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Domestic Livestock and Rewilding: Are They Mutually Exclusive?

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Human influence extends across the globe, from the tallest mountains to the deep bottom of the oceans. There is a growing call for nature to be protected from the negative impacts of human activity (particularly intensive agriculture); so-called "land sparing". A relatively new approach is "rewilding", defined as the restoration of self-sustaining and complex ecosystems, with interlinked ecological processes that promote and support one another while minimising or gradually reducing human intervention. The key theoretical basis of rewilding is to return ecosystems to a "natural" or "self-willed" state with trophic complexity, dispersal (and connectivity) and stochastic disturbance in place. However, this is constrained by context-specific factors whereby it may not be possible to restore the native species that formed part of the trophic structure of the ecosystem if they are extinct (e.g., mammoths, *Mammuthus* spp., aurochs, *Bos primigenius*); and, populations/communities of native herbivores/predators may not be able to survive or be acceptable to the public in small scale rewilding projects close to areas of high human density. Therefore, the restoration of natural trophic complexity and disturbance regimes within rewilding projects requires careful consideration if the broader conservation needs of society are to be met. In some circumstances, managers will require a more flexible deliberate approach to intervening in rewilding projects using the range of tools in their toolbox (e.g., controlled burning regimes; using domestic livestock to replicate the impacts of extinct herbivore species), even if this is only in the early stages of the rewilding process. If this approach is adopted, then larger areas can be given over to conservation, because of the potential broader benefits to society from these spaces and the engagement of farmers in practises that are closer to their traditions. We provide examples, primarily European, where domestic and semi-domestic livestock are used by managers as part of their rewilding toolbox. Here managers have looked at the broader phenotype of livestock species as to their suitability in different rewilding systems. We assess whether there are ways of using livestock in these systems for conservation, economic (e.g., branded or certified livestock products) and cultural gains.

Keywords: rewilding, livestock, Oostvaardersplassen nature reserve, conservation, safe operating space, first nations, ecosystems services

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INTRODUCTION

Across the globe, there is a growing recognition of the importance of wild landscapes for human wellbeing and the preservation of biodiversity and scenic values. In the USA this is driven by the wilderness agenda, whereas in parts of Europe it is because of the abandonment of pastoral systems of production as people move to the cities. Perhaps counterintuitively there is significant politics surrounding these areas where population densities are very low (Monbiot, 2014). This is because without deliberate intervention, landscapes may change in ways that are not desired by the public (e.g., forest encroachment in the French Alps; MacDonald et al., 2000). To avoid this scenario, managers need to decide when and how to intervene—even if the previous system of land management is no longer feasible. It is these contexts in which the connection between society and nature will play out. Thinking, imagining and acting will be key, because just doing nothing and letting nature take its course could lead to perverse outcomes (e.g., wildfires, loss of rare ecological assemblages such as grasslands), that will change the political agenda and humanity's relationships with nature. Now is the time to move beyond landscapes as simply a by-product of our production systems to deliberative *thoughtscapes,* and ultimately *actionscapes* before it is too late (portended by the recent fires in Australia and the western USA).

Nowhere on Earth is truly wild, human influence extends across the globe from the tallest mountains to the bottom of the deepest oceans (Goudie, 2018). These influences can be direct (e.g., land-use change, fishery harvest) and indirect (e.g., greenhouse gas emissions, pollution into rivers and coasts) (Rockström et al., 2009). Since the Pleistocene, humans have had negative impacts on ecosystems (over 75% of the land surface being significantly altered by human activity and over 85% of wetland area lost), and on species (with ∼25% of species threatened with extinction) (IPBES, 2019). This is likely to get worse as human populations grow and the global consumption of goods increases, both in developed countries and in emerging economies. It is commonly perceived that there is a conflict between human needs, for example, food production to meet the increasing demands (which is expected to grow by over 70% in the next 30 years) of the human population that is growing in size and wealth, and nature conservation (Gordon et al., 2017). The argument is that nature must be protected from the negative impacts of intensive agricultural production; so-called "land sparing" (Fischer et al., 2008). The extreme example of this is "rewilding", defined as "the reorganisation of biota and ecosystem processes to set an identified social–ecological system on a preferred trajectory, leading to the self-sustaining provision of ecosystem services with minimal ongoing management" (Pettorelli et al., 2018). It should be noted that rewilding is, in effect, a sub-set of restoration of ecosystems based upon the idea that restoration is "the process of assisting the recovery of an ecosystem that has been damaged, degraded or destroyed", Society for Ecological Restoration International Science and Policy Working Group (2004). Following its introduction in the academic literature in the late 1990s, rewilding has gained significant momentum in recent years (average just over 3 publications per year in the 2000s to around 80 publications per year in 2018 and 2019; **Figure 1**; see also Svenning et al., 2016; Pettorelli et al., 2019). This reflects the growing concern about the impacts of humans on natural systems, particularly as related to their wilderness [as in the case of the US Wilderness Act (1964)], the conservation of biodiversity (Johns, 2019), and a concern that current approaches are not effective (Butchart et al., 2010; Tittensor et al., 2014; WWF, 2016; IPBES, 2019). This in turn often sees humans as separated from wilderness areas e.g., "an area of land untrammelled by man, where man is a visitor who does not remain" [Section 2(c) of the US Wilderness Act (1964)] or "A wilderness is an area governed by natural processes. .... without intrusive or extractive human activity" (Wild Europe Initiative, 2013).

Though there have been attempts by academic ecologists to define and steer rewilding as a concept (e.g., Pettorelli et al., 2019), its undoubted intuitive resonance with non-academics (Monbiot, 2014) means it is destined to be a panchestron (all things to all people). We expect its definition will continue to develop as an emergent property as different kinds of rewilding emerge (rewilding is, after all, about "self-willed" processes where rewilding is possible). We believe this flourishing diversity of definitions should be embraced because we see several major concerns with adopting an overly purist approach to rewilding, i.e.:

(1) there are few places in the world where "pure" rewilding is possible – most have some form of social or ecological constraint (Fuller et al., 2017; Ward, 2019);
(2) humans have been part of wild landscapes for millennia, and the separation of humans from ecological systems runs counter to the broader view of socio-ecological systems in many other areas of academic and practical endeavour (Ostrom, 2009; Perino et al., 2019);
(3) the extinction of many keystone species (ecosystem engineers) from continents across the globe means that the restoration of functionally important native species is not possible in many cases (Sandom et al., 2014a,b; Richmond et al., 2016); and,
(4) it is not necessary to "de-domesticate" congeners of extinct wild species to achieve the outcomes we want where we have hardy domestic breeds that most likely have ecologically equivalent, or near identical, impacts if kept in wild/semi-wild conditions. These breeds can fulfil ecological functions that reinstate processes representative of wilded systems.

For these reasons we see the potential benefits of including species of domestic (e.g., cattle, goats, sheep, horses/ponies, pigs) and semi-domestic (e.g., reindeer) livestock in the toolkit of managers responsible for rewilding. Unlike many proposed functional "niche substitutes" where rewilding involves evolutionarily distinct species to replace lost processes [(e.g., African lions (*Panthera leo*) to replace predation by sabre-toothed cat (*Smilodon* spp.) in North America; Donlan, 2005; Lundgren et al., 2020)], many domesticated species are the same species, or closely related, to the species that have been lost from the landscape (Lundgren et al., 2020). Logically,

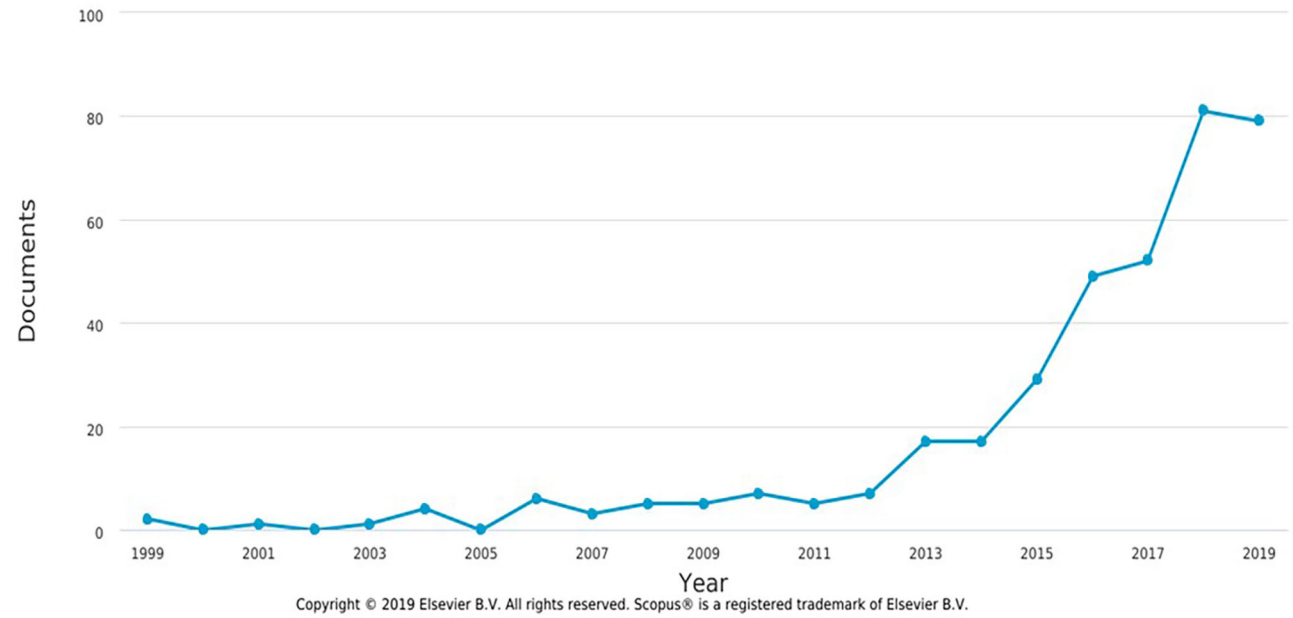

FIGURE 1 | Number of articles listed in Scopus that mention "rewilding" or "re-wilding." The search led to 370 papers.

this means that the domestics' ecological function will be very similar to their wild ancestors/relatives, the key differences likely related to impacts of husbandry on social structure, mate choice by humans (selection), constraints on spatial movements, aggression, and body size (Clutton-Brock, 1989). However, it is not clear that these would significantly influence the ecological function if domestic animals were maintained "as-wild". Indeed, the Chillingham cattle in Northumberland (United Kingdom), that are thought to be derived from domesticated animals, have been maintained as-wild for at least 700 years, and live "probably close to the natural state" (p. 215) (Hall, 1989). The cattle display many wild behaviours, and rarely exhibit some behaviours associated with husbanded cattle (Hall, 1989). This raises questions about whether de-domestication (the process of turning domestic breeds into wild, self-sustaining animals; Gamborg et al., 2010) is systematically necessary to achieve rewilding goals if existing hardy livestock breeds are permitted to live as wild animals. If not, the use of hardy breeds which are less aggressive [noting there concerns that auroch (*Bos primigenius*) may be "too dangerous"; Stokstad, 2015] and have production value, might encourage livestock keepers to develop systems that deliver on rewilding principles. This would of course require a re-evaluation of the characteristics of rewilding and/or rewilded landscapes, changes in policy/regulation, financial mechanisms (e.g., subsidies), and changes in attitudes, particularly amongst some environmentalists and conservationists.

It is worth noting that, as compared to rewilding in the academic literature (with over 370 articles and reviews) the inclusion of AND "livestock" in our search turned up only 21 articles and reviews since 1980, with seven appearing in 2019 (**Supplementary Material 1**). These include publications on the relationship between livestock and predators/scavengers (Arrondo et al., 2019), and advocacy for multifunctional landscapes based upon extensive livestock production for economic, conservation and carbon storage outcomes (Hall, 2018). However, to date there has been no clear articulation of the potential for including livestock within the rewilding agenda. In fact, it is generally declared that livestock are not part of the equation for rewilding unless, of course they have been used to 'reconstruct' wild progenitors of domestic species (e.g., Heck cattle; Heck, 1951; Stokstad, 2015). Obviously, the role that livestock might play in rewilding will be context-specific, but it is by no means unique to only certain specificities (e.g., in the heavily transformed landscapes of Europe). For this reason, we will set out the stall for:

(1) the fact that, no matter how large, rewilded landscapes cannot be isolated from human activity, and therefore, management will be required even if it is to achieve 'an area governed by natural processes";
(2) that livestock should be included in the toolbox of such management actions;
(3) that livestock can provide an economic return for such management actions; and,
(4) in the long-term rewilding needs to be seen within a broader socio-ecological system, where external influences will shape the future of wild landscapes.

THE BROADER THEORY OF REWILDING AND POTENTIAL ROLE FOR LIVESTOCK

Since the concept of rewilding was first published in the late 90s (Soule and Noss, 1998), with a focus on the "three Cs" (i.e., carnivores, corridors, and core areas), several variants of its definition have been proposed (Jørgensen, 2015), ranging from passive approaches on abandoned land (Navarro and Pereira, 2012) to the reintroduction of functional equivalents of the extinct megafauna of the Pleistocene (Donlan et al., 2006). While seemingly different, these approaches converge on the concept at the core of rewilding, which is the restoration of self- sustaining and complex ecosystems, with interlinked ecological processes that promote and support one another while minimising or gradually reducing human intervention. Recently, the ecological theory supporting rewilding allowed the formulation of a framework focusing on three ecological processes that interact with one another, and that should be restored to return an ecosystem to a wilder and self-sustainable state (Perino et al., 2019): (1) stochastic disturbances; (2) dispersal; and (3) trophic complexity. In the following sub-sections, we discuss the three ecological processes core to rewilding, the potential limits to their restoration, and the role that domestic species can play in the process.

Stochastic Disturbance Regimes

Disturbances that are natural in frequency and intensity promote spatial and temporal heterogeneity of habitats and the complexity of their structure (Turner, 1998; Kulakowski et al., 2017; Perino et al., 2019). Typical disturbances are, for instance, those created by large herbivores through their foraging, defecation and trampling (Navarro et al., 2015; Ripple et al., 2015). Fire regimes are also critical disturbances for the creation and maintenance of ecosystems (Bowman et al., 2009), and these are directly influenced by the grazing and browsing pressure (van Langevelde et al., 2019).

One of the most pervasive effect of human activities in a landscape, in addition to land- use change, is the alteration of the natural disturbance regimes: natural fires are suppressed (Archibald et al., 2013), and the stochastic disturbance by wild herbivores is replaced by long term deterministic disturbance by livestock and agronomic fertiliser application (Navarro et al., 2015; Perino et al., 2019). These anthropogenic landscapes have characteristic plant and animal assemblages that reflect the fact that herbivory has created and maintained assemblages that rely directly or indirectly on disturbance, historically by now extinct large herbivore species but now mainly by domestic livestock (Gordon et al., 2017; Bond, 2019). These modified ecosystems, and the economic, social, and cultural activities that depend upon them, are at risk once those livelihoods are abandoned (Cava et al., 2018; Van Meerbeek et al., 2019). Depending on the land-use legacy and the naturalness of the broader landscape, the abandoned land is vulnerable to significant degradation until the natural disturbance regimes are restored. Restoring natural disturbance regimes is, therefore, key in rewilding management (Torres et al., 2018) including to increase the resilience of the ecosystems to current and projected climate change (e.g., Kulakowski et al., 2017).

Domestic and semi-domestic livestock species can play an important role in the restoration of stochastic disturbance regimes, particularly in areas where wild large herbivore species are absent, as is often the case in areas with long-term and large-scale human pressure (Sandom et al., 2014a; Svenning et al., 2016). Until natural fire regimes have been restored, grazing by livestock could also limit the accumulation of fuel and thus lower the risk of wild and intense fires with risks to natural and human capital (Davison, 1996; Bruegger et al., 2016).

Dispersal and Connectivity

Dispersal is essential for the viability of wild populations, to increase access to ephemeral resources, facilitate recovery from disturbances, as well as to reduce inbreeding (Moseby et al., 2018; Perino et al., 2019). Dispersal by large herbivores also facilitates a range of ecological processes including pollination and seed dispersal (Corlett, 2013; Dirzo et al., 2014; Rey Benayas and Bullock, 2015). Where wild large herbivores have been lost from the landscape, it is important to ensure that the use of domestic livestock reproduces the movement patterns, large and small scale in space and time, of those wild species (García-Fernández et al., 2019). This can include active herding the ensures that ecological processes are restored or maintained. Nonetheless, land-use change and the fragmentation of landscapes, including due to linear infrastructure, greatly affect the size and integrity of habitats, thereby affecting the ability of individuals to disperse (Berger-Tal and Saltz, 2019).

Rewilding projects consider the restoration of the connectivity between patches of habitats, for instance by establishing corridors and making linear infrastructure more permeable and less lethal (Root-Bernstein et al., 2017; Torres et al., 2018; Perino et al., 2019). The restoration of dispersal can also be directly embedded within the human-dominated landscape, for instance by adding natural elements such as woodland islets in agricultural fields (Merckx and Pereira, 2015; Rey Benayas and Bullock, 2015). Furthermore, free-ranging livestock can play a role as seed dispersers (Bruun and Fritzbøger, 2002; Couvreur et al., 2004) and their trampling, as well as dung deposition, has been shown to contribute to germination, although with seldom discrimination between native and non-native species (Faust et al., 2011; Hogan and Phillips, 2011). Whether the ecological processes are restored by wild, semi-wild, or domesticated species, the ability of herbivores to disperse has implication for the viability (and welfare) of the populations, and their ecological role in the system Root-Bernstein et al., 2017; see Case study of Oostvaardersplassen below).

Trophic Complexity

Ecological theory supports the role of trophic complexity and trophic interactions in maintaining ecosystems, for instance *via* the regulation of populations sizes and distributions through processes such as predation and competition, as well as its impact on other processes such as disturbance and dispersal (Perino et al., 2019). The consequences of the degradation of trophic complexity is being increasingly witnessed and understood

globally (Estes et al., 2011; Dirzo et al., 2014), particularly with the loss of large carnivores and large herbivores from ecosystems (Ripple et al., 2014, 2015).

An approach to rewilding illustrates the importance of trophic complexity i.e., "trophic rewilding" which places an emphasis on the reinforcement of populations, or on the reintroduction of missing species, particularly large carnivores and large herbivores (Svenning et al., 2016). However, in several cases, the restoration of complex trophic networks will not be possible because some species have gone regionally or globally extinct (Svenning et al., 2016; Fernández et al., 2017). Even when keystone species are only regionally extinct, public acceptance of their reintroduction might be low, e.g., European bison (*Bison bonasus*) (Decker et al., 2010; Klich et al., 2018), often due to a phenomenon known as the 'shifting baseline' syndrome, whereby the human expectation of what are 'good' or 'natural' environmental conditions is determined by the current experience rather than a historic diversity that is not present in living memory (Pauly, 1995; Manning et al., 2006; Papworth et al., 2009; Clavero, 2014). The case studies as presented below fall on a gradient from greater human intervention in the case of reindeer herding through to much lighter management input in the case of OVP and Knepp. This demonstrates how the approach we are presenting can be applied in different rewilding contexts.

In the case of the restoration of trophic complexity specifically, the potential of livestock is still limited. For instance, the extent to which livestock can be considered as a replacement for wild herbivores will depend not only on their functional role in herbivory and fire suppression but also on people's acceptance of depredation by wild predators on those domestic or semi-domestic populations (Bautista et al., 2019). However, we know a huge amount about the interaction between livestock and a broad range of natural ecosystems and this knowledge can be used in replacing extinct species disturbance regimes (Gordon et al., 2004).

Interacting Processes

The three ecological processes discussed above do not act in isolation and their interactions should be considered for rewilding. For instance, the natural recolonization or reintroduction of large herbivores, or the use of livestock as functional proxies for wild species, without control by natural predators could alter the natural disturbance regime within the landscape and lead to detrimental grazing impacts. The restoration of the spatial and temporal variability of the trophic interactions is also important to take into consideration in rewilding projects, for instance with the restoration of a "landscape of fear" (Manning et al., 2009; Suraci et al., 2016), and its impact on the spatial distribution of nutrient deposition and grazing pressure. The landscapes to be rewilded must also be sufficiently large, or connected, to allow the movement of predators and prey species. Predation, by stochastically distributing carcasses in the landscape, also plays an indirect role in both the size of populations of detritivores and plant growth *via* nutrient depositions (van Klink et al., 2020). While large carnivores are not yet part of the ecosystem, managers of rewilding areas should consider how to replicate these trophic interactions artificially (ICMO, 2006).

Ultimately, restoration is a societal vision for interactions between humans and nature, and the choice of given interventions and their likely outcomes. In the case of rewilding, approaches and outcomes can vary greatly depending on the historical baseline considered and the intensity of the action that one is willing to apply (Fernández et al., 2017). This explains why the interventions considered to date can range from letting wild species recolonize recently abandoned farmland (Navarro and Pereira, 2012), to the reintroduction of elephants (e.g., *Elephas maximus*) as proxies for the ecological role that mammoths (*Mammuthus* spp.) played in the landscapes of the Pleistocene (Donlan et al., 2006). This broad spectrum of interventions for rewilding also means that there is room to shift from considering that the role of livestock exclusively for food production and the maintenance of cultural landscapes, towards including their functional role into strategies for the short- or medium-term creation of self- sustaining and wild ecosystems.

GENERAL CASE STUDIES

Given the emphasis in rewilding is on restoring natural ecological processes, rather than species *per se* there is no logical reasons against using domestic animals or niche substitutes if they provide ecosystem functions, achieve the desired ecosystem state, and provide the same ecosystem services. This may be particularly important in the early stages of a rewilding project. However, using domestic livestock for rewilding has implications for both the nature managers and for the animals themselves; in the upcoming section we will outline four case studies, and discuss how they have used, more or less successfully, domestic animals for projects associated to rewilding. These examples inform and generalise guidelines for the use of domestic animals to restore or retain key ecological processes for rewilding. Here domesticated animals are meant as animals that are tame, have their reproduction controlled by humans and are dependent upon humans for their survival (Drenthen and Keulartz, 2014), and semi-domesticated are meant as animals who still need some human intervention for their survival, but have some autonomy in their movements. However, there is a continuum between wildness and domesticity that depends on the amount of human intervention and care given to the animals, but also on the adaptability of the animals to their environment (Keulartz, 2010). Hence, we advocate for the inclusion of domestic animals in the toolkit of rewilding projects and for the increased deliberative intervention of managers in cases where scale, type of animal or social context do not leave room for a large scale, hands-off rewilding approach.

Reindeer Engineer in Swedish Lapland

Our first case study explores the initiative, launched in 2015 by Rewilding Europe, Rewilding Lapland (since renamed Rewilding Sweden). It is a unique project to encourage a new economy based on the cultural landscape of Saami and the Laponia region, that stretches over the north of Sweden and Norway. The area is populated by the First Nations Saami people and

herding of semi-domesticated reindeer (*Rangifer tarandus*) is an essential part of their culture and has shaped the landscapes for generations. Reindeer herds wander freely in unfenced areas between foraging in the tundra during the snow free season and spend the winter in the boreal coniferous forest where they feed on lichen, thereby limiting the need for supplementary feeding. Comparably to other indigenous populations elsewhere in the world, the relationship of the Saami people with the Swedish State is complex and there is a long history of State repression of cultural activities (Lantto and Mörkenstam, 2008). Today, tensions are mostly with the forestry sector, representing a powerful industry that intensively manages forest plantations in Laponia. The region also includes the Laponia World Heritage area, which comprises large areas of old growth forest and stands as a symbol of co-management of natural resources between the Saami and the Swedish State (Reimerson, 2016).

The Rewilding Sweden project seeks to create an economy based on the unique socio- ecological system that includes Saami culture, wildlife, and free flowing rivers (Koninx, 2018). Reindeer and reindeer herding are an essential part of this nature-culture landscape, influencing landscapes through their grazing and trampling. In turn reindeer are connected to the semi- nomadic herders who engage in transhumance with the reindeer herds (Rouet-Leduc and von Essen, 2019). Reindeer are an important source of income for reindeer herders, in terms of meat products but also products derived from the reindeer skin, antlers, etc. as well as tourism activities related to reindeer (Koninx, 2018). The path followed by Rewilding Europe (2020) generally is a bottom-up, network-based approach putting Saami knowledge and cultural relationship with nature at the heart of the vision for the new economy, with reindeer being the most important keystone species of the area because of their disproportionately large impact of the ecosystems compared to their abundance (Paine, 1966; Power et al., 1996). The Rewilding Sweden project promotes a network of nature conservation actions, with a focus on reindeer herding and river catchments, valuing pre-existing human-modified systems using semi- domestic reindeer. In this context, rewilding with predators or wild herbivores could create great disruption in the reindeer herding activities, since predator presence creates a major issue for herders (Sandström et al., 2009), and other wild herbivores are likely to compete with the reindeer for limited forage resources. Recognising reindeer as the keystone species of the area, despite it not being a truly wild animal, allows for a "relevant and minimally respectful compromise" to be made as the animal is at the heart of Saami livelihood and tradition (Rouet-Leduc and von Essen, 2019).

In Rewilding Sweden, approval from local, and especially Saami, communities is especially crucial; therefore, synergising the interests of reindeer herders and other issues of nature conservation allows for the creation of a long-term, large-scale project that has a social licence to operate. In contrast with the intensive forestry activities that occupy major areas of Swedish Laponia region, the project's approach is based on common interests in preserving wild areas (Widmark, 2009), since reindeer herding, like rewilding projects, depends on restoration or protection of wild nature, in this case old-growth forest.

Livestock Fire Brigade and Free Running Horses in the Côa Valley, Portugal

The Faia Brava reserve in Portugal, illustrates how the use of domestic livestock and human management is necessary, either as a transition period towards future "self-willed" wild nature, or because of other limitations that requiring cognisance of animal welfare, human-animal relations, or legislation.

In recent years, the Mediterranean region of Europe has seen a rise in the abandonment of farmland and traditional land management practises. This transition has led to shrub encroachment, increased fuel load (because domestic herbivores are no longer removing biomass and populations of wild herbivores are still relatively low), increasing the risk of wildfires (Moreira et al., 2011). This land abandonment process takes place on former traditional landscapes such as the Montado/Dehesa silvopastoral systems in Portugal and Spain that combine silvicultural activities, usually of cork oaks (*Quercus suber*), with agriculture and extensive grazing (Oteros-Rozas et al., 2014; Godinho et al., 2016). In the North East of Portugal, the Côa Valley is a textbook example of the rural exodus leaving large swathes of disused agricultural areas. The Portuguese Non-Governmental Organization Associação Transumância e Natureza (ATN), together with the support of the European organization Rewilding Europe, has established a reserve on former agricultural land, Faia Brava. The area was previously used for olive (*Olea europaea*), cork (*Quercus suber*), and almond (*Prunus dulcis*) groves, as well as extensive herding of goats and sheep (DeSilvey and Bartolini, 2019). The reserve, created in the 2000's, is now home to semi-wild Garrano horses (*Equus ferus caballus*) and cattle (*Bos taurus*) herds.

For several reasons, Faia Brava illustrates well the use of domestic animals and the human intervention in rewilded landscapes. The size (about 850 ha), as well as the nature of the reserve being situated in a highly anthropogenised landscape with a strong cultural value, calls for multiple human interventions to maintain the reserve and the animals that are present in it, creating a natural and cultural landscape of co-habitation and co-production (DeSilvey and Bartolini, 2019). As well as being limited in size, the reserve is surrounded by land that is still used for agriculture and pastoral activities. Therefore, a completely hands-off approach is not possible, and some level of management of the animals is necessary, to avoid human-animal conflicts and to meet requirements for animal welfare. The horses and cattle, therefore, receive supplementary feeding, especially in the years with harsh conditions, and have access to artificial water points in the reserve. Also, due to the near absence of predators in the area, managers of the reserve mimic predation and maintain populations of animals at a level they judge to be in accordance with carrying capacity of the area. In theory, the number of animals could be regulated bottom-up by the amount of food available, similarly to the initial management practises at Oostvaardersplassen, but the need for public acceptance requires human intervention in regulating populations of animals, to avoid public outrage in the absence of regulation by predators. Excess cattle are sold for meat while horses are sold as pets.

The management of the horses and cattle in the reserve is made easier by the relative tameness of the animals. Rewilding Europe aims at having a "self-sufficient wild bovine grazer" in multiple places, including Faia Brava, as part of their Tauros program but in this long transition phase, the cattle are still managed. The "back-breeding" process used in the Tauros project, selects traditional local breeds like the Maronesas and Sayaguesas cattle, and seeks to eventually bring back a functional relative of the extinct auroch (Goderie et al., 2016; Rewilding Europe, 2020), although we would assert that this is not necessary given that hardy domestic breeds are available.

In Faia Brava, as with all rewilding projects, social context must be taken in to consideration, in terms of social preference as well as nature's contribution to people's lives and livelihoods in the form of ecosystem services (Perino et al., 2019). The successful annexation of the reserve was dependent on good relations with both regional authorities and local inhabitants. The use of semi-wild animals made their management easier but the continuous existence of traditional herding of cattle and sheep (*Ovis aries*) in the area made the relationships with herders a challenging cooperation (Pellis, 2019). In these post-agrarian landscapes (Lorimer and Driessen, 2016), transition is a lengthy process and requires cooperation across the traditional agricultural and rewilding sectors.

An important aspect that characterises this project is the will to involve and include the local community in deriving benefits from the reserve. This creates nature-based economic activities, as an alternative to land abandonment (with its associated reduced economic opportunities), as well as encouraging social acceptance of the rewilding project. Rewilding Europe and ATN have been actively collaborating with the local community, especially the local shepherds and the inhabitants of the neighbouring village of Cidadelhe (Pellis, 2019). The Faia Brava reserve is already home to ecotourism activities, based on wildlife viewing and other nature-based activities related to the area. Rewilding Europe is also emphasising the nature-culture aspects of these enterprises by combining the allure of the rewilding project with the broader benefits of the location in the Côa Valley, which is listed as a UNESCO World Heritage Site, for its Prehistoric rock art depicting large herbivores (UNESCO, Rewilding Europe). More generally, managers of rewilding projects are aware of potential tensions that their vision of future landscapes can spark in traditional agrarian landscapes, where the culturally-based assumptions for how landscapes should be managed do not necessarily match with rewilding projects. Reconciling different management paradigms is a challenge which justifies, in the Faia Brava case, the use of semi-wild (or semi-domestic animals), that are similar to the domestic animals present in the area and are, therefore, more familiar and acceptable to the people living in the area. This case study, therefore, shows that, because of the strong cultural aspects and the omnipresence of traditional agrarian activities and cultures, rewilding must happen within a socially acceptable operating space that identifies and respects societal norms (Corlett, 2016; Perino et al., 2019).

Ecotourism and Sustainable Meat at Knepp Estate, England

The Knepp Estate in England is one of the most famous examples of rewilding in Europe, stretching over 1,400 ha of former farmland, and home to numerous wild-living herbivores, such as longhorn cattle, Dartmoor horses, red (*Cervus elaphus*) and fallow deer (*Dama dama*) and Tamworth pigs (Tree, 2018). While it is using some domestic species, the vision for the Knepp Wildland project is to create a rewilding area, that is not determined by the conservation of a specific species or habitat, but rather by the restoration of natural processes and the use of large herbivores as keystone species to achieve this vision. In just two decades, since the Knepp Wildland project began, the estate has seen a remarkable restoration of biodiversity, including rare species like the purple emperor butterfly (*Apatura iris*) and the peregrine falcon (*Falco peregrinus*).

The Knepp Wildland project started as a rewilding experiment on impoverished farmland and is now seen as an example of successful land management, and also a good case of nature-based economy. Indeed, the Estate is both an important place for ecotourism with its relative closeness to London, and it also produces around 75 tonnes of "wild" organic meat per year. The Knepp Wildland project started in 2001 and aims at creating a rewilding area with naturalistic grazing acting as a model for rewilding agricultural land in the UK (Overend and Lorimer, 2018). Considering the size of the Knepp Wildland, and the fact that there are no predators of large herbivores in the area, animal numbers must be controlled artificially. The domestic breeds such as longhorn cattle and Tamworth pigs are culled for the meat market, while deer are culled by stalking. Additional management is required by regulations, meaning that all the animals, except for the deer, must be registered, taken care of, and slaughtered in accordance with national legislation. The livestock, even though feral are managed so as not to pose a threat to humans and are not "too" wild (Rotherham and Handley, 2011) to keep public support for the project. Knepp Wildland has developed a broad range of activities based on rewilding that provides an alternative income to using the land for agriculture purposes. For example, the Estate sells sustainable premium meat from the longhorn cattle, the Tamworth pigs, as well as different types of venison from the deer. It focuses on the meat products being "wild range meat", and the fact that the meat comes from ancient breeds and that the animals have lived and fed in a "wild" environment is a selling point. Also, the Estate offers numerous opportunities for recreation, such as wildlife watching and safari-like excursions.

The Knepp Wildland project is an excellent illustration of how domestic breeds of livestock can be included in the toolkit of nature managers in rewilding projects. As keystone species the animals perform specific roles in shaping the landscape, providing multiple ecosystem services including habitat for biodiversity, while also giving an economic return in the form of premium wild meat and ecotourism. However, in other circumstances there may be social and ethical issues associated with the harvesting of animals in rewilding projects (as has been discussed for wildlife species, see Thulin and Röcklinsberg, 2020).

Oostvaardersplassen: The "Wild Experiment"

Oostvaardersplassen (OVP), in South Flevoland in the Netherlands, is one of the most famous, influential but controversial, rewilding projects in the world (Lorimer and Driessen, 2014a). It was established on a reclaimed polder, originally intended for industrial development, but due to economic downturn in the early 1970s, was instead turned into a nature reserve (Vera, 2009; Lorimer and Driessen, 2014b). The reserve is about 6,000 ha of wetlands, grasslands with some trees and shrubs, surrounded by human dominated landscapes (intensive agriculture, urban fabric) with no connectivity to other (semi-)natural areas. This means that populations of large herbivores are not only not top-down regulated, but they can also not disperse. The site has become a very important habitat for birds, with over 78 species recorded (Schwartz, 2019). Species such as spoonbill (*Platalea leucorodia*), bittern (*Botaurus stellarus*), marsh harrier (*Circus aeruginosus*) and bearded tits (*Panuris biarmicus*), all previously rare in the Netherlands, established there (Vera, 2009). Also, bird species that were completely extinct as breeding species in the Netherlands established including the graylag goose (*Anser anser*), great white egret (*Ardea alba*) and white-tailed eagle (*Haliaeetus albicilla*) (Vera, 2009). Over 30,000 greylag geese over-winter there and influence the ecosystem through their grazing (Vera, 2009).

To avoid willow (*Salix cinereal*) encroachment onto grasslands two large de- domesticated forms of herbivore species were introduced in the mid-1980s, i.e., Heck cattle (*Bos taurus*) and konik horses (*Equus ferus caballus*). Red deer were introduced in the 1990s. These introductions were also underpinned by an alternative theory of past forest dynamics in which it was argued that ancient forests were more open than previously assumed, because of herbivore grazing and browsing (Vera, 2000). Critically, the herbivores were to be "unmanaged" and live as wild (i.e., free mate choice, social structuring) with population numbers being determined by food availability in the winter (Vera, 2009). As such, there were "no targets, no models and no explicit action plan" (Lorimer and Driessen, 2014b, p.48), which was a major divergence from mainstream conservation practise and regulation. The fact that the land was reclaimed from below sea-level, perhaps provided greater flexibility in thinking and experimentation with the focus on nature and natural processes ("new wilderness"—Schwartz, 2019), rather than the more traditional guided conservation management pathway towards a past or pre-determined state. Critically, the reserve is surrounded by human dominated landscapes (intensive agriculture, urban fabric) with no connectivity to other semi-natural areas.

From the initial introduction of founders (32 Heck cattle, 18 Konik horses and 40 red deer), the populations grew to over 5000 individuals, and the philosophy meant there were no prescribed targets (Schwartz, 2019). This meant that animals would die of starvation in tough winters (though rangers would proactively cull animals that were suffering), and carrion would provide food for predators including white-tailed eagle (Vera, 2009; Schwartz, 2019). This approach was controversial and challenged in court but was permitted to continue with some recommended changes (Vera, 2009; Theunissen, 2019). Though a review in 2006 noted that "the public preference for avoiding OVP management policies that involve the routine culling of substantial numbers of healthy animals" (ICMO, 2006, p. 7), indicating divergence in community views on the management principles. However, during a harsh winter in 2017 over 3,000 (∼60% of the population) animals were euthanized or died of starvation. There were public protests, and people illegally threw bales of hay over the fence surrounding the reserve (Schwartz, 2019). The provincial authority of Flevoland reviewed the management of the large herbivores (van Geel et al., 2018) and changed the management regime to set target populations sizes (210 Heck cattle, 550 Konik horses and 500 red deer). The populations were to be managed through active control and relocation to other projects. There was also a stipulation that each individual herbivore should be sighted three times a week, its condition assessed, and veterinary attention provided if needed (Schwartz, 2019). The changes effectively ended the "self-willed" management of the herbivore population. There was perhaps, a missed opportunity, following the earlier review of management in 2006 by independent large herbivore experts at a time when public opinion appeared to have supported the novel management regime, but issues were emerging (ICMO, 2006). They outlined a range of alternative management scenarios: (1) no intervention (2) proactive culling or removal (3) reactive culling (4) contraception. They recommended proactive culling or removal to minimise starvation and winter mortality *but* suggested these could be designed to mimic natural processes by (i) simulating the impact of natural predation and episodic mortality; (ii) removal of a fixed level of annual recruitment – but that range could be varied according to ecological carrying capacity; and (iii) removal of a variable numbers of animals each year based on body condition (ICMO, 2006). This recommendation allowed for a more nuanced, naturalistic management regime than eventuated in van Geel et al., 2018, when public opinion appeared more fixed against the original principles. This outcome serves as an important reminder of the need to consider the interaction of the society and ecology when defining management goals for rewilding (while at the same time recognising that all outcomes cannot be predicted at the outset).

There are many lessons from the Oostvaardersplassen "wild experiment"—these are not just ecological, but also social, philosophical and theoretical. Although it has been criticised as a "failure" by some (e.g., Theunissen, 2019), given it was largely experimental, and the outcomes of the novel approaches were not known *a priori*, it is perhaps unfair to apply measures of success retrospectively. While it may have failed by some perspectives, it has allowed the exploration of the principles of rewilding, and the relationship between this process and the public (i.e., social licence), and arguably helped to propel the broader rewilding movement to where it is today—on the cusp of becoming mainstream (Bakker and Svenning, 2018; Pettorelli et al., 2018, 2019).

Oostvaardersplassen raises important questions about the definition of rewilding, or rather whether there should be accommodation of different types of rewilding. At its core is a debate about human intervention—how much, when and what? Some of the criticism of Oostvaardersplassen has been that the area was too small and there was no natural predation

(Schwartz, 2019) —though noting that Vera (2009) argued that evidence from Africa suggested bottom-up processes (i.e., food availability) would naturally drive the majority of mortality, and, therefore, overwinter deaths were to be expected. Therefore, in order to maximise the level of "self-willed" properties and processes, should human intervention be considered (can it be avoided?) in some parts of the ecosystem? —at least in the establishment stages? At the same time, it is likely that rewilding projects will want to avoid succumbing to the previous constraints (Butchart et al., 2010; WWF, 2016; IPBES, 2019; indeed many of the cumulative failures, e.g., at a global scale) of more mainstream "command and control" resource management (*sensu* Holling and Meffe, 1996). In short, and perhaps counterintuitively, is deliberative, measured, targeted intervention the price that must be paid to have rewilding at a broadscale?

The introduction of population targets at Oostvaardersplassen in 2018 raises some interesting research questions and highlights an opportunity. Firstly, is it necessary to have to intervene in herbivore populations, as a price for having "rewilded" populations and ecosystems? How can evidence-based offtake targets be derived based on assumed bottom-up and top-down (predation) pressure? How do managers mimic natural mortality to maintain the ecological and evolutionary processes that are desired? The ICMO (2006) provided some valuable suggestions of how this might be achievable. The Heck cattle and Konik horses of Oostvaardersplassen had been under bottom-up selective pressure since the mid-1980s, but how will the culling towards the new targets change selection pressure across the population? Secondly, the combination of annually determined harvest levels, but the continuation of otherwise "wild" life history of the large herbivores, potentially opens the possibility of an integrated rewilding-farming model that markets the meat of the harvested animals, as in the case of the Knepp Wildland project above. Such products could be branded as supporting the rewilding of these extensive ecosystems and all of the co-benefits seen at Oostvaardersplassen [though we are not advocating this for Oostvaardersplassen, rather the concept, noting that using culled animals for human consumption was floated in the ICMO (2006) review]. The benefits of such a model are that the potential for financial feedback means more farmers could consider this as an alternative model for their land management, and, therefore, more land could operate under rewilding principles. In essence, this could be a Knepp+ or Faia Brava+ model in which feral livestock and wild herbivore species live as wild for their full life history (i.e., "self-willed"), but are monitored to meet societal expectations for their welfare and harvested to manage population size and to fund rewilding activities that would otherwise not take place.

CONCLUSIONS

Rewilding, as a conservation practise, is regularly criticised for being the subject of internal disagreement regarding its definition (Lorimer and Driessen, 2014a; Jørgensen, 2015; von Essen and Allen, 2015). The idea of using domestic animals in rewilding projects can appear to be in opposition to some of the core definitions of rewilding, inasmuch as the term of rewilding involves restoration of "self-willed" nature or the "autonomy of the more than human world" (Jørgensen, 2015; Prior and Ward, 2016). We argue, however, that a lighter version of rewilding, *rewilding lite* if you will (Carver, 2014), allows for the use of livestock in support of these broad objectives. To re-emphasise, this is not restoration dressed up in sheep's clothing but still has at its heart the core outcomes of rewilding but through a different mechanism of reinstating lost processes.

It is still early days for the rewilding agenda within conservation science and practise. However, there are large areas of historic research that can be brought to bear in support of the outcomes that are the philosophical underpinnings of the approach (e.g., conservation/ecological sciences, agricultural research, community-based conservation). From this, key lessons can be applied in the new context of rewilding. Firstly, there must be clear statements of the objectives for any rewilding project, and a plan (preferably based upon a theory of change) to get to the outcome. Just 'letting nature take its course' is not likely to be enough in many situations and can be a derogation of the duty of those responsible for the project. Not doing anything is a management decision in itself and must be assessed in the same way as interventionist options. In the early stages of a rewilding project, it is likely that the management interventions will be required, and the manager is best served by having a broad range of options in the toolkit. These should include the opportunity to use livestock to remove vegetation (native and invasive) and change vegetation structure in support the improvements of biodiversity or the provision of ecosystem services on the site. Secondly, attempts to de- domesticate livestock to create facsimiles of ancient breeds may not be necessary if the goal is to facilitate ecological process for rewilding. The desire to create an animal that looks like a lost species, such as an auroch (Stokstad, 2015; Goderie et al., 2016), should not be conflated with the goal of finding an animal that returns lost processes. The reconstruction of the facsimile of extinct species is fraught with challenges and may lead to animals that are more needy than their constituent ancient breeds [e.g., Heck cattle appeared to be susceptible to competition from other grazers which impacted the cattle's condition; ICMO (2006)]. Indeed, there is a circularity in the logic of the process of de-extinction given that creating such a species depends on existing hardy breeds as founders—which raises the question why not just use the hardy breeds? Selective breeding to create facsimiles also assumes humans can pick traits through selection that confer adaptive advantage in the wild better than does natural selection. For example, an unintended consequence of the new management regime at Oostvaardersplassen may be ceasing natural selection and de-coupling of animals from the ecosystem—because natural selection of cattle, horses and deer has, largely, been replaced with human selection (the antithesis of rewilding). It may instead be more effective to use existing hardy breeds bred by humans for many generations to thrive in regional conditions, or to establish a rewilding project with a mix of livestock breeds and let selection evolve a locally adapted wild breed. Having

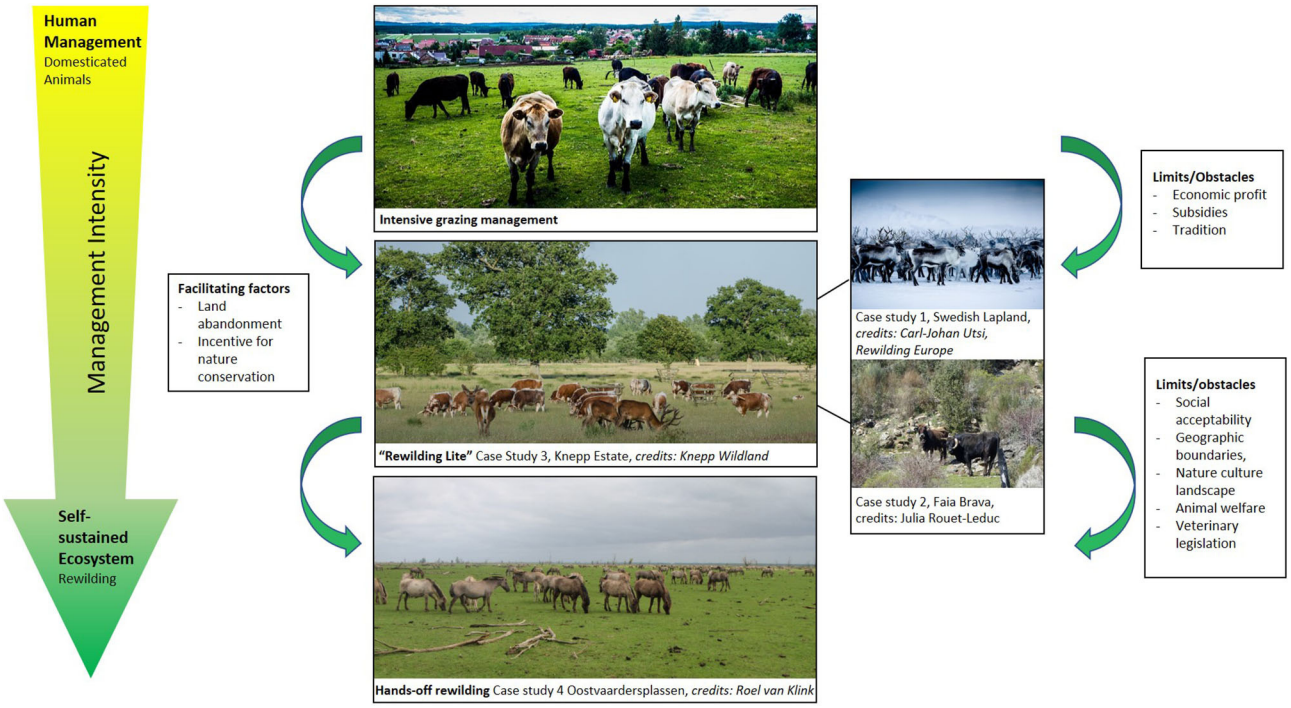

FIGURE 2 | Schematic representation of how different types of land managements with large herbivores are facilitated or hindered by different factors. Our case studies are all situated within the second type of land management, that is rewilding with domestic animals. The top panel represents traditional rearing of animals with high management intensity, and the bottom panel represents "hands-off" rewilding (i.e. "rewilding max") with minimal human intervention, in this case Oostvaardersplassen.

said that, the new suit of gene editing techniques may help offer an alternative route to bringing back extinct species in the future (Richmond et al., 2016). Thirdly, except in exceptional circumstances, rewilding projects do not sit in isolation from the broader socio-economic system of the region, country, or continent (even though the approach appears to be setting nature in juxtaposition to humanity). There is, of course, the real risk that rewilding becomes tarred with the same brush as the 19th- and 20th-century approach called fortress conservation that attempted to isolate nature from people's impact by removing indigenous communities and only allowing access to the elites (Dowie, 2009). As such, from even before the inception of the rewilding project, mechanisms need to be in place to ensure that the broader community is on board with the project and ideally is invested in the project. Particularly, traditional livestock keepers (i.e., pastoralists, herders and farmers) could have an important role to play in broad-scale rewilding rather than being opposed to it. This is for instance the approach taken by Rewilding Europe when designing and establishing a rewilding project together with local populations (Helmer et al., 2015). Finally, linked to the third point, but separate from it, in its purest form rewilding posits people as external to the restoration of ecological processes. First Nations people have been engaged in the management of ecosystems for generations, and the keeping of livestock, both domestic and semi-domestic for millennia; First Nations people should, therefore, be encouraged to initiate rewilding projects and be central to the development of project across the continents of the planet. This socio-ecological systems approach should, in our view, be foundational to rewilding philosophy and practise.

The case studies outlined above represent points on a rewilding continuum for the role that semi- domestic, domestic livestock could play in rewilding projects (**Figure 2**). In the case of the semi-domestic reindeer herds of the Saami First Nations people in northern Scandinavia (Rewilding Sweden), the transition to support rewilding objectives requires very little change to the management regimes. For Knepp and Faia Brava the removal of inputs through, energy, labour, and fertiliser/irrigation were key to meeting the objectives, however, clarity is required on what ecological process states are the intended outcomes of the rewilding project. If these entail removal of vegetation, or the maintenance/creation of open areas within potentially wooded/forested landscapes, then grazing is an effective way of achieving this over large areas. If there are constraints (management, social, economic, environmental, regulatory, welfare) to the use of wild herbivore species then domestic livestock species are a potential option. When livestock species are used, be they semi-domestic or domestic, there will be a requirement for intervention in most situations (the same is the case for wild species where predators are not present in the system). These interventions will depend upon the local circumstances but are likely to include aspects of livestock

husbandry required to meet environmental, biosecurity, legal and welfare objectives. The Oostvaardersplassen example, demonstrates the need for such measures to be put in place early so that public support for the rewilding project is not compromised.

In some cases (as exemplified by Knepp Wildlands) money can be generated from harvesting livestock products, but it should be noted that this would be counter to the original principles of rewilding if this were the primary reason for the husbandry activities. So, the offtake of products needs to be a byproduct of delivering the rewilding outcomes. The degree to which livestock are managed will vary depending upon circumstances, however, the introduction of a safe operating space (c.f., Rockström et al., 2009) could be incorporated into the rewilding principles. In this paradigm managers can be hands-off whilst the system fluctuates within a set of predefined boundary conditions (though these will be broader than those in traditional agriculture and conservation), be they structural or process-based; however, interventions will be brought to bear when the system is at risk of moving beyond those boundaries (see also Corlett, 2019). In effect, this is what happened in the case of Oostvaardersplassen, however, it was not formally incorporated into a management plan until after the project had run into severe public relations problems. The safe operating space will, therefore, incorporate a component of the socially acceptable operating environment (social licence to operate) as defined by the community of engagement with the rewilding project. Obviously, there will be ecological and evolutionary consequences of this approach, that will play out in the wild and livestock species within the system.

In conclusion, we see the potential benefits of including species of domestic and semi-domestic livestock in the toolkit of managers responsible for rewilding. This will require a re-conceptualisation of the characteristics of rewilding and/or rewilded landscapes, along with release from some of the policy/regulation constraints imposed on feral/free-living livestock (Hall et al., 2005), and changes in attitudes, across all sectors engaged in this thought-provoking and forward-looking approach to the engagement between nature and people.

AUTHOR CONTRIBUTIONS

IG, LN, JR-L, and AM conceptualised the overall theme of the manuscript and wrote the manuscript. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2021.550410/full#supplementary-material

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