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Perspective

Challenges of ecological restoration: Lessons from forests in northern Europe

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ABSTRACT

The alarming rate of ecosystem degradation has raised the need for ecological restoration throughout different biomes and continents. North European forests may appear as one of the least vulnerable ecosystems from a global perspective, since forest cover is not rapidly decreasing and many ecosystem services remain at high level. However, extensive areas of northern forests are heavily exploited and have lost a major part of their biodiversity value. There is a strong requirement to restore these areas towards a more natural condition in order to meet the targets of the Convention on Biological Diversity. Several northern countries are now taking up this challenge by restoring forest biodiversity with increasing intensity. The ecology and biodiversity of boreal forests are relatively well understood making them a good model for restoration activities in many other forest ecosystems. Here we introduce northern forests as an ecosystem, discuss the historical and recent human impact and provide a brief status report on the ecological restoration projects and research already conducted there. Based on this discussion, we argue that before any restoration actions commence, the ecology of the target ecosystem should be established with the need for restoration carefully assessed and the outcome properly monitored. Finally, we identify the most important challenges that need to be solved in order to carry out efficient restoration with powerful and long-term positive impacts on biodiversity: coping with unpredictability, maintaining connectivity in time and space, assessment of functionality, management of conflicting interests and social restrictions and ensuring adequate funding.

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Contents

1. Introduction

Twenty years ago in Rio, the global battle against biodiversity loss made its way to the premier global political agenda. The battle has continued ever since, and the COP 10 Convention on Biological Diversity in Nagoya, Japan (CBD, 2010) resulted in a strategic plan including 20 significant new targets for conservation of biodiversity and maintenance of ecosystem services. The Convention recognizes that severe ecosystem degradation has occurred throughout all biomes (Foley et al., 2005), and in its Strategic Plan, it is stated that we need "*continuing direct action to safeguard and, where necessary, restore biodiversity and ecosystem services*" (CBD, 2010). The European Union has adopted the COP 10 Strategic plan and the Aichi targets into the EU 2020 Biodiversity strategy (Council of the European Union, 2010; European Commission, 2010). Restoration of natural habitats is emphasized as one of the main tools, and the declared target is "*halting the loss of biodiversity and the degradation of ecosystem services in the EU by 2020, and restoring them in so far as feasible, while stepping up the EU contribution to averting global biodiversity loss*".

The Society for Ecological Restoration International (SER) has defined ecological restoration as: "*the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed*" (SER, 2004). Central to this definition is "*assisting the recovery*", which implies two things: (i) the aim of ecological restoration is to return the system to some previous state and (ii) active management is the appropriate means for achieving this return. Accordingly, we use the term "*ecological restoration*" here, to refer to actions aimed at assisting the recovery of ecosystems, rather than broadening the definition to include practically any target, such as a novel ecosystem (Hobbs et al., 2009; Jackson and Hobbs, 2009). Although not necessarily aiming to restore a pristine ideal (Higgs, 1997; Clewell and Aronson, 2006), restoration should be seen as a key element in achieving conservation and natural resource management goals (Hobbs et al., 2011).

Given the dynamic state of the world, the question of what and how to restore is further challenged by uncertainties about future climate and environmental change. This complicates the choice of optimal conservation actions (Moilanen et al., 2009; Polasky et al., 2011; Strange et al., 2011) and influences intervention risk (Matthews and Turner, 2009). Thus, the ultimate long term goal of restoration should be to maintain biodiversity together with the resilience and adaptive capacity of ecosystems to environmental change. The aim should therefore be to secure the natural complexity of the whole landscape in a way that helps the ecosystems to resist degradation in the future (Jackson and Hobbs, 2009). It is clear that single restoration measures often have more local and short-term objectives, such as restoration of some lost structures in a stand. Nevertheless, these actions should be taken acknowledging the long-term landscape level targets.

Restoration ecology is a relatively young science. A search for the topics "forest AND (restoration ecology)" and "restoration ecology" in the Thomson Reuters (formerly ISI) Web of Science shows that the use of these terms has doubled since 2000, but has somewhat stabilized recently. The countries publishing most actively on forest restoration ecology include United States of America, Australia, and Brazil, while the North European countries are relatively rarely represented in the literature. This may partly be due to the different usage of terminology. In some parts of the world, forest restoration is currently equated with the traditional discipline of silviculture, with the aim of re-establishing trees required for timber, fuel, or to increase carbon stocks (Burton and Macdonald, 2011; Suding, 2011). In northern Europe, forest restoration is understood in a broader ecological context, as the aim is to reintroduce natural forest structures, species and processes that are currently scarce or completely lacking, due to human influence.

This paper is based on discussions started in a workshop organized by PRIFOR, Nordic working group on the history of primeval boreal forests. The workshop focused on the ecological effects of restoration of North European forests. Even though the experience of the researchers at the workshop was mainly from boreal and hemiboreal regions, we believe that the conclusions are general rather than specific to North European Forests, and the paper will be relevant for researchers working on different forest ecosystems. In this paper, we discuss the objectives, theory, practice and problems related to ecological restoration of forests. We focus on the North European restoration tradition, which predominantly focuses on promoting biodiversity values as an essential part of the ecosystem services that forests provide. We find the restoration of North European forests to be highly illustrative in this context for three reasons: (i) in North European forests, we have an exceptionally wide continuum of naturalness from (nearly) pristine natural forests to completely degraded lands, (ii) there is a good and solid knowledge base and understanding of these ecosystems due to a long research tradition and (iii) the experience of ecological restoration actions in the North European forests has accumulated rapidly, and we have several carefully implemented and well replicated research and monitoring schemes already in place. These can now be used to evaluate the restoration actions taken and the scientific basis on which decisions for the actions were made. Finally, we summarize the major lessons learnt from forest restoration in Northern Europe and identify some future challenges.

2. Structure, dynamics and human impact in North European forests

North European forests represent a relatively young biome that has developed mostly on the former mammoth steppe since the last glacial maximum ~21,000–18,000 years ago. The boreal species expanded their range northwards with a vegetation composition broadly resembling that of today by approximately 6000 years ago. The resulting species composition of northern forests was different from the previous interglacial periods because of changing plant community patterns at the end of the Pleistocene and the early Holocene, and the extinctions of many large herbivores, which may have had a large impact on the distribution and structure of the northern hemisphere forests (Barnosky, 2008; Bjune et al., 2009; Burney and Flannery, 2005; Mitchell, 2005).

Forest structure is affected by regional and local scale natural disturbances, such as fire, wind, snow, insects, fungi and ungulates (Korpilahti and Kuuluvainen, 2002). In the natural disturbance regime, partial and fine-scale disturbances dominate over stand-replacing ones (Kuuluvainen and Aakala, 2011), resulting in highly diverse and heterogeneous forest in terms of structure, tree species and age class distributions, both within stands and among stands in landscapes. Natural disturbance regimes are probably never in equilibrium, but fluctuate regionally according to the complex interaction between biogeophysical and macroclimatic conditions (Angelstam, 1998; Bergeron et al., 2002; Kuuluvainen, 2002).

Agriculture started to reduce forest area 3000–5000 years ago, especially on the most fertile soils at the southern margins of North European forests (Lindbladh and Bradshaw, 1998; Alenius et al., 2008; Overland and Hjelle, 2009). Historical human land use, such as slash and burn cultivation and intentional burning to improve grazing habitat, also had a dramatic effect on fire regimes, resulting in landscapes dominated by a higher frequency of fires (Granström and Niklasson, 2008; Wallenius, 2011). However, the common view that fire is a ubiquitous and frequent disturbance agent in boreal forests has been recently challenged (Ohlson et al., 2011). A steep decline in the number of fires took place in the 19th century, probably because of a reduction in human-caused ignitions (Wallenius, 2011). Today, fire plays a minor role in Fennoscandian forests due to efficient fire prevention and suppression, and expected fire return intervals are thousands of years (Niklasson and Granström, 2000; Wallenius, 2011).

With the booming post-WWII economy, forestry soon became the backbone of national economies. The current forest management systems in North European forests, based on clear-cut harvesting, are probably an order of magnitude more intensive than the traditional ways of using forests during past centuries. A shift towards management resembling plantation forestry, although using mostly native tree species, has moved the forest structures outside their historical range of variability (Cyr et al., 2009; Kuuluvainen, 2009). Current forestry is based on promoting and securing the timber flow for nationally important forest industries. For example in Fennoscandia more than 90% of the productive forests are under intensive forest management aiming at the maximization of timber volume production with little consideration, and often with the expense, of other ecosystem services (e.g. Gamfeldt et al., 2013). The current forest management system typically includes pre-commercial thinning and removal of unwanted tree species and individuals, later commercial thinning and finally clear-cutting followed by mechanical site preparation and establishment of a new stand. The rotation of each forest cycle is rather short and varies from 40 to 120 years. In addition, the development of a dense forest road network has been associated with increased fragmentation of forests (Angelstam et al., 2004a).

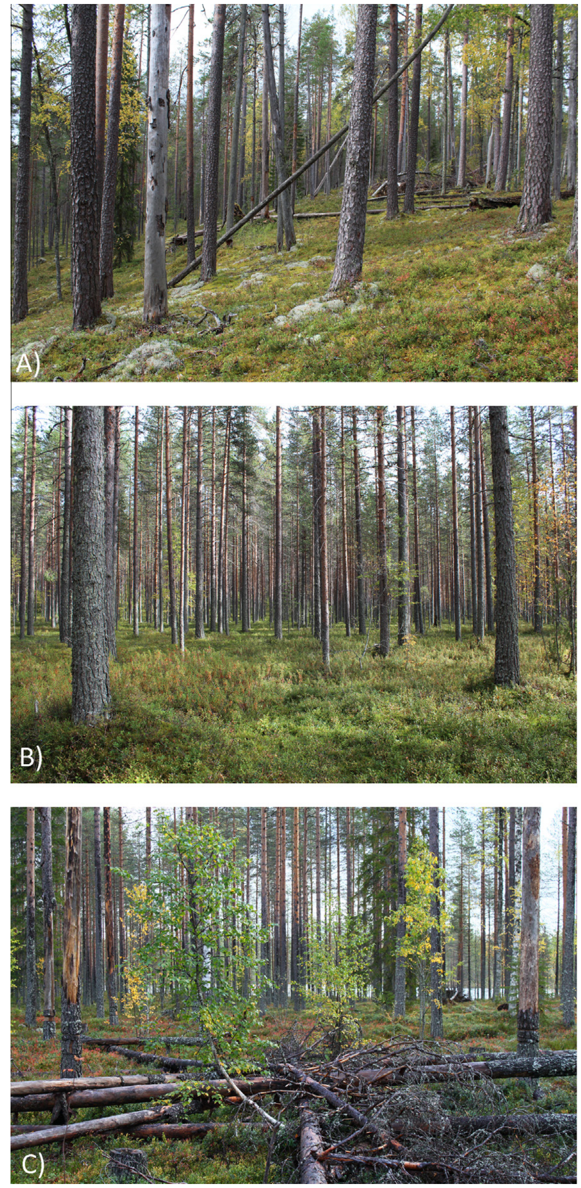

Fig. 1. (A) A natural pine-dominated boreal forest with several tree age classes, a lot of standing and fallen dead wood and natural ground layer vegetation. (B) A managed pine-dominated forest with only one tree age cohort, absence of dead wood and altered ground floor vegetation. (C) A formerly managed pine-dominated forest where restoration treatments (dead wood addition) have been conducted after the stand was incorporated into a national park. The aims of the treatments have been to (i) increase resources for wood-inhabiting species (ii) add canopy gaps and (iii) assist the recovery of light-demanding species. Figures © Maarit Similä.

Table 1
Differences in the species assemblages, forest structures and processes between natural and commercially managed forests, and examples of measures to restore the related natural or near-natural features in forest habitats (modified from Similä and Junninen, 2012 where practical examples can be found). The table applies best to boreal forests in Fennoscandian conditions.

Natural forests	Commercially managed forests	Restoration methods
Species		
Species		
Species adapted to natural forest habitats and disturbance regimes	Dominance of generalist species	Creation of natural habitats and substrates by prescribed burning and creation of deadwood
Species with specialized habitat requirements	Many native deadwood-dependent species absent	Reintroduction of species into restored areas
Diverse species assemblages living on deadwood		
Species that require long-lasting habitats and substrates		
Fire-dependent species in burnt areas		
Structures		
Living trees		
Diverse tree species assemblages	Uniform stands dominated by a single tree species (mostly pine or spruce)	Variable density thinning
Trees of various ages, incl. damaged, large and old trees	Trees mainly of similar age and evenly or randomly spaced	Controlled burning
Spatial pattern of trees highly varied, resulting in variable canopy cover		Creation of canopy gaps
		Protection of deciduous tree seedlings
Dead trees		
Plenty of deadwood especially in early and late stages of forest succession	Paucity of deadwood	Controlled burning
High variability of deadwood quality in terms of tree species, diameter and degree of decay	Dead trees only of limited diameter, with poor continuity	Creation of deadwood
Stumps and snags of different heights	Even stumps may be harvested for energy wood	Variable density thinning (Creation of canopy gaps)
Soil		
Heterogeneous soil structure due to disturbances such as fire and windthrows	Soil scarified uniformly to promote tree regeneration, decayed logs mostly destroyed in this process	Controlled burning, creation of deadwood
Varied degree of upheaval due to disturbances of varying intensity	Paucity of dead wood or areas of exposed mineral soil	Trees felled with their root systems uprooted
Decaying trunks form an important substrate for tree regeneration		
Hydrology		
Natural stream dynamics, springs, groundwater seepage areas and moist hollows	Springs, groundwater seepage areas and moist hollows often drained; streams cleared to speed drainage	Restoration of natural hydrological conditions, e.g. by filling in ditches and restoring natural stream courses and water flow dynamics
Structure of the forest landscape		
Late-successional forests with variable canopy cover dominate landscapes	Landscape composed of mosaic of even aged stands of different age, with high proportions of young stands	Spatial landscape-level planning of restoration
Forest stands merge into each other with fuzzy boundaries	Clear man-made artificial boundaries between managed stands with trees of different species and ages	Emulation of natural disturbances and their spatial pattern at the landscape-scale
Heterogeneous landscape structure shaped by multi-scale disturbance dynamics	Specific habitat types, e.g. habitats for species dependent on decaying wood, often fragmented and isolated	
Continuity in the availability of deadwood of all kinds		
Processes		
Nutrients and carbon storage		
High amounts of nutrients and carbon are stored in living wood, dead wood and the soil	Thinning, site preparation and the harvesting of energy wood speed up the nutrient cycle and reduce the amount of carbon stored in trees and the soil The use of fertilizers increases eutrophication	The impacts of habitat restoration on the nutrient store and dynamics of forest soils, and the carbon cycle are not yet well understood
Disturbance dynamics		
Partial and fine-scale disturbances dominate	Regular and predictable disturbances at the stand-scale dictated by the 'command and control' management regime	Emulation of natural disturbances needed to restore and maintain natural structure and dynamics
Major disturbances such as high-severity forest fires and storms occur but infrequently	Natural disturbances eliminated	Measures include controlled burning, variable density thinning and creation of dead wood and canopy gaps

3. What has been lost?

Overall, human exploitation in the distant and recent past has led to substantial changes in forest dynamics, structure, age distribution and species composition (Fig. 1, Wallenius et al., 2010). The disturbance regimes have markedly deviated from historical conditions. Old-growth forests and natural early-successional forests have virtually disappeared from the landscape, and forest structural complexity has dramatically declined resulting in habitat loss and degradation from the perspective of thousands of forest species (Siitonen, 2001; Brūmelis et al., 2011). In Table 1 we list the structures and functions that existed in forests under natural disturbance regimes but have been lost. These changes are interconnected between different levels (processes, structures and species). For example the reduction of natural disturbances in managed forests has resulted in a scarcity of dead wood, reduced species richness and local population sizes of wood-inhabiting fungi (Junninen and Komonen, 2011; Stokland and Larsson, 2011).

Considering the long history of human use of the landscape, there are almost no truly natural areas remaining in Fennoscandian forests, and we need to view forests as existing in different stages of naturalness (Peterken, 1996; Brūmelis et al., 2011). The forests hold a complete gradient of habitat and landscape alteration, from large, almost intact benchmark areas and slightly modified forests to totally degraded forests in need of restoration (see Angelstam, 1998). This variation in human impact has resulted from the gradual spread of forest exploitation towards more remote areas. With a few exceptions, where large scale forest clearings have taken place, North European forests still consist of functional, yet often taxonomically-deprived ecosystems. Therefore, the ultimate motivation for restoration in North European forests focuses on the improvement and maintenance of biodiversity in forests, the species and their habitats and not restoring forest productivity.

4. Restoration in North European forests

A multitude of restoration practices are currently being used in the North European forests (Table 1 and Fig. 1). In Northern Europe, Finland leads the field, using a wide spectrum of restoration methods, listed in Table 1 (see Similä and Junninen, 2012), but other countries are launching similar actions. Several measures aim at restoring the function of forest ecosystems or the structure of the forested habitat. There is often a need to restore the hydrology of altered habitats (e.g. by blocking ditches in drained swamp areas) to facilitate natural processes such as peat and dead wood accumulation. Forest structure can be modified, e.g., by creating small gaps in conifer monocultures to enable regeneration of deciduous trees (Komonen and Kouki, 2008), or by adding dead wood (Olsson et al., 2011). Besides hosting high biodiversity, the latter is an important structural and functional element in forests (Stokland et al., 2012). Reforestation of roads, tracks and compartment lines is also used to restore large, continuous forest areas.

The lack of fires due to active fire suppression has also led to the intentional use of fire as a restoration tool, especially in Sweden and Finland (Olsson and Jonsson, 2010; Similä and Junninen, 2012). Re-introducing fire affects forest dynamics, structures and species (Vanha-Majamaa et al., 2007). High intensity fire can be applied as a stand-replacing disturbance creating conditions that allow for complete re-establishment of the forest stand, including successful establishment of deciduous pioneer tree species, like e.g. birch and aspen. Lower intensity fires create a wide spectrum of structures increasing a stand's heterogeneity in terms of tree mortality, species composition and age structure, and thus essential for forest diversity on different levels (Granström, 2001). Restoration burning is performed under strict control by fire protection authorities. It is remarkably expensive and as a result, the burnt areas in current restoration practice are a tiny fraction of the annually burnt areas in the previous centuries.

5. What can and cannot be restored?

Understanding how current forests differ from the forests under natural disturbance dynamics in terms of structure and function provides the basis for restoration activities (Kuuluvainen, 2009). It is also crucial to realize which structures and functions of the natural ecosystems that are feasible to restore, and which are beyond our capacity to restore for climatic, ecological, social or economic reasons (Hobbs et al., 2006). As some are easier to restore than others, we must be realistic about what we can and what we cannot do. For example, at a forest stand level it is fairly straightforward, even if expensive, to use prescribed burning to restore post-fire structures (e.g. burned living and dead trees) and processes (e.g. succession), but it may be unfeasible to restore the natural variability of fire regime at the landscape scale (Niklasson and Granström, 2000; Table 1).

If we set the goals of restoration at species level, we need detailed understanding of a species habitat and microhabitat requirements and of dispersal potential to facilitate successful colonization of the restored habitats. For example, the minimum amount of particular habitat or resource required for viable populations is likely to vary among landscapes, habitats and species (Müller and Bütler, 2010). On the other hand, providing adequate resources may be ineffective if species are absent from the landscape for historical reasons (Ikauniece et al., 2012) or if they are unable to recolonize due to limited habitat connectivity (Verheyen and Hermy, 2001). In such cases it would be more effective to concentrate restoration efforts in the vicinity of existing high-quality habitats (Kouki et al., 2012). It is worth adding, that while the aim of restoration is to reintroduce dynamic habitats, single species are often specialized to a particular stage of forest succession or wood decay. Restoration actions should therefore be planned in a way that maintains habitat continuity in time and space, enabling species to disperse to new patches of suitable habitat.

Finally, even though some habitats and structures within northern forests could be relatively easily restored (Table 1), this is not always possible due to some unwanted side effects of the restoration measures. Restoration can affect many ecosystem processes in a way that is in conflict with other environmental policies: for example, carbon storage in forests may be reduced, soil erosion may accelerate and pests may become more abundant (reviewed by Bullock et al., 2011). Such side effects may imply additional restrictions to any restoration program. A carefully chosen balance between the aimed biodiversity benefits and the unwanted side-effects is likely to be highly context-specific, where local and national rules and regulations and public opinion provide inputs (Angelstam et al., 2004b). Clearly, any restoration program requires also consideration of aspects other than ecological ones.

At present, it is difficult to evaluate if the recent restoration measures which have been carried out in North European forests have truly increased, or will increase, biodiversity values in a meaningful way. Data are available mostly on the short-term effects of restoration due to the relatively short history of restoration actions and restoration research in northern forests. Recent research has particularly focused on evaluating the immediate effects of fire, which has been shown, for example, to increase substantially the number of rare and red-listed beetle species (Hyvärinen et al., 2006; Toivanen and Kotiaho, 2007) and to modify fungal assemblages (Junninen et al., 2008; Berglund et al., 2011). While these short-term studies do not allow us to determine whether or not ecosystem function and forest dynamics have been successfully restored, there is evidence that the effects of fire need to be considered in a landscape context, particularly the presence of source habitat in the surrounding landscape (Kouki et al., 2012). Additionally, the effects of fire may prove to be short-lived in certain habitats and species groups (Toivanen and Kotiaho, 2010).

6. Lessons learned

6.1. Lesson 1: acquire better ecological knowledge of the target ecosystem

A need for novel approaches to forest restoration and ecologically sustainable management has been driven by recent advances in ecological theory and better understanding of the dynamics of unmanaged forest ecosystems (Bergeron et al., 2002; Kuuluvainen, 2002, 2009; Puettmann et al., 2009; Kneeshaw et al., 2011). In particular, since the 1970s, there has been a growing recognition of the importance and ubiquity of natural disturbance in forest ecosystems, first in tropical and temperate forests and later in boreal forests (Pickett and White, 1985; Clark, 1989; Attiwill, 1994; Kuuluvainen, 1994; Kneeshaw et al., 2011). Shortly thereafter, the concept of mimicking natural disturbance as an approach in restoration and ecologically sustainable forest management started to appear rather rapidly in the research literature (Attiwill, 1994; Angelstam, 1998; Bergeron et al., 2002; Perera et al., 2004). This knowledge is now inbuilt into many practical restoration projects in Northern Europe (Similä and Junninen, 2012).

Based on our experience, natural forest dynamics and disturbance regime can serve as guidelines for restoration actions (Kuuluvainen, 2009). Those are highly specific for each region and, therefore, the specific knowledge cannot be usually transferred to other regions. Experiences from one system must be generalized to other ecosystems with caution. For example, fire as a restoration tool can be successfully used in northern forests but it need not to be suitable elsewhere (e.g. in tropical forests) where it is not part of the natural disturbance regime. Understanding of the disturbance regimes, prevalence and spatial distribution of the different stand dynamics is needed (even in northern Europe; Shorohova et al., 2011) and research is thus still required on the long-term disturbance dynamics of natural landscapes.

6.2. Lesson 2: be aware of the problems in defining naturalness

While it is crucial to have proper ecological knowledge of the ecosystems we wish to restore, we should be aware of problems related to naturalness, as well as reference and target ecosystems. The aim of restoration is often to add components (species, structures or dynamics) that are considered natural to the target ecosystem. However, the range of reference conditions used is usually derived from analyses of historical forests that may themselves have been altered by past human influence because humans have been altering forests and their disturbance regimes for thousands of years. Therefore we can hardly know the precise structure of natural ecosystems or even the structure of the past (reference) ecosystems, nor can we predict with accuracy the dynamics of an ecosystem at a particular site following restoration actions. Different historical periods give different reference points with varying degrees of human impact, further increasing the uncertainty in choice of restoration targets (Hobbs et al., 2011).

Knowledge of vegetation patterns in the past demonstrates the constant dynamics of boreal ecosystems. For instance, the increasing dominance of *Picea* spp. in much of Canada and Scandinavia is a relatively recent development which overlaps with the period of increased human impact. During the last millennium, the rates of community change within boreal forests have been faster than at any time since the last ice age (Bjune et al., 2009). Changing climate also sets new, partly unpredictable challenges to restoration. Climate models strongly suggest that North European forests are now experiencing rapidly changing conditions and may soon develop novel species combinations (Sykes, 2009) and fire regimes (Flannigan et al., 2009), even without management intervention. Realizing that biomes and ecosystems are constantly changing in composition and spatial distribution, the ultimate long-term goal for restoration must be to maintain the resilience of ecosystems to environmental change. Even though the ultimate target involves the distant future, in practice the restoration measures must usually be targeted towards some present-day reference ecosystem, which can be seen as a short-term restoration target (Ruiz-Jaen and Aide, 2005; Fritschle, 2011).

6.3. Lesson 3: assess whether restoration is needed and can be successful with feasible resources

To assess whether, when and where to act, is a difficult task. To successfully predict the success and feasibility of the restoration action, one should consider the present state of the ecosystem (Wilson et al., 2011), the quality of the surrounding landscape (Kouki et al., 2012), and the potential of the ecosystem to recover (or degrade even further) without restoration. The last point is important because examples of rapid recovery of forest biodiversity without human intervention are globally numerous (Jones and Schmitz, 2009; Holl and Aide, 2011). One such example is Latvian deciduous forests which were left for natural succession after the harvesting of Norway spruce stands between 1920 and 1940 (Tērauds et al., 2011). Today, these semi-mature mixed forests already host relatively high biodiversity compared to the nearby spruce forest (Madžule et al., 2012).

It is clear that in some degraded ecosystems, restoration is not a cost-efficient method to improve the biodiversity qualities (Wilson et al., 2011). This may be the case even if restoration has been deemed as necessary. The cost-efficiency of restoration can be investigated by estimating the difference in biodiversity outcomes between active restoration and passive set aside with neglect while assessing the monetary cost of the marginal biodiversity gain as the sum of the cost of the restoration action and the possible opportunity costs.

Naturally, the outcome of the restoration necessity and feasibility assessment is dependent on the motivation for the restoration action. Globally it seems that the most important motivation for ecological restoration is to restore the degraded ecosystem services, with the aim to secure a well-functioning ecosystem from an anthropocentric point of view (Aerts and Honnay, 2011; Suding, 2011). This may mean restoring freshwater services, agroforestry potential, hunting possibilities or increasing carbon stock in sites where these ecosystem services have been degraded. In a North European context however, the key question is how the available restoration measures can halt the ongoing biodiversity loss caused by human activities.

6.4. Lesson 4: set proper targets and monitor progress

Setting a target for ecological restoration action is essential for verifying the success of the action. Contemporary 'near natural' references may no longer resemble pristine ecosystems, partly because they have naturally evolved, and partly because all forests have experienced some form of human influence (Frelich et al., 2005). However, to assess whether the restored ecosystems are recovering, we should look for reference areas that are as natural as possible, and include these areas in the monitoring schemes. Monitoring reference sites is of particular importance because they are not static but subject to natural dynamics, and also because they may alter in response to global climate change. Thus restoration is likely to have a moving target.

A variety of methods to monitor and evaluate the success of restoration actions have been proposed (Ruiz-Jaen and Aide, 2005). However, we have to consider carefully whether the monitoring really is able to provide the answers we are looking for, i.e. how well it is linked with the restoration objectives. Research on biodiversity monitoring has shown that many monitoring programs have been of questionable value or even complete failures (Field et al., 2007). Furthermore, the potential rate of ecosystem recovery needs to be considered so that appropriate targets are set for restoration and the monitoring program. It must be considered that long-term monitoring is difficult to finance. Thus, without long-term financial plan, setting up a large scale complicated monitoring scheme is risky and may result in wasting resources and lowering the chances of detecting the potential effects of restoration.

Monitoring results from the restored ecosystems and increasing knowledge of the dynamics of the reference ecosystems should also be closely integrated with ongoing restoration action. We should be able to revise our restoration and utilize adaptive management methods (Angelstam et al., 2004c) according to the latest knowledge. Optimally, monitoring should always involve both scientists and practitioners to ensure that the results are both scientifically solid and useful as a guide for future actions (Villard and Jonsson, 2009).

6.5. Lesson 5: if you still have it – do not destroy it

It is evident that conserving existing diversity and ecosystem services is economically more viable than trying to restore them. Therefore, despite the apparently high opportunity costs, setting aside areas with high biodiversity values where we still have them, may in the long term turn out to be a better option both ecologically and economically.

7. Future challenges

7.1. Challenge 1: coping with unpredictability

Predicting ecosystem response to restoration is a complicated task (Burton and Macdonald, 2011). One main reason is system complexity and incomplete knowledge about causal relationships across all of the natural biological hierarchical levels (Kuuluvainen, 2009). The task is further complicated as the restored areas are usually relatively small due to social, economic and practical restrictions, and thus vulnerable, for example, to unpredictable catastrophic events. Finally, even if we had full understanding of the natural processes to be restored, future climate change may make our understanding outdated and we may see the ecosystem developing in an unpredictable way to an unintended or unwanted direction (Strange et al., 2011).

7.2. Challenge 2: maintaining connectivity in time and space

Restoration projects deal with spatially and temporally dynamic ecosystems and habitats. After any restoration action, habitats and associated species assemblages will continuously change due to succession, disturbance, and other factors. Thus, to maintain viable habitat networks and species populations in a long-term, it is critical to consider the spatial and temporal aggregation of different restoration measures within the landscapes (Wilson et al., 2011). There is, however, a potential contradiction between increasing the diversity of habitats within a landscape and enhancing connectivity between patches of a given habitat type. One solution could be to define critical habitat types and focus on increasing specifically their connectivity.

7.3. Challenge 3: assessing functionality

It may take hundreds of years until the goal of self-sustaining processes of natural forest ecosystems is reached (Kazimirov, 1971, c.f. Shorohova et al., 2009). A critical question related to this ultimate goal is how to actually define a naturally functioning ecosystem and how to measure and monitor whether the function of the ecosystem is developing towards the desired state. Most of the current studies measuring the success of conducted restoration actions focus on very basic measures, such as plant species diversity (Ruiz-Jaen and Aide, 2005). Based merely on such variables, it could prove difficult to estimate whether the ecosystem has changed towards a resilient state. More comprehensive monitoring methods supplementing species with structures and processes (Table 1) should thus be developed and utilized, including, for instance, measuring future tree population structure or dead wood profiles based on knowledge of natural regeneration, tree mortality and wood decomposition data.

7.4. Challenge 4: conflicting interests

Fighting climate change may be in short-term conflict with the aims of other restoration actions, such as prescribed fires. European environmental policies are not only directed towards halting the decline of forest biodiversity but also towards increasing CO_2 storage in the forest. The perception of forests as a tool for carbon fixation may easily be used to justify extensive forest management that aims to maximize forest growth but ignores biodiversity values. To mitigate climate change effects, there is also increasing pressure towards more intensive use of wood-based energy and the extraction of dead wood material from clear-cut areas and harvested forests. This leads to a situation where restorative measures are carried out to increase the availability of dead wood in the landscape, while other actions, considered important for meeting other environmental objectives, dramatically reduce the availability of dead wood (Eräjää et al., 2010). This can lead to decreasing biodiversity which potentially requires even more restoration actions to compensate the loss of habitat (Rabinowitsch-Jokinen et al., 2012; Toivanen et al., 2012). The rationale, cost-efficiency and biodiversity effects of such potentially conflicting actions should be evaluated at a larger scale to avoid the most irrational treatments.

7.5. Challenge 5: social restrictions

The fine-scale targets of ecological restoration are normally biologically determined. However, the means to reach even local targets may be socially restricted. For example, it may be impossible to choose the optimal sites for restoration due to unwillingness of the land owners (Knight et al., 2011). Furthermore, it may prove problematic to find areas large enough to host and maintain restoration objectives, especially in densely populated areas characterized by highly fragmented forests and diversified forest ownership. High human population densities can cause potential social conflicts and discussions around some restoration techniques, but even in sparsely populated areas, conflicts over resource and land use can prevent restoration measures, especially at the landscape scale. There is also a need for education to change public perception of natural catastrophic events and processes. On the other hand there is also a need to provide local people and owners with employment and other resources, if they were previously dependent on commercially exploited forests. New methods are constantly developed to accommodate the challenge of integration of societal needs and conservation targets (e.g. Wilson et al., 2010).

7.6. Challenge 6: funding

Funding for restoration action and monitoring of its effects is often granted for short periods, and granting is more politically than scientifically motivated. However, long term funding is necessary to ensure the continuity of actions and monitoring of their effects. Without sufficient funding, the success of our efforts will be difficult to assess, or have the option to revise actions if necessary (Villard and Jonsson, 2009). At some sites, the lack of funding may be compensated by combining restoration actions with partial felling. If selling wood from restoration sites becomes a common practice, however, there is a risk that public funding is replaced by requirements that restoration has to cover its own costs.

8. Conclusions

Habitat loss and degradation are the main reasons for current biodiversity loss. Recent experience and research on ecological restoration in boreal forests shows the potential of restoration in halting biodiversity loss. However, in the light of the presented lessons and challenges, it seems that in order to make restoration efforts globally successful, at least the following issues have to be considered: (1) Integrating ecological knowledge and restoration targets into fully working implementation plans requires increased cooperation between researchers and planners; (2) Planning across administrative and ownership borders needs to be implemented, to achieve targets of improved connectivity and more natural disturbance dynamics at the landscape level; (3) Long-term funding for monitoring should be secured, so that ecological effectiveness can be secured and constantly evaluated, and (4) Societal problems in the use and restoration of forests should be addressed by integrating all stakeholders as a part of the planning process.

There are global initiatives underway, designed to restore huge areas of forest land (IUCN, 2012). Our experience from the boreal forests in northern Europe provides insights into the ecological knowledge required for successful restoration. The main message we have, is that forest restoration is much more than restoring tree cover, although this is obviously the priority and the first step in completely deforested areas. In order to achieve the long-term goal of functioning forest ecosystems, including their essential structures, successful restoration of the natural dynamics and disturbance of those forests is required with landscape management securing these dynamics.

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