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SPECIAL FEATURE: ECOLOGICAL RESTORATION

Optimization of intervention levels in ecological restoration

Lawrence R. Walker, Norbert Hölzel, Robert Marrs, Roger del Moral & Karel Prach
SPECIAL FEATURE EDITORS

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Walker, L.R. (corresponding author, walker@unlv.nevada.edu): School of Life Sciences, University of Nevada Las Vegas, Las Vegas, NV, 89154-4004, US
Hölzel, N. (nhoezel@uni-muenster-de): Institute of Landscape Ecology, University of Münster, Heisenbergstr. 2, 48149, Münster, Germany
Marrs, R. (calluna@liverpool.ac.uk): Department of Ecology, University of Liverpool, L69 3BX, Liverpool, UK
del Moral, R. (moral@uw.edu): Biology Department, University of Washington, Seattle, WA 98195-1800, USA
Prach, K. (prach@prf.juc.cz): Faculty of Science USB, Branišovská 31, CZ-370 05, České Budějovice, Czech Republic & Institute of Botany, AS CR, Dukelská 135, CZ-37982, Třeboň, Czech Republic

Abstract

Question: Are optimal intervention levels in ecological restoration linked to disturbance severity or spatial and temporal scales of restoration activities in the studies included in this special feature?

Methods: Comparison of ten studies of restoration in the context of disturbance severity, regional biodiversity, and predictability of succession trajectories.

Results: The ten studies largely represent restoration of grasslands in Europe but also include restoration following disturbances by mining, invasive species, and trampling by tourists. Maximal intervention levels were used in studies with high or low disturbance severity, low regional biodiversity, and high predictability of successional trajectories. The spatial and temporal scales of restoration activities had little effect on intervention levels.

Conclusions: General guidelines on how to optimize intervention levels in restoration activities can be sought by comparing success rates across gradients of disturbance severity.

Introduction

The eighth biannual conference of the European branch of the Society for Ecological Restoration (Vegetation Dynamics in Ecological Restoration) was held in České Budějovice (Budweis), Czech Republic, from 9 to 14 September 2013. The theme of the conference was 'near-natural restoration', which puts the emphasis on restoration procedures that exploit natural processes. These procedures can include little or no manipulation (e.g. spontaneous succession), and focus on reaching desirable stages of succession that resemble natural communities. Ecological restoration involves the manipulation of succession. Therefore, restoration attempts to accelerate or slow the rate of successional change; reverse or divert the trajectory of succession; or simulate the stages of succession. Although succession is clearly a key topic in contemporary restoration ecology (Walker et al. 2007; Prach & Hobbs 2008), questions remain concerning the optimal degree of intervention (Walker 2011) and links to successional theory (Hölzel et al. 2012). In this introduction to the Special Feature of *Applied Vegetation Science*, we explore if the degree of intervention in ten studies presented at the conference is related either to the level of disturbance severity that triggered the restoration activity or to the spatial and temporal scales of each study.

Intervention level

We suggest that the optimal degree of intervention in ecological restoration varies depending on the site conditions created by the disturbance and on the scales at which restoration is attempted. The type and timing of intervention remains largely a site-specific process, but the choice of how and when to intervene is a major concern regardless of the kind of restoration. Broadly applicable guidelines would be very useful to practitioners. When terrestrial habitats are only mildly disturbed, for example, restoration can focus on the manipulation of species interactions, because initial steps, including physical amelioration and soil development, are unnecessary. Even where disturbances are severe (e.g. mine tailings), extensive site manipulation can often be avoided if there is an ample supply of propagules that are able to establish (Prach et al. 2007).

One measure of the degree of intervention in ecological restoration is the level of activity needed to achieve a desired diversity of species or ecological function. We propose that maximal intervention would be expected to be most appropriate under conditions of lowest regional biodiversity, which usually coincides with extremes of disturbance severity and maximal predictability of successional transitions (Fig. 1; Walker & del Moral 2009a). For example, heavily damaged sites may allow only a few colonists without some site amelioration, whereas sites with little damage may require removal of undesirable, dominant species. Maximal intervention also may be appropriate at both low and high productivity (Prach et al. 2007; Prach & Hobbs 2008). Low productivity sites will require intensive site amelioration, while high productivity sites will require the reduction of competition. Minimal intervention may be appropriate when successional trajectories cannot be predicted and at high levels of diversity and/or productivity. This approach, termed spontaneous succession, is a viable alternative that relies on natural processes rather than on technical manipulation, although a substantial propagule pool in the surrounding region is essential. Although recognized as relevant to mining (Řehounková et al. 2011) and agricultural (Csecserits et al. 2011) sites in Central Europe, the broader applications of spontaneous succession have not been analysed in detail (but see Prach & Hobbs 2008). However, disturbance severity is often not a good predictor of biodiversity (Hughes et al. 2007), productivity (Geider et al. 2001) or successional trajectories (Walker et al. 2010), so each restoration project must first evaluate site conditions. Furthermore, the severity of an initial disturbance is influenced over time by many other variables (e.g. repeated disturbances, changes in abiotic and biotic site conditions), and is never the sole determinant of biodiversity or predictor of how much to intervene. Nevertheless, we examine common relationships among disturbance, biodiversity and predictability of succession as represented by the papers in this Special Feature.

Restoration goals ideally specify a desirable and feasible level of maintenance effort by humans, varying from intensive to little effort after the completion of direct manipulations. On-going intervention may be inversely proportional to initial effort, but this relationship depends on restoration activities achieving a relatively stable ecosystem or a predictable series of successional changes. Successional trajectories are often most predictable when they have low biodiversity and high or low disturbance severity (Fig. 1), high or low disturbance frequencies, and fast or slow species turnover (Prach et al. 2001; Walker & del Moral 2009a; Walker et al. 2010) and are least predictable at intermediate levels of these factors.

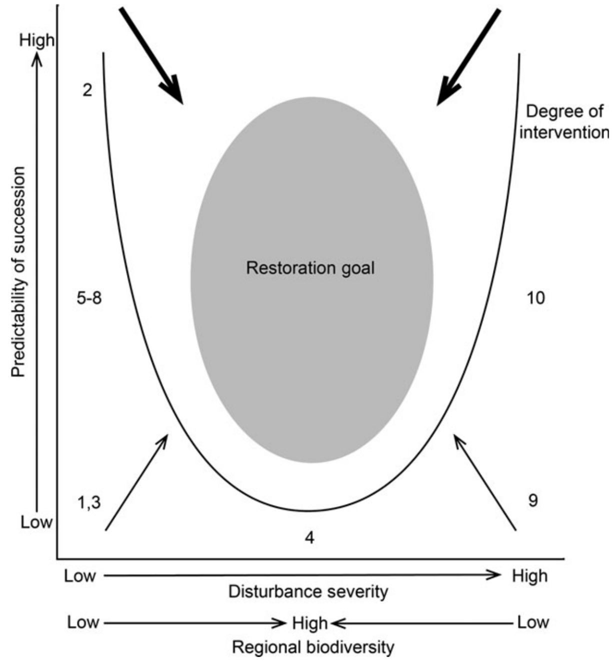

Fig. 1. Hypothesized relationships between disturbance severity, or levels of biodiversity, and predictability of successional trajectories on the optimal degree of intervention during ecological restoration. Arrows represent restoration actions (thickness indicates projected relative efficacy). Spontaneous succession can be most successful at intermediate levels of disturbance severity, high regional biodiversity and low predictability of successional trajectories. Numbers of studies (see Table 1) indicate their disturbance severity and intervention levels.

Disturbance severity

Both natural and anthropogenic disturbances can be characterized through their severity or through the amount of damage they cause. Damage can be measured as a loss of biomass, structure or function (Pickett & White 1985). Primary succession is the process of ecosystem development following disturbances that leave little biological legacy (propagules, organic matter or nutrients). Secondary succession occurs when substantial legacy remains following a disturbance. Restoration goals and tactics must vary with

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the degree of severity (Walker 2011). They focus on ameliorating abiotic stress, promoting or replacing dispersal, altering site fertility, enhancing biodiversity, improving resistance and resilience to future disturbances and promoting species interactions that improve predictability of successional trajectories (Walker & del Moral 2009b). The degree of effort expended toward each of these goals varies depending on need, likelihood of influence and resources available (money, people or time). Yet no large-scale, systematic evaluation of optimal effort has been attempted, in part due to heterogeneity among restoration activities. Conducting such an analysis across disturbance severity gradients would be useful.

Spatial and temporal scales

Restoration activities are generally conducted locally and at annual to decadal time scales. Yet ecological processes like succession span a much broader array of scales (Fig. 2). At larger scales (regions and centuries), the effects of restoration activities remain untested. Meta-analyses of success rates of many restoration activities can begin to answer such questions (Rey Benayas et al. 2009), but have not been analysed for their success by the level of intervention. Plentiful data exist, however, on restoration efforts required on projects at a range of scales that could be evaluated (Kiehl et al. 2010; Török et al. 2011). There are likely to be trade-offs, however, between the minimal effort traditionally expended per unit area for manipulations (e.g. sowing grasses) and the greater effort often needed to establish natural processes (e.g. dispersal or successional transitions), particularly across large scales.

Emergent themes

The papers in this Special Feature address primarily the restoration of grassland habitats in Europe (typically following cessation of agriculture), but also include restoration following disturbances by mining, invasive species and trampling by tourists (Table 1). Disturbance severity is generally (but not always) low, and spatial and temporal scales are approximately within the scales found in Fig. 2, although sometimes extended temporally through the use of a chronosequence approach (involving a space-for-time substitution). The degree of intervention is typically low to moderate, or absent when spontaneous succession is sufficient. Despite this relatively homogeneous sample of disturbance types, there is a range of disturbance severity and spatial and temporal scales to provide a useful comparison of intervention levels.

The simplest approach is monitoring spontaneous succession, with no intervention. Spontaneous succession, initially used in primary seres such as mine tailings (Prach 1987), has been demonstrated as a tool for grassland

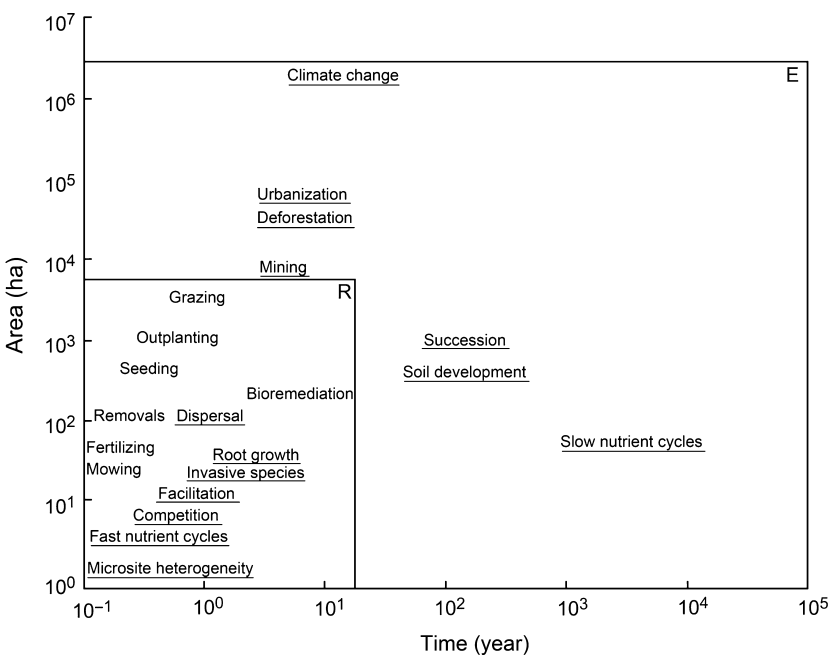

Fig. 2. Contrasting spatial scales (in ha) and temporal scales (in years) for ecological processes (box E; underlined) and restoration activities (box R; not underlined). Boxes indicate maximum scales for the two types of process. Processes are located approximately in the centre of the range of scales at which they are important. Note the log scales and how restoration processes are limited to smaller spatial and shorter temporal scales compared to the broader range of scales at which ecological processes occur.

Table 1. Characteristics of the studies in this Special Feature. Plot = sampling unit; Study area = sum of plot area; NA = not applicable.

No.	Authors	Habitat, location	Disturbance type	Disturbance severity*	Scales: plot size (m^2); study area (ha); time (yr)	Experimental treatment or observation	Degree of intervention†
1	Albert et al.	Grassland, Hungary	Agriculture	Low	4; 0.04; 40	Observation	None
2	Alday & Marrs	Heath, Great Britain	Non-native invasive fern	Low	1; 0.24; 10	Removals	High (repeated removals)
3	Bartha et al.	Grassland, Hungary	Invasive native grass	Low	4; 0.07; 69	Observation	None to low
4	Gallet & Sawtschuk	Grassland & heath, France	Trampling by tourists	Moderate	NA; 18; 27	Fencing, grazing, mowing	Low
5	Jaunatre et al.	Grassland, France	Rangeland	Low	100; 357; 3	Soil and seed additions	Moderate
6	Metsoja et al.	Grassland, Estonia	Agriculture	Low	1; 0.007; 50	Ploughing, soil transfers	Moderate
7	Mudrák et al.	Grassland, Czech Republic	Agriculture	Low	0.25–100; 100; 2.5	Seed additions; litter removal, mowing	Moderate
8	Muller et al.	Grassland, France	Agriculture	Low	50; 0.05; 2	Soil removals, seed additions	Moderate
9	Prach et al.	Various, Czech Republic	Various new substrates	High	16–25; 5; 100	Observation	None
10	Tischew et al.	Grassland, Germany	Mining	High	25–100; 1,575+; 40	Observation	Moderate

*Examples of high severity: soil removal, nearly complete community disruption; moderate: removal of some vegetation and soil or species invasion that significantly alters biodiversity; low: species invasion with little effect on biodiversity.
†Examples of high levels of intervention: site reclamation, multiple species removals and additions (de novo community assembly); moderate levels: single species manipulations, soil and seed additions or removals; low levels: fertilization, weeding, mowing; none: spontaneous succession.

recovery following abandonment of croplands in Hungary, where crop duration was short, propagules were proximate and abundant and the risk from non-native invasive species was low (Albert et al. 2014; Bartha et al. 2014). Prach et al. (2014) extend the range of habitats where spontaneous succession achieves restoration goals (e.g. rapid, continuous cover; initiation of successional processes) beyond mine wastes and abandoned agriculture to include other anthropogenic habitats such as urban lots, sand pits, road edges, forest clearings, emergence of previously flooded surfaces and mined peat lands. They found broadly similar patterns of vegetation development (e.g. woodland establishment within 20 yr) and species composition across this variety of habitats, arguing that spontaneous processes were more desirable, and certainly less costly or intrusive, than traditional intervention. These three contributions broaden the applicability of spontaneous succession to a wide range of disturbance severity, but still limit its usefulness to areas of high regional biodiversity, low risk of invasions by undesirable species and abundant seed rain. In these studies, disturbance severity ranged from low (Albert et al. 2014; Bartha et al. 2014) to mostly high (Prach et al. 2014), suggesting little direct connection between disturbance severity and intervention level. In addition, studies of spontaneous succession often employ a chronosequence approach that allows them to consider relatively long time scales (40–100 yr), while the spatial scale of their study areas varied from 0.04 to 5.00 ha, suggesting little effect of either temporal or spatial scales on their conclusions.

A low level of intervention occurs through modest alterations of a site, such as mowing, weeding or fertilizing without substantial alteration of species composition. For example, Gallet & Sawtschuk (2014) found that restrictions on trampling by tourists, combined with some grazing and mowing of trampled areas in France, led to desirable decreases in bare soil and the establishment of grassland and heathland vegetation. Management treatments, species interactions and local conditions all influenced successional trajectories.

Three studies in this Special Feature examine moderate intervention strategies involving soil transfers. Jaunatre et al. (2014) found that following abandonment of French rangelands, topsoil removal and replacement with more desirable soils and seed banks (hay transfer) was most useful in reducing soil nutrients and preventing growth of weeds. Topsoil removal (particularly from the top 5 cm) and hay transfer also improved restoration of former rice fields in France (Muller et al. 2014), but grazing was also suggested as a supplementary treatment. Although they did not manipulate their sites, Metsoja et al. (2014) suggest that ploughing (to expose seed banks) and soil transfers would be useful restoration techniques to maximize recovery of native grasslands in abandoned, flooded meadows in Estonia. They noted the high restoration potential due to seed banks, as indicated by higher diversity in the seed bank than in above-ground vegetation. These differences in seed bank diversity were found among sites with different management histories and among successional stages.

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Two studies suggested moderate levels of intervention involving species manipulations. For restoration of grasslands in the Czech Republic (Mudrák et al. 2014), hemiparasitic plants (*Rhinanthus* spp.) are desirable because they promote biodiversity by reducing dominance by competitive grasses. Restoration was promoted through mowing or grazing, litter removal and proper timing of sowing. In more severely disturbed German mine wastes (Tischew et al. 2014), regional propagule pools lacked target species, so species introductions were used to augment spontaneous succession. The rapid establishment of vegetation cover, and subsequent erosion control, was also improved by sowing grasses. However, Tischew et al. (2014) caution that biodiversity is generally enhanced in post-mine succession when intervention is minimal, in part because such sites provide unusually open, heterogeneous and nutrient-poor conditions.

Disturbance severity for those studies employing moderate intervention was low (agriculture or rangeland) for four studies but high (mining) for the fifth study. It appears that moderate intervention, like low intervention, is not associated with a particular scale or degree of disturbance severity. Average time scales were highly variable (<1–50 yr) and there was also a substantial variation in spatial scale of the study area, from a fraction of 1 ha to over 1500 ha (Table 1).

High levels of intervention can include repeated species removals or additions, often involving multiple species in attempts to assemble communities from their component parts. Alday & Marrs (2014) attempted to replace the undesirable bracken fern when it invades native communities. They compared single treatments involving a chemical spray and repeated removals by cutting in a multi-site study to control the bracken and help to re-establish either grassland or heathland. For grassland restoration the single treatments were most cost-effective, but for heathland restoration repeated treatments were needed. These experiments had two advantages not frequently seen in the practice of restoration: they were conducted over a relatively long time period (>10 yr) and included controls.

Conclusions

A preliminary relationship was found between disturbance severity and degree of intervention, but high variation within and among studies in scales, site conditions and restoration applications confound our ability to make broad conclusions. Seven of the studies fit our suggested intervention level based on disturbance severity, whereas the other three suggest no intervention or spontaneous succession. However, our categories are crude and our sample size is small and heterogeneous (despite all studies occurring in Europe and many at sites of abandoned agriculture). Perhaps patterns of intervention are best compared across more detailed severity levels within a disturbance type or within a region (although defining and applying severity levels to field conditions is problematic). Bartha et al. (2014) and Prach et al. (2014) notably sampled from a wide range of sites, while Jaunatre et al. (2014) and Tischew et al. (2014) sampled from relatively large plots. In addition, many of the studies were observational, and thus either lacked controls or had minimal influence over many complex site variables. We suggest that to begin to extract broadly applicable principles of restoration, detailed examinations of multiple restoration studies are needed within specific habitat types and across carefully defined gradients of disturbance severity and spatial and temporal scales, perhaps with larger sample sizes and finer categories of analysis (but see Alday & Marrs 2014). Nonetheless, the studies of this Special Feature provide important site- or region-specific analyses of restoration techniques that continue to build the necessary database for future meta-analyses.

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