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Commentary

Rewilding should be central to global restoration efforts

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Rewilding should be central to the massive restoration efforts needed to overcome the global biodiversity crisis and enhancing the biosphere's capacity to mitigate climate change. Key elements include large areas for nature, restoration of functional megafaunas and other natural biodiversity-promoting factors, synergy with major societal dynamics, and careful socio-ecological implementation.

Humanity is facing a massive human-driven environmental emergency composed of the dual biodiversity and climate crises. Around a quarter of extant species are currently at risk from extinction, wildlife populations are widely declining, and extinction rates are several orders of magnitude higher than the natural norm. Climate change will strongly enhance these negative trends and furthermore poses an existential threat to human societies. The ultimate cause is human resource use, highlighting the need to steer toward much greater ecological sustainability. Representing rising awareness of the severity of the situation, the United Nations (UN) has appointed 2021–2030 as the UN Decade on Ecosystem Restoration with the explicit aim "to prevent, halt, and reverse the degradation of ecosystems on every continent and in every ocean. It can help to end poverty, combat climate change and prevent a mass extinction" (https://www.decadeonrestoration.org/). Restoration will only have a meaningful impact on the biodiversity and climate crises if applied to large proportions of Earth's area.[1]

Rewilding should be central to the restoration efforts to overcome the biodiversity crisis while also enhancing the biosphere's capacity to mitigate human-induced climate change in a resilient manner (Figure 1). Rewilding can be defined as restoration to promote self-regulating complex ecosystems through restoring non-human ecological factors and processes while reducing human control and pressures. This definition is consistent with most definitions and general usage.[2–4] The relation to restoration is sometimes discussed. The Society for Ecological Restoration defines restoration as "the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed."[5] This readily includes rewilding. However, restoration in definition and practice also includes efforts that are clearly not rewilding, e.g., restoration of cultural ecosystems or other efforts based on chronic human intervention. Key reasons for a focus on rewilding are its reliance on mechanisms of long-term effectiveness, high upscaling potential, and enhancement of resilience.

Rewilding reinstates long-term effective mechanisms

Rewilding involves reducing human control and therefore is an open-ended approach to restoration without highly specified static end goals in terms of species composition and ecosystem structure. In consequence, it is often associated with real or perceived uncertainty.[4] Nevertheless, rewilding reinstates the only proven effective long-term mechanisms for generating and maintaining biodiversity. The far majority of current species are hundreds of thousands to millions of years old, and their functional traits—determining their ecological requirements and effects—are often even older.[6] The non-human factors and processes that have generated and maintained Earth's rich biodiversity prior to human societies have proven their effectiveness through the eons, even through periods of enormous climate instability. The main real uncertainty pertains to rewilding's effectiveness under incomplete implementation, e.g., in landscapes with small, fragmented natural areas or where societal constraints require incomplete restoration (e.g., avoiding the most dangerous fauna). Positive evidence is emerging but should be the focus of further research.

The need to restore functional megafaunas

A lesson from the long-term perspective is that rebuilding of food web complexity via megafauna restoration should play a central role in restoration and rewilding, complementing the widespread focus on trees and soils (Figure 1). Megafauna restoration involves re-establishing functionally diverse faunas of large-bodied animals, typically native species or replacements for extinct species or forms.[3,6] Megafauna species include large herbivores from deer and gazelles to horses, camels, and bison to elephants and rhinos as well as large carnivores and omnivores such as wolves, big cats, and bears.

Current faunas are strongly downsized relative to the norm for the last 30–40 million years.[6,7] These losses of megafauna span the last 100,000 years and are still widely ongoing. Among the 74 species of large herbivores (≥100 kg body mass) surviving globally, 59% are threatened with extinction.[8] The megafauna losses represent a major loss of biodiversity in themselves but also have functional ramifications. The losses are associated with strong reductions in functional diversity and total abundance, notably with respect to large herbivores.[3,9] A large collection of literature exists on the functional importance of

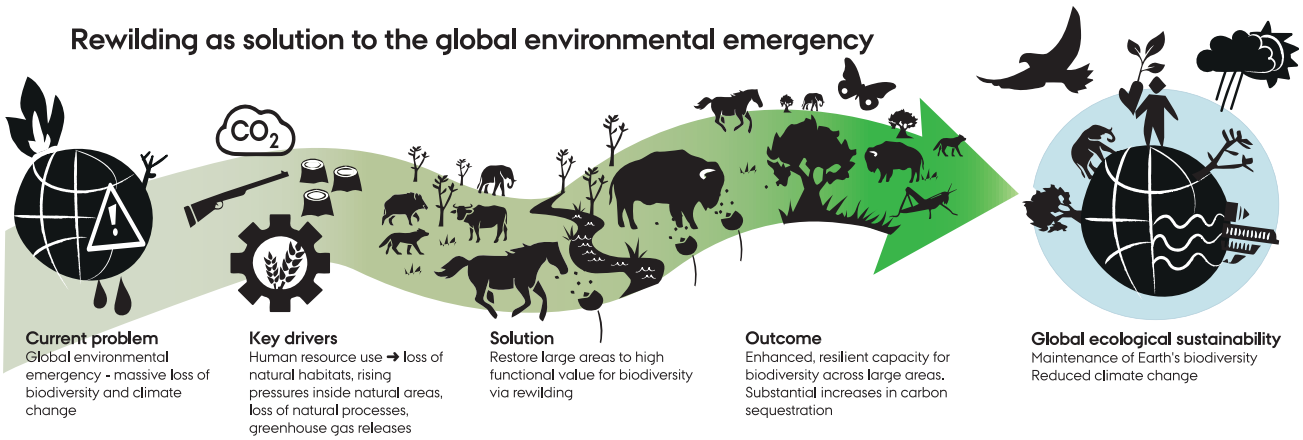

Figure 1. Outline of rewilding as a contribution to solving the global environmental emergency

Humanity is facing a massive human-driven environmental emergency composed of the dual biodiversity and climate crises, ultimately driven by human resource. Ambitious rewilding efforts restoring functional faunas of large-bodied animals (megafaunas) and other natural biodiversity-enhancing factors across large areas are needed to safeguard Earth's rich biodiversity in the long-term while also enhancing the biosphere's contribution to reducing human-induced climate change via resilient carbon sequestration. Large-bodied animals have a key role through enhancing landscapes' biodiversity capacity via increasing environmental heterogeneity and dispersal dynamics, with the needed high upscaling potential through their spontaneous population growth and expansion.

megafauna, and in summary, complex megafaunas with well-developed large-herbivore assemblages promote landscape-scale biodiversity through at least two mechanisms—via generating environmental heterogeneity such as a varied vegetation structure (notably through browsing, grazing, and physical disturbance) and via dispersal of propagules such as seeds.[6,10] For example, reduced levels of grazing drive woody densification widely across natural areas in Europe, reducing vegetation heterogeneity and causing widespread declines in plants and insects adapted for open and semi-open conditions. Heterogeneity and dispersal are of well-established importance for enhancing landscape biodiversity and should also strengthen species' resilience to climate change via local environmental buffering and facilitation of range shifting to track climate change.

Rewilding also considers restoration of factors and processes beyond megafauna, such as habitat connectivity and natural disturbances, e.g., fire and hydrological regimes.[2] These also need careful attention, especially in anthropogenic landscapes where they are often compromised by habitat fragmentation, artificial drainage, fire suppression, etc.

Rewilding has unique, much-needed upscaling potential

Rewilding has unique upscaling potential through its reliance on non-human biotic processes, as these spontaneously scale up.[11] Notably, megafauna populations can quickly build and expand to extend their effects to large landscapes over one or a few decades. As an example, rewilding following war-induced wildlife collapse led to a greater than 4-fold increase in large herbivore biomass from 2007 to 2018 in parts of the Gorongosa National Park in Mozambique, with re-establishment of strong herbivore effects on the vegetation as the outcome.[12] In contrast, ongoing active management is limited by high costs and available human resources.[11] Effective upscaling is crucial as to allow restoration efforts at the massive scales needed. A key observation is the strong positive relation between habitat area and species richness alongside the fact that current biodiversity is a legacy from when natural habitats occupied all of Earth. This suggests that long-term maintenance of biodiversity is unlikely to be possible unless large, representative proportions of Earth's surface are ensured high value for biodiversity. This becomes even clearer if climate change is considered. Past major climate change had massive impacts on ecosystems and biodiversity, sometimes causing ecological disruptions and high rates of extinctions. Nevertheless, high levels of biodiversity survived via dispersal across large regions tracking suitable climates and via survival in relatively stable refugia. These mechanisms will be compromised if there are only small, downgraded areas left for nature. Rewilding provides scalable functionality for the needed large areas for nature, promoting their value for biodiversity even under climate change via enhancing environmental heterogeneity and dispersal dynamics.

Rewilding is expected to promote resilient ecosystems

Ambitious rewilding on massive scales should enhance climate change resilience at the ecosystem level. This would occur via biodiversity buffering against climate-driven declines of individual species through large population sizes and differing sensitivities among locally resident species and through facilitating immigration of species tolerant of new climate conditions. Similar effects would also be expected with respect to pressures from biological invasions, where enhanced predation and herbivory may further help limit overdominance by invasive species. For example, recovering large herbivores has strongly reduced the abundance of an invasive shrub in the Gorongosa National Park.[12] These mechanisms favor the maintenance of biodiverse ecosystems, even if climate change and invasions force changes in species composition. Hereby, rewilding is likely to also enhance resilience of ecosystem functioning and services, including long-term maintenance of carbon stocks.

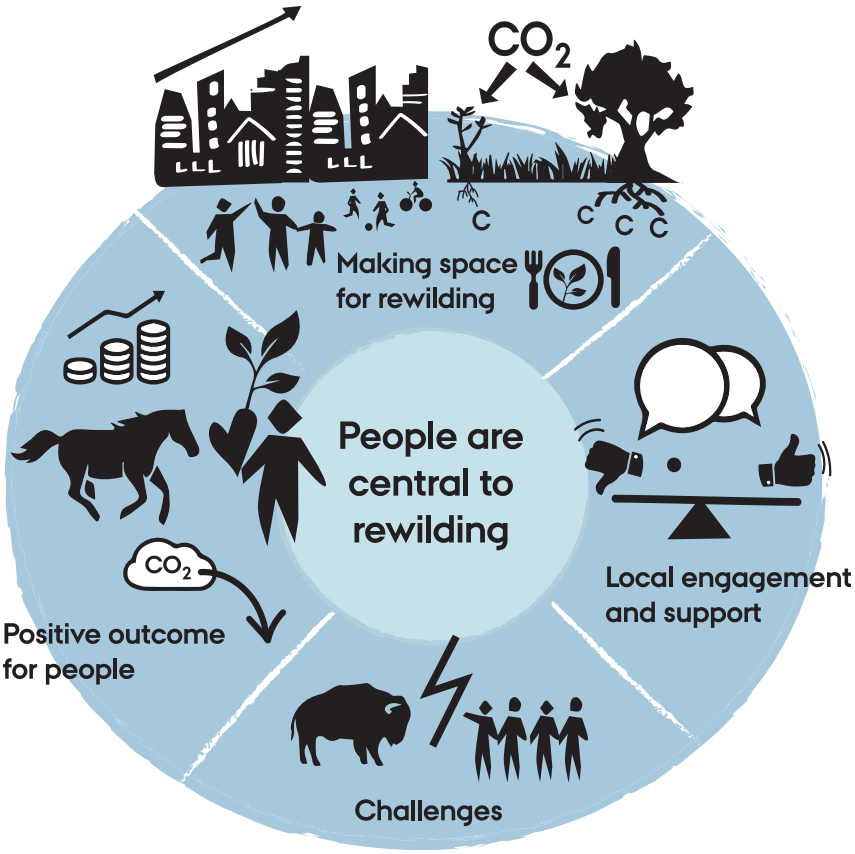

Figure 2. Key aspects of the multi-scale, complex roles of people in rewilding
With billions of people on the planet and even more in the future, people are central to successfully realizing the potential in rewilding. Major societal dynamics are needed to create space for rewilding. Some occur spontaneously such as rural-to-urban migration, but overall active policies will be necessary to realize the potential in rewilding. Decreasing demands for agricultural land through increasing farming yields and shifts toward less resource-demanding diets are key elements. Further, rewilding efforts should be applied in democratic manners with local engagement and support, and it is important to ensure that benefits (e.g., economic opportunities, positive effects of nature on quality of life) and challenges (e.g., human-wildlife conflicts) are well understood in a socio-ecological context and shared in a fair manner, morally and for long-term support.

The latter highlights that rewilding has a positive role to play in climate mitigation. Natural ecosystems will generally sequester larger amounts of carbon than areas under intense use. For example, it is estimated that natural ecosystems relative to croplands on average store an additional 120 tons C ha^{-1} in the tropics and 63 tons C ha^{-1} in temperate areas.[13] Increased carbon sequestration occurs both aboveground via build-up of more complex vegetation with greater biomass and in the soil. While this outcome is clear, there are many open questions on the details, e.g., under which circumstances do megafauna restoration enhance or reduce carbon sequestration in natural ecosystems?[14] Importantly, megafauna restoration likely often reduces fire risk,[15] promoting enhanced long-term carbon sequestration. Overall, by promoting resilient ecosystems through enhancing biodiversity's adaptive capacity, rewilding is expected to reduce the risk of ecosystem breakdowns and associated carbon releases.

People are central to rewilding's success

Billions of people live on the planet—therefore, people are central to rewilding even if rewilding is focused on reduced human control and restoring non-human processes (Figure 2).[2,4] Rewilding has synergy with major societal dynamics. The strong rural-to-urban migration worldwide alongside improved efficiency in agriculture provides increasing opportunities for rewilding; i.e., land abandonment offers much needed area. Dynamics toward decreased per capita resource use and area needs would also help provide area for rewilding. Further increases in farming yields could reduce cropland needs by almost 40%.[16] Shifts toward increasingly plant-based diets would reduce per capita area needs for food production, e.g., using crops exclusively for human consumption rather than animal feed would increase available food calories globally by 70%, and substituting soy for meat as a human protein source would reduce plant biomass appropriation by >90%.[17] Reducing food waste, shifting from ruminant livestock such as cattle and sheep to poultry and pigs, and integrating livestock production into diversified agricultural systems would also substantially reduce area demands.[17]

Solutions to the global environmental emergency—rewilding or otherwise—should be applied in a democratic manner, and it is important to ensure that services and disservices (e.g., human-wildlife conflicts) are well understood in a socio-ecological context and shared in a fair manner. This can be argued from a moral standpoint but also for ensuring long-term support. Highlighting the need for a socio-ecological approach, Indigenous peoples' lands account for 37% of all remaining natural terrestrial areas.[18] Rewilding can have positive potential even there. Populations and cultures change, which on one hand may lead to ecological degradation due to rising pressures, e.g., unsustainable hunting or habitat degradation. Alternatively, shifting toward rewilding could lead to local societal benefits from new opportunities, e.g., ecotourism, alongside helping to maintain the often important cultural heritage associated with wildlife and natural habitats. In all settings, it is important to properly engage local communities and stakeholders, consider local knowledge, analyze how people and restoration efforts interact, and identify ways to avoid or overcome unwanted outcomes. Implementation of rewilding should include continued monitoring of ecological outcomes and socio-ecological dynamics to allow for adjustments via adaptive management if necessary. Importantly, with more and more people living in densely settled areas, rewilding

offers possibilities for re-engaging with nature, positively affecting quality of life and mental health, especially if also implemented at smaller scales with heavily populated landscapes.[19]

Conclusions

The Decade on Ecosystem Restoration is urgently needed. To overcome the biodiversity crisis, much more ambitious efforts are needed for not only protecting but also re-expanding nature.[1] Massive restoration of nature will also help overcome the strengthening climate emergency and, if wisely implemented, has potential to improve quality of life for many people. Rewilding should be a central approach here because it (1) relies on reinstating the natural processes that have generated and maintained biodiversity through deep time, offering a truly long-term perspective; (2) inherently scales up due to the self-expanding nature of natural biotic processes such as population growth and expansion; and (3) promotes ecological resilience. Key elements include large areas for nature, megafauna restoration, restoration of connectivity and other non-megafauna factors, plus careful societal implementation and synergy with major societal dynamics, e.g., rural-to-urban migration. Quoting Sir David Attenborough on his recent witness statement, the documentary *A Life on Our Planet*, "we must rewild the world" (https://www.netflix.com/title/80216393).

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