New Jersey, USA, 485 pp.

Willer, H., Travnicek, J., Meier, C., Schlatter, B., 2021. The world of organic agriculture. Statistics and emerging trends 2021. FiBL, Frick and IFOAM, Bonn.

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Competing interests

The authors declare no competing interests.

Additional information

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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
		Decrease fertilisation rate	Arthropods, plants	Humbert et al., 2016; Huguenin-Elie et al., 2018
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	Ribeiro et al., 2016

Table 2. Approaches, associated visions, aims and management interventions of the main forms of rewilding, including agricultural rewilding, which encompasses Rewilding Lite (Gordon et al. 2021b) and 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

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
Steart 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

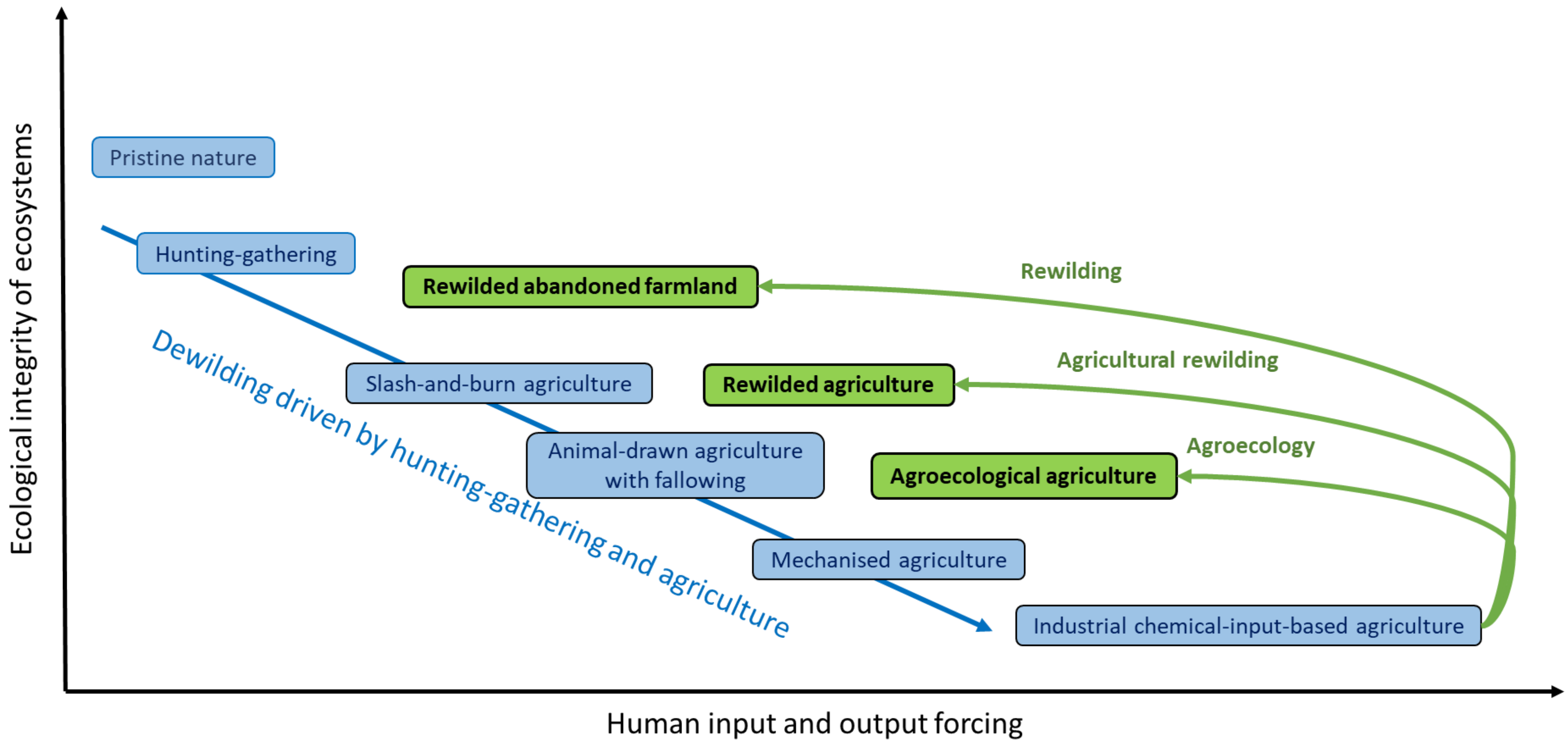

Figure 1. Over time, human food procurement has involved increased human forcing of natural processes and degraded the ecological integrity of ecosystems. This evolution can be considered as a continuous dewilding process. Recently, certain agricultural landscapes and farms have decreased human forcing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

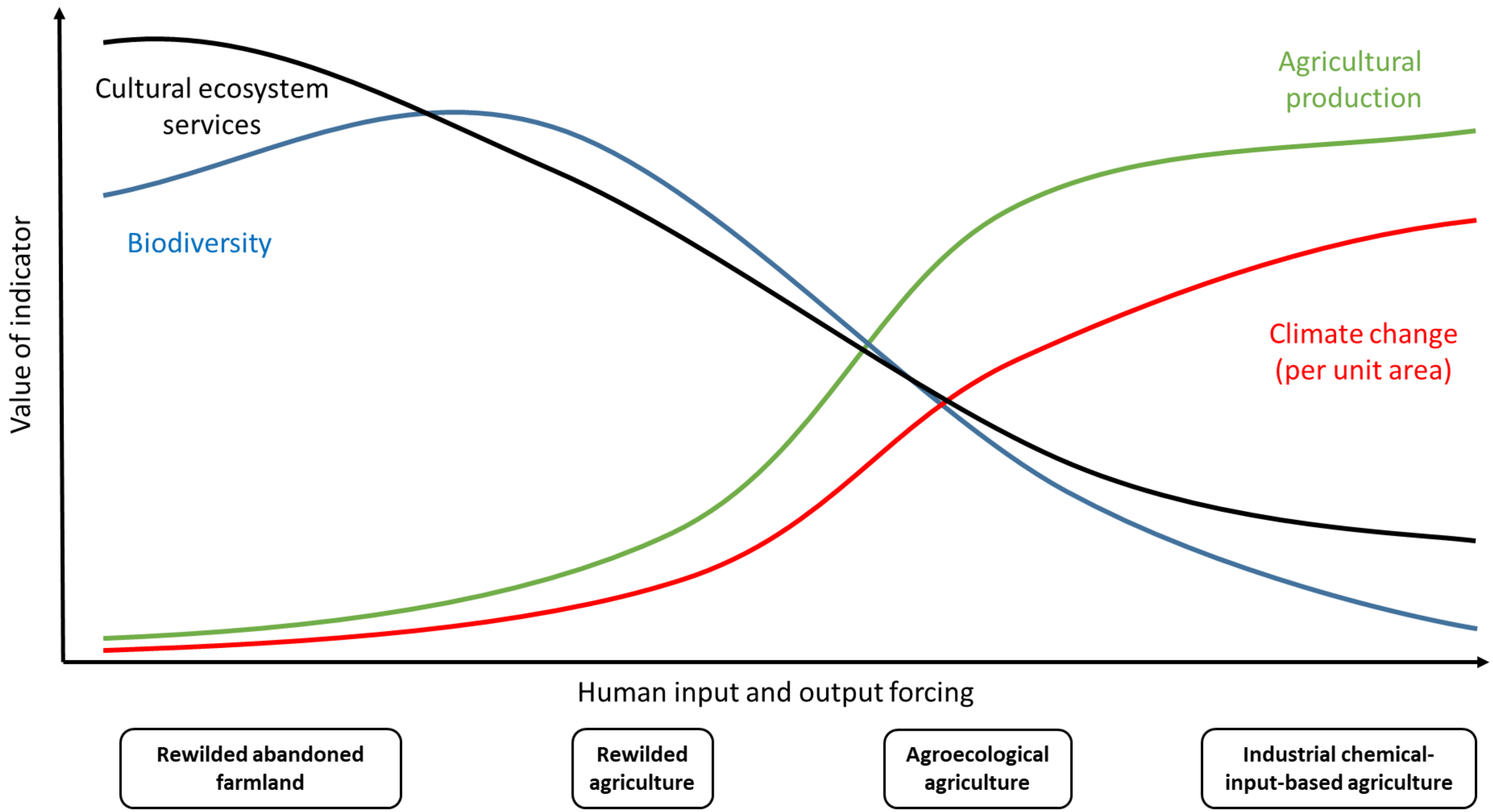

Figure 2. Conceptual representation of potential values of selected performance indicators to assess four land-use forms.