A multi-scale approach to integrating rewilding into agricultural landscapes

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Finding ways to improve the sustainability of modern agriculture by recovering nature in agricultural landscapes is critical for conserving biodiversity and enhancing human well-being. Rewilding principles could be applied to any type of landscape, which raises the possibility of employing rewilding approaches in agricultural areas while maintaining some degree of food production therein. Moving beyond the simple dichotomy of land sparing versus land sharing, here we propose a multi-scale approach that integrates rewilding principles into agricultural landscapes by combining the creation of wilder ecosystems in separate set-aside recovered areas with the implementation of farming approaches that are more sustainable, such as precision farming, ecologically intensified farming, and extensive farming, in adjacent areas. Adoption of such approaches would allow for more biodiversity elements to persist within the agricultural matrix. We explain how this approach could support the three critical components of rewilded land—dispersal, trophic complexity, and stochastic disturbances—and create agroecological landscapes that are biodiverse, resilient, and functionally connected at multiple scales.

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Cropland and pasture extend over 4.75 billion ha worldwide (32% of total global land area) and agricultural land conversion has accelerated in this century (Potatov *et al*. 2022). While critical for increasing yields over the past few decades, agricultural intensification has also been a major driver of biodiversity loss, ecosystem degradation, climate change, and other environmental damage (Pörtner *et al*. 2021). Furthermore, loss of biodiversity is itself thought to be undermining agricultural productivity, for example through loss of pollination and soil, reduced biological control of pests, and decreased water and nutrient retention (Burian *et al*. 2024). Therefore, finding ways to improve the sustainability of modern agriculture by recovering nature in agricultural landscapes is receiving increasing attention. For example, the Kunming-Montreal Global Biodiversity Framework (CBD/COP/DEC/15/4; www.cbd.int/gbf) has several targets related to recovering degraded ecosystems and improving the sustainability of agriculture (Targets 2, 10, and 11). Taking this a step further, the EU Nature Restoration Law [COM(22)304], which received final approval in June 2024, has an entire section dedicated to the restoration of agroecosystems, including rewetting of drained peatland.

In a nutshell:

- Improving the sustainability of modern agriculture by recovering nature in agricultural landscapes is critical to biodiversity and human well-being
- Multi-scale approaches for rewilding in agricultural landscapes while maintaining some degree of food production move beyond simple land sparing versus land sharing dichotomies
- Integrating rewilding approaches into farmland could create agroecological landscapes that are biodiverse, resilient, and functionally connected
- Operational actions include a suite of options related to separate, locally recovered lands in combination with precision, ecologically intensified, and/or extensive farming techniques so that biodiversity elements are also restored in the farmland matrix

How to improve agricultural sustainability as well as enhance nature in human-dominated landscapes remains a topic of heated debate (Bateman and Balmford 2023). There is mounting evidence that agricultural sustainability can be improved by increasing delivery of ecosystem services and the biodiversity that underlies these services (Burian *et al*. 2024). At the same time, research on biodiversity and ecosystem functioning has shown that ecosystem resilience and ecosystem services are interrelated (Parrot and Meyer 2012). However, approaches to enhance biodiversity and related functioning in farmed landscapes generally work within an agricultural paradigm to benefit farmland wildlife (Burian *et al*. 2024), which, while often in decline, comprises only one aspect of biodiversity loss. Given the areal extent of land currently under cultivation worldwide, there is a need to address its role in also supporting non-farmland species. To this end, rewilding is increasingly seen as a key nature recovery strategy to benefit a wide range of species and reverse ecosystem degradation by restoring key processes.

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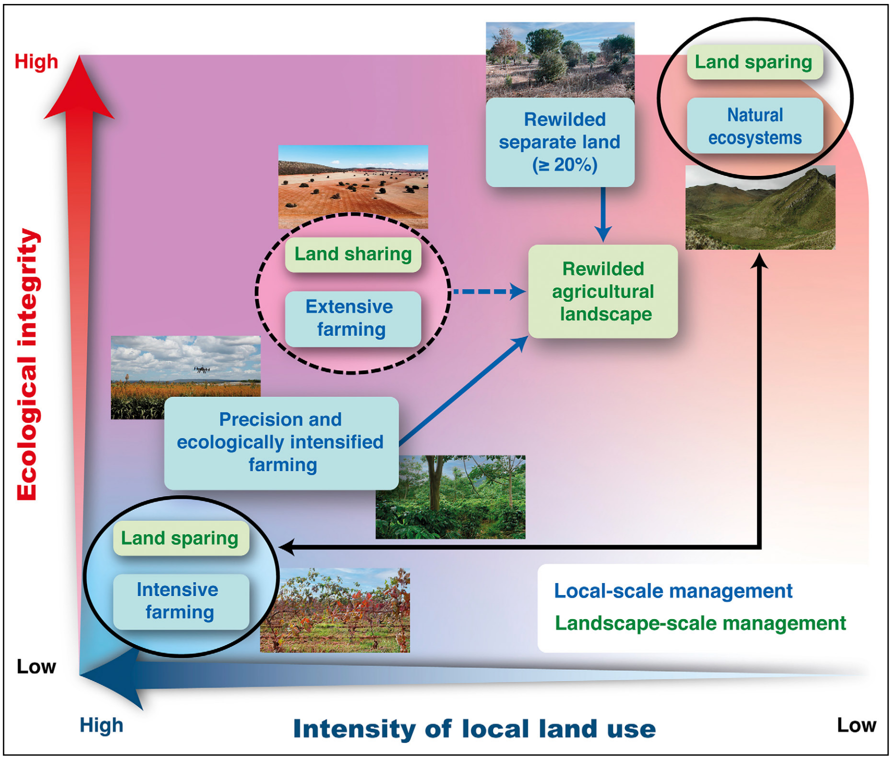

Figure 1. Conceptual framework for integrating rewilding into agricultural landscapes. By adopting a whole-landscape perspective, the framework moves beyond the simplified view of having at the local scale either a mix of intensive farming and natural ecosystems (land sparing) or only extensive farming (land sharing). The space for nature recovery is defined by two axes: ecological integrity (*y* axis) and intensity of local land use (*x* axis). The rewilded agricultural landscape represents intermediate values along these axes, in contrast to the extremes of intensive farming and natural ecosystems. A combination of farming practices (precision, ecologically intensified, or extensive), on one side, and nearby separate rewilded land, on the other side, contribute to forming wilder, multifunctional agricultural landscapes. The dashed arrow from extensive farming denotes that moderate ecological integrity comes at the expense of crop production. The framework differentiates local-scale management (in blue) from landscape-scale management (in green). Ultimately, the multi-scale management results in a rewilded agricultural landscape. The photographs illustrate representative examples (clockwise from top-left): extensive cropland in central Spain; cropland restored by planting a mixture of native trees in central Spain; a nature reserve in the Páramos of Chingaza, in Colombia; an ecologically intensified coffee plantation shaded by *Erythrina* trees, a leguminous, natural fertilizer species, in Costa Rica; intensive vineyard in central Spain; and precision agriculture in Germany. All photographs by JM Rey Benayas except the example of intensified farming (Pixabay/clarrycola [CC0]).

The rewilding concept has evolved over time (Mutillod *et al.* 2024). It is currently seen as a process-oriented approach that identifies dispersal, trophic complexity, and stochastic disturbances as three critical components for recovering well-functioning, resilient, and self-sustaining ecosystems; indeed, the recovery of these processes and their interactions is at the heart of rewilding (Perino *et al.* 2019). Typically, rewilding projects and initiatives target natural processes through actions such as reintroduction of key species intended to recover ecological processes, relaxation of traditional agricultural or conservation management, and removal of human infrastructure such as roads and dams to create more pristine landscapes (Corlett 2016). Notably, the distinctiveness of rewilding is its focus on recovering ecological processes and creating more self-sustaining ecosystems, and so these actions are not exclusive to rewilding and are sometimes used to achieve traditional conservation and restoration goals.

It has been argued that rewilding principles allow for a broad range of activities that could be employed in any type of landscape (Pettorelli and Bullock 2023), raising the potential of applying rewilding approaches in agricultural landscapes while maintaining some degree of food production. Here we explore this idea by discussing how the rewilding concept can be adapted for agricultural landscapes and examining potential associated opportunities, challenges, and operational insights. Our argument that rewilding approaches can be introduced alongside ongoing farming contrasts with that of Corson *et al.* (2022), who considered agricultural rewilding ("Rewilding Lite") as an intermediate step between agroecology and comprehensive rewilding ("Rewilding Max").

Integrating rewilding principles into agricultural landscapes

The popular dichotomy of land sparing versus land sharing (Bateman and Balmford 2023) in agricultural areas offers a simple view of landscape-scale conservation. Sharing versus sparing is fundamentally about comparing landscape-scale nature conservation strategies that, conceptually, produce a similar quantity of food at the landscape scale. Under land sparing, different areas of land are allocated to intensive agriculture or to nature, at the extremes of a land-use intensity gradient (Figure 1). Alternatively, under the land sharing principle, land management is a compromise of use for agriculture and nature at the same time, but at the cost of both agricultural productivity and biodiversity (Figure 1). These visions ignore the need for both more biodiversity and ecological resilience in intensive agricultural areas, and the spatial and temporal scaling of processes that permits the co-existence of different approaches (Merckx and Pereira 2015). Building on these concepts, we propose a multi-scale approach that integrates rewilding into agricultural landscapes by combining the creation of wilder ecosystems in separate, locally rewilded lands alongside areas with more sustainable farming approaches that allow for more biodiversity elements to be embedded within the agricultural matrix—precision farming using modern agricultural methods, ecologically intensified farming, and/or extensive farming—to produce agroecological landscapes at the regional scale (Figure 1). At the landscape scale, the approach compensates, at least in part, for the land taken out of production with enhanced production on a portion of the remaining agricultural land (Dainese *et al.* 2019).

Rewilding of the separate, set-aside land

We suggest that the first element for integrating rewilding into agricultural landscapes is to retain or set-aside for nature at least 20% of land, with the aim of increasing resilience, biodiversity, and ecosystem services. This approach aligns with available evidence for the importance of natural habitats in human-dominated landscapes (Garibaldi *et al.* 2021; Tscharntke *et al.* 2021), while acknowledging that farmland is critical for providing food and other essential products for society. The scale at which rewilding of set-aside land should occur will ultimately depend on the availability of land for this purpose and the size of the agricultural landscape. There is also a trade-off between having small/linear rewilded areas that deliver benefits to large amounts of adjacent farmland and larger, less "edgy" patches that have greater internal integrity (Storkey *et al.* 2024). While our framework allows for small and linear patches in the agricultural matrix, separate patches of rewilded areas ideally should be as large as possible, at least several hundred hectares.

Although any land set aside for rewilding is lost to cultivation, it may still render benefits to the remaining agricultural land at the landscape scale through provision of services such as soil protection, pest regulation, and pollination, which increase food production and partially compensate for the land taken out of production (Bullock *et al.* 2021; Burian *et al.* 2024). In the set-aside land, wilder ecosystems can harbor a wide variety of species that avoid agricultural land and need natural vegetation to persist (Newbold 2018). Rewilding of these separate areas can be achieved through land abandonment (passive or spontaneous rewilding; Chazdon *et al.* 2020) or a suite of interventions to initiate rewilding processes (eg tree planting or introduction of key species; Rey Benayas *et al.* 2008). The rewilded areas could be connected (eg by corridors) to core conservation areas (eg nature protection areas), which function effectively as source areas (Pereira and Daily 2006) at regional scales and could maintain dispersal, which is key to rewilding (Perino *et al.* 2019). Core conservation areas and corridors are two relevant components of the original rewilding concept (Soulé and Noss 1998). Achieving this connectivity in areas dominated by smallholder farmers would require planning at the level of cooperatives or associations of farmers.

Management of the agricultural matrix

In many landscapes, agroecosystems are the only ecosystem over very large areas (indeed, up to thousands of square kilometers), and in mixed landscapes that comprise agricultural land and semi-natural/natural ecosystems (eg forest, wetland, grassland), agroecosystems are often the dominant ecosystems. The set-aside rewilded land that we propose leaves a large proportion of land committed to agriculture. Consequently, the management of agroecosystems using a variety of less intensive farming practices (eg reducing excess fertilizer or pesticides; Bullock *et al.* 2024) together with the application of rewilding principles has the potential to substantially increase biodiversity within the entire landscape and improve ecosystem function.

The three critical components of rewilding—dispersal, trophic complexity, and stochastic disturbances—should be key processes in the set-aside rewilded land, but could they also be enhanced through farmland management in the areas remaining under cultivation? We suggest that the adoption of practices like precision farming, ecologically intensified agriculture, and extensive farming could contribute to enhancing the agricultural matrix of the rewilded agroecological landscapes (Figure 1) in terms of biodiversity and ecological processes. As compared to conventional industrial farming, precision farming relies on modern agricultural methods and technology that reduce impacts on biodiversity, soil, and water, thereby producing high yields while supporting greater biodiversity (Duff *et al.* 2022). Sowing flower strips that enhance pollination of crops (Albrecht *et al.* 2021) and fostering populations of raptors and insectivorous birds are well-known examples of ecological intensification (Monteagudo *et al.* 2023). Although precise definitions of extensive farming and agroecological operations are lacking, in general they embrace the principles of and practices behind traditional farming systems, organic agriculture, conservation agriculture, regenerative agriculture, permaculture, and agroforestry (Storkey *et al.* 2024). These practices promote biodiversity and ecological processes in several ways. In particular, the many small (eg ~0.1–1 ha or linear elements of 100–1000 m), species-rich, landscape elements created in agricultural fields have disproportionately high and positive impacts on biodiversity and services such as pest regulation, pollination, water and nutrient retention, and control of soil erosion; because these services have the potential to enhance agricultural production, they can also be viewed as a form of ecological intensification (García de León *et al.* 2021). These elements include small forest islands and tracts of scrubland and grassland, hedgerows, ponds, refuges and nesting sites for many animals, and perches for birds (Rey Benayas and Bullock 2012). Critically from a rewilding standpoint, networks of hedgerows, woodland patches, and other small, species-rich landscape elements, which occupy a small fraction of the landscape, could enhance dispersal throughout the agricultural matrix and are an alternative, or complement, to the corridors that connect set-aside and rewilded tracts of former agricultural land (Wintle *et al.* 2005; Perino *et al.* 2019). These elements provide ecosystem functions that contribute to agricultural productivity without hampering mechanization (García de León *et al.* 2021).

However, critical issues for these practices are that *by themselves* they only increase biodiversity (especially for species that rely on these specific agricultural habitats) by a limited amount and that, in the case of extensive agriculture, this increase comes at the expense of production (Tscharntke *et al.* 2021). Consequently, agricultural rewilding has the potential to benefit both farmland and non-farmland biodiversity by creating multiple habitats across a range of scales, while simultaneously embracing agricultural technologies that facilitate increased productivity with less environmental impact.

Operational actions and challenges

Aiming for establishment of the three components of rewilding in agricultural areas will likely require active interventions due to the degraded nature of these ecosystems. The small, species-rich elements should add up to at least 10% of total field area (the goal of the EU Biodiversity Strategy for 2030), a proportion that together with the 20% of rewilded separate land achieves the goal for restoration of 30% of degraded land (and sea) that signatories have agreed to under the Kunming-Montreal Global Biodiversity Framework. This could be established as a legal requirement for farmers, but acceptance and success are more likely if it is supported by incentives in the form of payments for ecosystem services and tax deductions.

The recovery of natural vegetation and wildlife are usually linked, assuming the latter is present regionally to colonize new habitat. The resulting enhanced interactions among species of different guilds, such as herbivores, predators, and scavengers, should restore trophic complexity in both the farmland matrix and the separate rewilded land. Recovering high levels of trophic complexity will be more straightforward if the separate rewilded tracts are large. For instance, these areas may be suitable for trophic rewilding, a strategy that uses species translocations, particularly of megafauna, to restore trophic interactions and associated trophic cascades to promote large-scale, self-regulating biodiverse ecosystems by increasing heterogeneity and dispersal (Svenning *et al.* 2019). Incidentally, trophic rewilding can also provide natural climate solutions (Schmitz *et al.* 2023). However, in small rewilded areas and within the farmland matrix, strategic actions that trigger wildlife recolonization and increase species abundance, including feasible (eg avoiding human–wildlife conflicts) translocations of relevant guilds, are other options. In Europe, for instance, these habitats may be unsuitable for translocations of large top predators and herbivores, such as brown bear (*Ursus arctos*), red deer (*Cervus elaphus*), and European bison (*Bison bonasus*), but may be suitable for translocations of smaller species like the Iberian lynx (*Lynx pardinus*, a top predator), wildcat (*Felis silvestris*), and European hare (*Lepus europaeus*). More extensive livestock systems allowing free-range grazing and even a mixture of large herbivores (Zuleger *et al.* 2024), in particular the use of traditional breeds, in both the separate rewilded land and the farmland, could contribute to restoring dispersal (movement of seed by livestock), trophic complexity (herbivory and resources for predators, coprophagous insects, and scavengers), disturbance of vegetation and soil (trampling, browsing, and dunging), and heterogeneity in space and time (Gordon *et al.* 2021).

Stochastic disturbances linked to climate (droughts, heat waves, frosts, and so on) are unavoidable and will occur in the rewilded agricultural landscape. Others, such as flooding and wildfire, are likely among the more difficult aspects of rewilding to recreate due to potential impacts on people and property but may be acceptable in certain managed circumstances and as rewilding principles become more popular (Dunn-Capper *et al.* 2024). In agricultural landscapes, some flooding may be possible on river floodplains by restoring geomorphology and topography and by eliminating dams, embankments, and drainage ditches (Serra-Llovet *et al.* 2022). Indeed, the careful placement of such actions could reduce flood risk elsewhere, for example in populated areas (Opperman and Galloway 2022). Increases in the rate or intensity of wild grazing would likely interact with fire likelihood. Passively rewilded temperate ecosystems and agroecosystems that are not grazed or browsed have greater potential to burn (Kelly *et al.* 2020), but the recovery of extensive husbandry and of wild or semi-wild herbivores could counteract this propensity. Furthermore, natural fires can be mimicked somewhat through application of prescribed burns (Scasta *et al.* 2016), and rewilding reinforced by reduced fire suppression may provide a nature-based solution when societal support through agricultural policies fails (Campos *et al.* 2021). Allowing livestock to decay in place after death in extensive grazing systems (albeit being mindful of the risk of disease spread) is another form of disturbance that could occur in the farmland matrix; however, this action may require changes to current legislation in some regions, such as those in Europe.

Conclusions

In agricultural landscapes, recovering dispersal, trophic complexity, and stochastic disturbances will likely lead to synergistic interactions that increase ecological resilience, biodiversity, and ecosystem services. For instance, connectivity elements could facilitate recolonization of landscapes by key species, which could in turn contribute to the regulation of stochastic disturbances such as fire. However, rewilding will likely not fit into all agricultural systems; indeed, nature recovery will not be achieved by single, "silver bullet" approaches. The main agricultural areas that could benefit largely from agricultural rewilding are the most intensive and degraded ones where little biodiversity remains, which are likely at most risk of ecological collapse and are concentrated in, but not unique to, the Global North. In those areas, agricultural rewilding might increase ecological integrity with relatively small impacts on productivity, as the loss of production from set-aside land is partially attenuated by a concomitant increase in ecosystem services (eg Burian *et al.* 2024). By contrast, in more intact landscapes where a substantial number of natural ecosystems remain and/or in less intensive agricultural systems, which are common in some regions of the Global South, such as those managed by Indigenous peoples (Garnett *et al.* 2018), agricultural rewilding would provide comparatively fewer benefits. Overall, agricultural rewilding could be a key approach to maintaining food production in a way that is sustainable in the long term for people and the planet.

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Data availability statement

No data were collected for this study.

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