RESEARCH ARTICLE

Trophic Rewilding Advancement in Anthropogenically Impacted Landscapes (TRAAIL): A framework to link conventional conservation management and rewilding

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Abstract A variety of rewilding initiatives are being implemented across Europe, generally characterized by a more functionalist approach to nature management compared to the classic compositional approach. To address the increasing need for a framework to support implementation of rewilding in practical management, we present TRAAIL—Trophic Rewilding Advancement in Anthropogenically Impacted Landscapes. TRAAIL has been co-produced with managers and other stakeholders and provides managers with a framework to categorize rewilding initiatives and to link conventional nature management and rewilding by guiding steps towards a higher degree of self-regulation. Applying TRAAIL to data obtained in a Danish survey of rewilding-inspired initiatives we find that out of 44 initiatives there is no “Full rewilding” initiatives, 3 “Near-full rewilding” initiatives, 23 “Partial rewilding” initiatives, 2 “minimal rewilding” initiatives and 16 “Effort-intensive conservation management” initiatives. This study shows how TRAAIL can guide and inform trophic rewilding on a local and national scale.

Keywords Categorization · Conservation management · Ecological restoration · Large herbivores · Protected areas · Trophic rewilding

INTRODUCTION

During the last two decades, nature conservation efforts in Europe have to a large degree been dictated in EU Member

States by the two main pillars of the nature policy in EU, namely the Habitats Directive (European Commission 1992b) and the Birds Directive (European Commission 1992a; Halada et al. 2011). The main tools fighting the species decline and deterioration of ecosystems or to ensure the so-called favorable conservation status (European Commission 2011) in Europe have therefore been species conservation and habitat conservation.

These approaches represent a compositional approach focusing on conserving specific landscape types, specific communities and specific populations and genes as opposed to a functional approach focusing on conserving processes of the landscape, the ecosystem, the population and the genes (Noss 1990), which on the contrary underpins the focus of rewilding. The compositional focus has been promoted and supported legally by the Nature Directives and economically by the main economical conservation tool in the EU, LIFE-Nature (Hermoso et al. 2017), and has also been reinforced by large international conservation agreements (Bern Convention 1979; UNEP 1992). The static habitat types in the Nature Directives still underpin the current nature policies in the EU, e.g., the EU Biodiversity strategy to 2020 (European Commission 2011), including guidelines for management of designated wilderness areas (European Commission 2013). This has wide implications for how nature practitioners in EU Member States manage ecosystems today and could be a major obstacle for implementing rewilding on equal terms as the classic conservation strategies in Europe.

Rewilding broadly refers to a restoration strategy to promote self-sustaining ecosystem and enhance the conservation of biodiversity while re-engaging people with nature (Torres et al. 2018). Most rewilding projects fit the more specific definition of trophic rewilding, i.e., an ecological restoration strategy based on reintroducing missing

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animal species to promote self-regulating biodiverse ecosystems via restoring trophic top-down interactions and associated cascades as well as non-feeding related processes such as trampling, wallowing, and other disturbances (Svenning et al. 2016). The focus on processes and functions builds on the recent paradigm shift in ecology from a world view of equilibrium in nature to a view that also recognizes non-equilibrium in nature (Vera 2000; Gillson et al. 2011). The idea of trophic rewilding has mainly been promoted by three recent scientific key findings (Svenning et al. 2016): (1) the dramatic decline in species richness leading to the proposal of an ongoing sixth mass extinction (Barnosky et al. 2011), (2) particular high rates of range declines and extinctions among large animal species (Smith et al. 2018), and (3) increasing evidence that large animals are important for ecosystem function and processes via top-down regulation and trophic cascades (Estes et al. 2011).

Through the last three decades, increasing evidence suggests that large herbivores and carnivores are important for the preservation of ecosystem function and biodiversity (Owen-Smith 1987; Estes et al. 1998; Terborgh et al. 1999; Vera 2000; Sinclair 2003) and that absence of large consumers close to the top of the food chain in marine, terrestrial and freshwater systems can have profound and far-reaching effects developing into trophic cascades (Estes et al. 2011; Dirzo et al. 2014; Ripple et al. 2015) causing past and future co-extinctions (Galetti et al. 2018). Mega-herbivores and other large herbivores, that are key focus in trophic rewilding (Svenning et al. 2019), can shape vegetation structure, composition and dynamics, e.g., through their feeding behavior and pressure (Owen-Smith 1987), seed dispersal (Janzen 1984; Griffiths et al. 2011), and nutrient dispersal (Doughty et al. 2016). The recent advances in ecological theory in terms of the ecospace concept for biotopes (Brunbjerg et al. 2018) further provide a framework (abiotic position, biotic expansion and spatiotemporal continuity) to understand how and why restoring, e.g., guilds of large herbivores can diversify the terrestrial biodiversity. From an ecospace perspective, large herbivores will expand the biotic dimension (diversify organ carbon) via, e.g., modifying vegetation composition and structure, providing dung and carcasses and disperse seeds to the ecosystem, and this will together with the abiotic disturbance caused by the animals differentiate the local abiotic position. This spatial extension of the biotic expansion and abiotic position create new habitats and resources for other organisms to live in and of resulting in more biodiversity.

The European rewilding approach has recently been described to be characterized by seven principles of which

one is the goal to: “move up a scale of rewilding/wildness within the constraints of what is possible” (Jepson and Schepers 2016; Jepson et al. 2018). This principle has also been the fulcrum of Torres et al.’s (2018) recently proposed rewilding scale where the authors give operational meaning to this principle by providing a framework to measure rewilding progress, i.e., human pressures and ecological integrity. In continuation hereof, the present work can be seen as an additional contribution to this endeavor.

In this study, the ambition has been to develop a framework to ease the implementation of rewilding in conventional nature management based on a co-production approach combining trophic rewilding theory with knowledge from conservation managers. We therefore surveyed all public nature managing entities in Denmark to identify management characteristics of rewilding-inspired initiatives. These characteristics guided the design of Trophic Rewilding Advancement in Anthropogenically Impacted Landscapes (TRAAIL) while presentation and discussion of the framework at various workshops, meetings and conferences improved the outcome. We applied the framework to the data on rewilding-inspired initiatives obtained in the national survey of 116 public nature management entities, showcasing how to use the framework on a local scale and a national scale in an anthropogenic context.

MATERIALS AND METHODS

Knowledge co-production based on a national survey

Queries were sent to all official Danish nature management entities (98 municipalities and 18 entities of Danish Nature Agency) in January 2013 (and repeatedly in February, March, April, August 2013, and January 2014) to establish an overview of the characteristics of current Danish rewilding-inspired initiatives (Fig. 1). The query included questions regarding ongoing or future rewilding-inspired projects, choice of animal species, habitat and management (Appendix S1). The last update on rewilding initiatives was enquired and obtained during summer 2015.

Co-designing and co-testing of the framework

Based on the identified characteristic of current rewilding-inspired initiatives and trophic rewilding theory TRAAIL was designed. As part of the co-designing and co-testing process, TRAAIL was presented at conferences, meetings and workshops (Fig. 1). Feedback on the TRAAIL was

Fig. 1 Work-flow of the co-production of TRAAIL. The co-production of TRAAIL involved three main processes: knowledge co-production, co-designing and co-testing. Knowledge co-production included a survey of Danish rewilding-inspired initiatives, co-designing TRAAIL involved feedback on presentations and discussion of TRAAIL with managers and other stakeholders at conferences, meetings and workshop and co-testing of TRAAIL involved testing TRAAIL on the survey data and specific reserve cases at a workshop. The arrows indicate the workflow, and the dashed arrow indicates the iterative integration of feedback from co-testing TRAAIL in co-designing TRAAIL

incorporated, and the design was further improved. TRAAIL was applied to the obtained survey data on a local and national scale.

To investigate the relation between population density and TRAAIL category, we retrieved municipality-level human population density from the official Danish key figures (Ministry for Economic Affairs and the Interior 2014) and tested if there was a difference among the TRAAIL scoring based on the survey using one-way analysis in R (R Core Team 2018). The map was created using ArcGIS 10.6.1 (ESRI 2018).

RESULTS

Characteristics of Danish rewilding-inspired initiatives from the survey

All existing and planned rewilding-inspired initiatives reported in the survey included herbivores in fenced enclosures except initiatives with Eurasian beaver and Exmoor ponies free-roaming on island Tærø (Table 1). Generally, enclosures were a few hundred hectares or less, with the largest planned initiative being 2100 ha. The starting point for many rewilding-inspired initiatives was

Table 1 Overview of animal species and types used or planned to be used in initiatives articulated as rewilding-inspired or used in whole-year grazing projects

(Re)introduced species	Number of initiatives
Aurouch-like cattle (e.g., Heck)	2
Eurasian beaver, <i>Castor fiber</i>	2
European bison, <i>Bison bonasus</i>	2
Exmoor pony	3
Fallow deer, <i>Dama dama</i>	3
Icelandic horse	3
Eurasian elk, <i>Alces alces</i>	1
Red deer, <i>Cervus elaphus</i>	3
Robust cattle (e.g., Galloway, Highland)	14
Sheep (Gute, Mufflon-Lunebuger)	7
Water buffalo, <i>Bubalus bubalis</i>	1
Wild boar, <i>Sus scrofa</i>	1

conventional conservation management, referring to seasonal grazing by domestic livestock. This management form is a remnant of the now vanishing farmland practices that once dominated in Europe and today is considered highly important for the conservation of European semi-natural grasslands (Halada et al. 2011; Tälle et al. 2016). Initiatives with whole-year grazing with domestic livestock were articulated as rewilding though management included, e.g., supplementary fodder, drugs and population regulation.

Seasonal grazing and high management pressure can be caused by, e.g., limited habitat suitability of small fragmented areas, prioritization of meat production, visitor demands, animal ethics originally targeting domestic livestock, but currently also encompassing fenced wildlife or livestock used primarily for conservation, or simply by tradition. Animal species/breeds used in rewilding-inspired initiatives are dominated by domesticated livestock (Table 1), which might be adopted from historic small-scale farmland practices (Tälle et al. 2016), or dictated by practicalities, e.g., related to providing animal species or breeds not used traditionally, and considerations of potential human–wildlife conflicts. Though the Danish rewilding-inspired initiatives are operationalized differently, initiatives generally fit under the definition for trophic rewilding (Svenning et al. 2016).

TRAIL design: Linking conventional conservation management and rewilding

To facilitate the link between conventional conservation management and rewilding, we designed the TRAIL Framework with a backbone targeting the identified characteristics of Danish rewilding-inspired initiatives. This

backbone we call the five ecological measures (eco-measures in Fig. 2) and were identified based on characteristics of conventional conservation management. The ecological measures therefore target features that have the potential to link conventional conservation management efforts to different levels of rewilding via management interventions suggested in the TRAIL Framework.

First and second ecological measure: continuity of accessibility to the ecosystem for the animals and opportunities for animals to exert their natural ecological function under low management regime address that animals used in conventional conservation management often are removed from the area in winter periods and generally experience high levels of management that reduce their opportunities to exert their ecological functions (Table 2). These characteristics modify the ecological functions of the animals, e.g., summer grazing causes the ecological impact to be very intensive during summer periods and non-existing during winter, with supplementary fodder and removal of dead animals weakening the natural ecological impact of the animal (Hodder et al. 2005; Kowalczyk et al. 2011), with implications for the ecosystem structure and functioning affecting organisms dependent on these (Bakker et al. 2016). The specific formulation of the second ecological measure embraces a so-called next generation of rewilding-inspired projects that are “kept wild” (Jepson 2018; Jepson et al. 2018). “Kept wild” refers to a strategy where managers facilitate that the rewilding agent species, defined as the animal species or breed that is put in place to rewild the ecosystem, behave like wild animals exerting their ecological role, but interfere continuously to some degree to, e.g., regulate population size or avoid inbreeding in size-restricted reserves or to make these initiatives more palatable to the general public in terms of, e.g., animal welfare.

The third ecological measure: potential of animal species to advance self-regulating biodiverse ecosystems focus on the match between the rewilding agent species and the ecosystem. A poor match between rewilding agent species and the ecosystem might reduce the potential of the rewilding agent species to increase the degree of self-regulation. For example, races of dairy cattle will most likely prefer staying in the drier parts of a meadow and therefore only impact the wetter parts minimally (Hughes et al. 2016) (Table 2). This ecological measure implies that the selected area does not significantly limit the potential of the rewilding agent species to increase the degree of self-regulation due to the ecological memory of the ecosystem, defined as the ecosystem’s accumulated abiotic and biotic material and information legacies from past dynamics (Schweiger et al. 2018), e.g., drainage, eutrophication, sowing of seed mixtures, or homogeneous plantations. In case of significant ecological memory limitations, these

Fig. 2 Trophic Rewilding Advancement in Anthropogenically Impacted Landscapes (TRAAIL). Restoration initiatives can be categorized into five categories: “Effort-intensive conservation management”, “Minimal rewilding”, “Partial rewilding”, “Near-full rewilding” and “Full rewilding”, based on five ecological measures (eco-measures): “Continuity of the accessibility to the ecosystem for the animal species”, “Opportunities for animals to exert their ecological function under low management regime”, “Potential of animal species to advance self-regulating biodiverse ecosystems”, “Potential of the ecosystem to support natural population dynamics” and “Potential of ecosystems to support natural species interactions networks”. “Animals” in TRAAIL refer to rewilding agent species, defined as the animal species or breed that is put in place to rewild the ecosystem. For each ecological measure, interventions to advance to the next ecological measure are suggested

Table 2 Characteristics of the five ecological measures of the TRAAIL within the five categories: effort-intensive conservation management, minimal rewilding, partial rewilding, near-full rewilding, and full rewilding

	Effort-intensive conservation management	Minimal rewilding	Partial rewilding	Near-full rewilding	Full rewilding
1 Continuity of the accessibility to the ecosystem for the animals	Low e.g., seasonal grazing regimes	High e.g., year-round grazing regimes	High e.g., year-round grazing regimes	High e.g., year-round grazing regimes	High e.g., year-round grazing regimes
2 Opportunities for animals to exert their natural ecological function under low management regime	Low e.g., provision of fodder year-round	Intermediate–high e.g., provision of supply fodder under extreme harsh winter periods	Intermediate–high e.g., periodical population regulation to avoid inbreeding	High e.g., periodical population regulation to avoid overabundance in a predator-free context	High Ideally the only human intervention is the initial (re)introduction of the animal species/race
3 Potential of animal species to advance self-regulating biodiverse ecosystems		Low Poor match between animal species and its habitat preferences, e.g., races of dairy cattle in a semi-wet meadow	Intermediate–high Moderate to good match between animal species and its habitat preferences, e.g., European bison on a semi-wet meadow	High Good match between animal species and its habitat preferences, e.g., water buffalo on a semi-wet meadow	High Good match between animal species, their ecological functions and the habitat, e.g., water buffalo and European bison on a semi-wet meadow
4 Potential of the ecosystem to support natural population dynamics			Low e.g., too small, too fragmented, or too homogenous to support natural population dynamics	Intermediate –high e.g., size and habitat heterogeneity support moderate to high levels of natural population dynamics	High e.g., quantity and quality of ecosystem is not limiting natural population dynamics in any way
5 Potential of the ecosystem to support natural species interaction networks				Low e.g., red deer with no presence of predators	Intermediate e.g., presence red deer and wolves, but poor presence of other apex consumers (e.g., brown bear), scavengers (e.g., eagles) decomposers (e.g., dung beetles), and potential competitors (e.g., other large herbivores) High e.g., same as above plus presence of other apex consumers, scavengers, decomposers and competitors

should preferably be addressed prior to the onset of rewilding efforts.

The fourth and fifth ecological measure: potential of the ecosystem to support natural population dynamics and potential of the ecosystem to support natural species interactions networks address that reserves in conventional conservation management often are size-limited and are suffering from loss of biodiversity. Natural population dynamics including natural social herd structures and

social behaviors might be restricted by the size of the conservation area or the naturalness of its biota and abiotic environment. These restrictions could be expressed in, e.g., unnatural feeding behavior or unnatural social behavior or inbreeding problems (Hodder et al. 2005). Social structure and behavior affect the distribution and activities of the individual animals (e.g., horse toilets or birthing grounds) (Vermeulen 2015). Correspondingly, the ecological functions of an animal species might be expressed in an

unintended or unfavorable way in terms of ecosystem function if its natural species interaction network is incomplete, e.g., when natural vegetation, competitors or predators are missing.

The order of the ecological measures is prioritized after what ecological measures we assess to be the most important in terms of increasing the self-regulation of the initiative: starting from simple ecological measures that can be addressed with relatively simple management interventions that most likely will increase the degree of self-regulation non-proportionately and ending with highly complex ecological measures that require larger and complex investments to restore natural biotas and environmental conditions.

Each ecological measure is associated with relevant management interventions toward a higher degree of self-regulation in the context of trophic rewilding (Fig. 2). The suggested management interventions should be thought of as an inspiration for relevant and possible interventions, but these could well include other actions as well. Like the ecological measures, the suggested management interventions address features that often restrict conventional conservation management in a rewilding perspective. These features can be management protocols accomplished according to, e.g., animal welfare regulations, visitor demand, livelihood opportunities, potential human–wildlife conflicts or to increase the ecological function despite a semi-wild setting (i.e., “kept wild” according to Jepson 2018; Jepson et al. 2018), but they can also be characteristics relating to the biology of the animals and abiotic and biotic conditions of the ecosystem, which are less management-dependent and more a prerequisite of restoration ecology in the Anthropocene.

TRAIL encompass five categories: “Effort-intensive conservation management”, “Minimal rewilding”, “Partial rewilding”, “Near-full rewilding” and “Full rewilding” (Fig. 2). This implies that the term rewilding is not proprietary to one particular approach and can be implemented in a reconciliatory and flexible manner. However, the adjectives “Minimal”, “Partial”, “Near-full” and “Full” clearly distinguish and rank the categories non-equidistantly acknowledging the concerns of diluting the term and approach (e.g., Jørgensen 2015).

While trophic rewilding is ultimately targeting non-intervention or, as phrased by Prior and Ward (2016) non-human autonomy, we recognize that implementation of rewilding in anthropogenic landscapes rarely would be successful without some interventions due to human–wildlife conflicts or spatial constraints from, e.g., infrastructure. Therefore, we distinguish between rewilding-unsuitable interventions, referring to interventions driven by, e.g., tradition and animal welfare regulation (e.g., year-round fodder to ensure certain body condition of animals)

that compromise the ecological potential for top-down regulation of vegetation, and rewilding-suitable interventions, such as “kept wild”-strategies (Jepson 2018; Jepson et al. 2018) that reduce human–wildlife conflicts (e.g., livestock guarding) or promote the ecological function of the rewilding agent species in the target area (e.g., fence).

Effort-intensive conservation management

This category comprises summer or seasonal grazing with livestock breeds or wild animals and could be under both low and high levels of rewilding-unsuitable and rewilding-suitable interventions. It also encompasses whole-year grazing with livestock breeds or wild animals under high rewilding-unsuitable interventions (e.g., whole-year fodder) (Table 2). Examples of short-term seasonal grazing with wild animals are rare.

Minimal rewilding

This category includes year-round grazing with livestock breeds or wild animals both under low and high levels of rewilding-suitable interventions or low levels of rewilding-unsuitable interventions (e.g., population density regulated below carrying capacity or supplementary fodder during harsh weather conditions). In terms of projects with large herbivores, this would also often be referred to as whole-year extensive grazing.

Partial rewilding

This category differs from minimal rewilding in terms of the rewilding agent species as these will not include non-hardy livestock breeds. If fenced, these initiatives often undergo population regulation according to food availability. These initiatives encompass whole-year extensively grazed conservation with robust livestock breeds or wild large herbivores.

Near-full rewilding

This category differs from partial rewilding as projects allow for natural population dynamics of the rewilding agent species. These initiatives are either not fenced or large fenced reserves. These initiatives encompass naturalistic grazing, which compared to other large, extensively grazed conservation allow natural processes such as resource-limitation of herbivores and thereby potentially radical population declines during periods of food scarcity (Hodder et al. 2005) and has been exemplified at Oostvaardersplassen (Vera 2009).

Full rewilding

This category differs from near-full rewilding as it is more, but not necessarily completely, intact in terms of the rewilding agent species' existing species-interaction network including mammal species richness and trophic completeness.

Testing of TRAIL: Local scale

Here, we provide two examples of applying TRAIL to two Danish restoration initiatives: the reintroduction of European beaver (*Castor fiber*) in Klosterheden, Jutland, and the reintroduction of Exmoor ponies (*Equus ferus*) on the island, Langeland, southern Denmark. For location and photos, see Fig. 3.

TRAIL challenge 1: Reintroduction of Eurasian beaver (*Castor fiber*) in Klosterheden, Jutland

18 Beavers were reintroduced in 1999 to Klosterheden in order to increase the natural dynamics and diversity of the ecosystem (Berthelsen and Nitschke 2015) in addition to fulfilling the encouragement of the Bern Convention to reintroduce native species (1979).

Continuity of accessibility to the ecosystem for animals Beavers are free-roaming and are allowed to expand their range.

Score: high.

Opportunities for animals to exert their natural ecological function under a low management regime Overall, the beavers are left to themselves. Generally, this reintroduction requires minimal intervention and intervention is overall only targeting human–wildlife conflicts. The entity managing the beavers receive 30–40 complaints annually related to flooding or damage to trees and bushes in populated areas. Conflicts are mitigated through installation of drainpipes installed in dams to avoid flooding of lowland agricultural fields or roads or rarely through removal of beaver dams (Berthelsen and Nitschke 2015). In the case that human–wildlife conflicts increased, causing managers to significantly reduce the potential of beaver to exert their ecological function, this initiative could score low and be categorized as “Effort-intensive conservation management”.

Score: high.

Potential of animal species to advance self-regulating bio-diverse ecosystem Eurasian beavers are native to Denmark (Aaris-Sørensen 2009) and were reintroduced after ca. 2000 years of absence. Beavers are considered a key-stone species because they build dams that create wetland

habitats, which increase the natural dynamics and biodiversity of the ecosystem (Rosell et al. 2005).

Score: high.

Potential of the ecosystem to support natural population dynamics Eighteen beavers were reintroduced in 1999 and have successfully established a viable population, reaching 203 individuals in 2013. This indicates that the population is generally thriving. By 2014, 37 dead beavers have been reported of which about half are considered to be road kills. Road kills are associated with locations where the stream is piped under a road (Berthelsen and Nitschke 2015). To reduce the number of road kills, managers could consider making beaver-friendly stream underpasses.

Score: high.

Potential of ecosystems to support natural species interaction network Natural predators are few, with red fox (*Vulpes vulpes*) being the only species present with a viable local population. White-tailed Sea-eagles (*Haliaeetus albicilla*) and wolves (*Canis lupus*) are present in low numbers, but could develop larger populations in the future. Apart from predator species, the species interaction network seems to be rather intact, e.g., in terms of the trees, shrubs and water plants that beavers utilize.

Score: low–intermediate.

Resulting TRAIL category: near-full rewilding.

TRAIL challenge 2: Reintroduction of Exmoor ponies (*Equus ferus*) on the island, Langeland

A group of 16 horses from the population of Exmoor ponies on Tærø Island were reintroduced to Klise Nor in 2003. Due to size-restrictions, the population (20 individuals) was moved to its present location at Dovns Klint (107 ha) in 2006, which is four times larger than the first location. The purpose of the reintroduction of Exmoor ponies was grazing in the context of conventional conservation management.

Continuity of accessibility to the ecosystem for animals Exmoor ponies were released to a 107 ha enclosure to roam year-round.

Score: high.

Opportunities for animals to exert their natural ecological function under a low management regime The stocking rate was limited to app. 0.5 livestock units per ha to reduce fodder supply during winter (Mannstedt 2015). Managers remove dead animals according to animal welfare regulations. The alpha stallion was replaced with a new stallion in 2013 to avoid inbreeding. Stallion groups are removed on a

Fig. 3 Map showing Denmark with administrative boundaries of the 98 Danish municipalities and indicating the highest obtained TRAIL category of a rewilding-inspired initiative within the border of the specific municipality and reported by public Danish nature management entities. If more rewilding-inspired initiatives were occurring within the border of one municipality, we colored the entity according to the rewilding-inspired initiative obtaining the highest TRAIL category. Red dots indicate the five larger cities in Denmark. The bottom-left photo illustrates a beaver dam across a wide stream in Klosterheden in north-western Jutland, Denmark (photo credit Pil B.M. Pedersen). Bottom-right photo shows Exmoor ponies at Bagenkop at the southern tip of the island Langeland, Denmark (photo credit Pil B.M. Pedersen)

regular basis. Allowing presence of dead animals would add a new level of scavengers and decomposers to the ecosystem.

Score: intermediate–high.

Potential of animal species to advance self-regulating bio-diverse ecosystem Wild horses, *E. ferus*, are native to Denmark and occurred here until app. 5000 years before present (Aaris-Sørensen 2009). The area and vegetation

might not be fully responsive to the impact of the reintroduced animals due to low-diverse improved grassland vegetation caused by former agricultural practices. A study by Mannstedt (2015) has shown that the vegetation of the former homogenous cultural landscape has become more heterogenous in terms of vegetation structure and species-richness. However, Mannstedt (2015) and managers report that the horses rarely browse in the forest patches and mires. Diversifying the grazing regime with, e.g., hardy cattle breeds under similar conditions as the horses would therefore be highly relevant (e.g., Cromsigt et al. 2017). Restoration of natural forest structure and grassland composition could also improve naturalness and diversity.

Score: intermediate–high.

Potential of the ecosystem to support natural population dynamics The area is dominated by former arable fields, wetlands, plantation and woodland. Managers keep the herd around 65 individuals including foals. We assess that the area is too small to allow natural population dynamics as the population is heavily regulated in order to minimize supplementary feeding. Enlarging the fenced area might reduce the demand for managers to intervene to avoid feeding and inbreeding.

Score: low.

Resulting TRAIL category: partial rewilding.

Assessing an ecological measure to either high or low might be difficult. We therefore recommend to follow the arrow “high” in Fig. 2 when the ecological measure is assessed to be between intermediate and high and correspondingly follow the arrow “low” when the ecological measure is assessed to be between low and intermediate. We also recommend using TRAIL repeatedly as experiences from the initiative accumulate and management interventions might become necessary, e.g., due to human–wildlife conflicts.

Testing of TRAIL: National scale

The public nature managing entities in Denmark reported 44 ongoing and 9 planned rewilding-inspired initiatives throughout the country (Table S1). Applying TRAIL to the 44 ongoing initiatives resulted in no “Full rewilding” initiatives, 3 “Near-full rewilding” initiatives (reintroduction of free-roaming beavers in northwestern Jutland and northern Zealand, and free-roaming Exmoor ponies on Tærø Island), 23 “Partial rewilding” initiatives, 2 “minimal rewilding” initiatives, and 16 “Effort-intensive conservation management” initiatives. Entities that did not report any rewilding-inspired initiatives or only reported initiatives, which conservation goal or conservation action was

outside the scope trophic rewilding, were categorized as “No rewilding initiatives”.

The map (Fig. 3) gives the impression that several municipalities house initiatives where the wildest initiative has a moderate degree of rewilding. We found no difference between municipality-level human population density and the rewilding status of the municipality [no rewilding initiatives, effort-intensive conservation management, planned rewilding initiatives, partial rewilding, and full rewilding (categories used as in Fig. 3)] ($F_4=1.104$, p value = 0.4, $n=98$). Figure 3 also illustrates that there are rewilding activities nearby cities as well as in rural areas.

DISCUSSION

Recently Torres et al. (2018) presented a bi-dimensional framework to measure rewilding progress based on human pressures (e.g., mining and hunting) and ecological integrity (e.g., naturalness of hydrological regimes) and Perino et al. (2019) presented a framework to design and evaluate rewilding plans based on three critical components of natural ecosystem dynamics: trophic complexity, dispersal and stochastic disturbances. As Torres et al. (2018) and Perino et al. (2019) adopt a broader rewilding definition (Fernández et al. 2017) than trophic rewilding, both frameworks are designed to evaluate interventions within the broader spectrum of ecological restoration interventions. The framework presented in this study is specifically designed to the specific case of trophic rewilding, and TRAIL can therefore be considered a more narrow and specific scale than that of Torres et al. (2018) and Perino et al. (2019). To make a clear link between Torres’s scale and TRAIL, TRAIL supplements Torres’s scale by describing relevant management interventions to reduce human pressures while increasing the ecological integrity within a trophic rewilding context (i.e., TRAIL concretize how to move from the top left corner to the bottom right corner in Fig. 1 in Torres et al. 2018 in a trophic rewilding context). Similarly, TRAIL supplements Perino’s framework by describing relevant management interventions to increase trophic complexity and thereby increase dispersal and stochastic disturbance by means of a rewilding agent species (i.e., TRAIL concretize how to move outwards on the three legs in the triangle in Fig. 2 in Perino et al. 2019). Further, TRAIL differs from Torres’s and Perino’s scales by focusing more explicitly on the practical nature management of trophic complexity in anthropogenic landscapes such as in northwestern Europe compared to other settings across the globe. We believe that further development of rewilding scales focused on providing land managers with more specific guidance on

how to operationalize rewilding and how to evaluate outcomes will be useful.

Targeting different TRAIL categories according to the socio-ecological context

Rewilding-inspired initiatives in natural versus cultivated landscapes are embedded in different socio-ecological contexts as they basically differ in two ways; (1) the degree of habitat fragmentation and connectivity, with implications for the geographical scale of rewilding area and choice of rewilding species, and (2) the type and level of human–wildlife conflicts, with implications for conflict management and mitigation (Fig. 4).

In urban areas, potential areas for rewilding-inspired initiatives will often be small and fragmented and

successful reintroduction of large herbivores rely on coexistence or appropriate mitigations (e.g., fencing) to reduce human-safety conflicts (Fig. 4). Successful coexistence with large predators does occur even in some of the world's most densely populated areas (Braczkowski et al. 2018). Consequently, conservation efforts in this context will be a trade-off between conservation and human-safety. Potential sites for rewilding-inspired initiatives in rural areas are less fragmented and comprised of large areas. Successful reintroduction of large herbivores is likewise dependent on coexistence or appropriate mitigations (e.g., crop guarding), but here the incentive for mitigation would rather be conflicts with human-food production (Fig. 4). In landscapes with low anthropogenic impact potential areas for rewilding-inspired initiatives could be of large spatial scale and successful reintroduction of large herbivores

Fig. 4 Schematic showing the socio-ecological context that TRAIL is embedded in. Potential rewilding areas of rewilding-inspired initiatives across high to low anthropogenic pressures, indicating the corresponding potential rewilding species, human–wildlife conflicts and mitigation tools, social benefits, and the conservation goals. The latter is specified for trophic rewilding initiatives and also indicates which TRAIL categories rewilding-inspired initiatives can target according to the anthropogenic pressure. HSC: Human-Safety Conflicts and HFC: Human-Food Conflicts

could be obtained with low levels of interventions due to the suitability of habitats (in terms of large size and low degree of fragmentation) and the assumed low human–wildlife conflicts (Fig. 4).

These differences in potential rewilding species, human–wildlife conflicts and possible mitigation tools in highly and low anthropogenic landscapes, of course, have consequences for the conservation goals and organization of the rewilding-inspired initiative. Rewilding-inspired initiatives in urban areas could strive to obtain TRAIL-category “Minimal rewilding” or “Partial rewilding”, and initiatives in rural areas could target TRAIL-category “Partial rewilding” and “Near-full rewilding” (Fig. 4). TRAIL-category “Near-full rewilding” and “Full rewilding” are thought to be well-suited for rewilding-inspired initiatives in large areas with low anthropogenic pressures (Fig. 4), but might also be obtainable in both rural and urban environments depending on the rewilding agent species, willingness to set aside reserves for fencing and attitude toward coexistence and mitigation approaches. Figure 4 also provides trophic rewilding conservation goals for rewilding-inspired initiatives framed explicitly within a trophic rewilding context (Svenning et al. 2016).

The lower the anthropogenic impact, the greater the potential to restore ecological processes and the related top-down and cascading effects and to obtain self-regulating biodiverse ecosystems under low human interventions (also see the bi-dimensional framework to measure rewilding progress Torres et al. 2018). This also entails targeting open-endedness, which according to Hughes et al. (2012) will be desirable in areas where the starting point is novel, e.g., nature areas that have been human-modified and have high restoration or management costs.

Societal benefits from rewilding-inspired initiatives could involve recreation, ecosystem services (Pettorelli et al. 2018), livelihood opportunities and ecotourism (Rewilding Europe 2016) independent of the level of anthropogenic impact. While ecotourism analogous to African safaris would be limited to wilderness areas, even novel urban or rural wilderness areas may turn out to be highly sought by tourists (e.g., Chernobyl (Barras 2016) and Knepp Safaris (Barkham 2018)).

CONCLUSION

Here, we present a framework—Trophic Rewilding Advancement in Anthropogenically Impacted Landscapes (TRAIL)—co-produced with managers and other stakeholders, providing managers with a framework to categorize rewilding initiatives and to link conventional nature management and rewilding by guiding steps toward a higher degree of self-regulation.

Applying TRAIL to two rewilding-inspired initiatives from Denmark exemplifies how TRAIL can be used in detail on a local scale. We also illustrate the use of TRAIL on a Danish-national level by categorizing all initiatives obtained in the survey of rewilding-inspired initiatives in public nature managing entities in Denmark. This exercise revealed that of the 44 ongoing and 9 planned rewilding-inspired initiatives Denmark houses no “Full rewilding” initiatives, 3 “Near-full rewilding” initiatives, 23 “Partial rewilding” initiatives, 2 “minimal rewilding” initiatives and 16 “Effort-intensive conservation management” initiatives. Applying TRAIL on a national scale might be a relevant approach for reporting National Biodiversity Strategies and Actions Plans for Contracting Parties of the United Nations Convention on Biological Diversity (CBD 2010).

We expect that the TRAIL can be used to support knowledge-sharing among rewilding managers and assist in developing initiatives to more fully implement rewilding in a flexible manner in human-dominated regions.

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