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Species introduction – a major topic in vegetation restoration

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Introduction

During the past two decades restoration ecology has emerged as a relatively new discipline in applied ecological research aiming to counteract the worldwide degradation of biodiversity and essential ecosystems services (Roberts et al. 2009). In fact, restoration ecology may be seen as a spin-off of community ecology, and the reestablishment of specific target vegetation is usually a vital part of any restoration project. Vegetation not only forms the essential habitat of plant and animal species but it is also a prerequisite for ecosystem services and functions such as nutrient cycling, soil protection and water purification. The major goal of restoration ecological research is to study and predict successional trajectories and to develop and test methods to steer and accelerate the development toward desired target communities and ecosystems. Despite an enormous increase in ecological knowledge during the past 20 yr, restoration projects and compensation measures are still often of low quality or fail completely, which is primarily due to poor communication between scientists and practitioners. We hope that this special issue may stimulate an intensified exchange between science and practice.

The present volume contains twelve papers presented at the 7th European Conference on Ecological Restoration held from 23 to 27 August 2010 in Avignon, France. Entitled 'Ecological Restoration and Sustainable Development – Establishing Links Across Frontiers', the conference was organized by the University of Avignon (Chair of the organizing committee Thierry Dutoit and chair of the scientific committee Elise Buisson) under the auspices of the Euro-

pean Chapter of the Society for Ecological Restoration (SER). The conference resulted in a total of 24 articles to be published in the journals *Applied Vegetation Science* (twelve papers in this issue), *Ecologia Mediterranea* (seven papers) and *Knowledge and Management of Aquatic Ecosystems* (five papers).

Limiting factor and starting conditions in vegetation restoration

Studies in restoration ecology usually try to identify factors limiting the success of a restoration project (Bakker & Berendse 1999). Such limiting factors may be either of abiotic (nutrients, hydrology) or biotic (e.g. seed and dispersal limitation) origin. Starting conditions are another important aspect in ecological restoration: They may range from abandoned semi-natural habitats to areas intensively used as cropland and heavily-disturbed locations such as mining sites. Both limiting factors and starting conditions of restoration can be used as a framework to describe current trends in restoration ecological research focusing on vegetation rehabilitation.

Successful vegetation restoration can be constrained by the following factors:

1. Abiotic site conditions in terms of microclimate and/or soil properties such as humidity, soil reaction and nutrient status may not be suitable for desired target communities. Nowadays this is often a serious initial problem, especially when restoration takes place on former cropland with a strongly raised nutrient status (Marrs 2002; Walker et al. 2004). However, even in relatively remote areas with low land-use pressure, biogeochemical changes in ecosystems via the atmospheric inputs of nitrogen and acids may necessitate restoration measures (Bobbink et al. 1998). Although highly-productive site conditions with abundant supplies of resources are often a major constraint, restoration efforts may also face the problem of extremely harsh abiotic site conditions. This is most often the case in industrially exploited areas such as quarries, mining sites or cut-over bogs, where there is little or no soil development, and hence primary succession.
2. Even if abiotic site conditions are favourable, the lack of propagules either at local scale (seed limitation) or at landscape level (dispersal limitation) (Münzbergová &

Herben 2005) may lead to a partial or even complete failure of target vegetation reestablishment. Persistent seed banks may be minimal, so with the increasing fragmentation and disconnection of habitats and the loss of effective dispersers, seed and dispersal limitation have been increasingly identified as a major constraint to vegetation restoration, especially in the highly intensively-used agricultural landscapes of Central and Western Europe (Bakker et al. 1996; Donath et al. 2003) or old Mediterranean fragmented agricultural landscapes (Buisson et al. 2006).

3. If a seed reaches a restoration site, successful establishment may still fail due to the competition of established vegetation and the lack of suitable micro-sites ('safe sites') for seedling recruitment (Donath et al. 2007). The seedling and juvenile stages are usually much more sensitive to inhibition by established vegetation than adult individuals of the same species. Colonization of restoration sites by target species can be considerably enhanced and accelerated by breaking the dominance of established vegetation and creating open soil with low competition for seedling recruitment. The making of such conditions is often related to particular single disturbances such as topsoil removal (Hölzel & Otte 2003) or management like mowing or grazing (Bissels et al. 2006).

4. After successful restoration, semi-natural habitats such as calcareous grasslands, wet fen meadows and heathlands crucially depend on regular management to ensure their long-term persistence. Thus, in many cases, successful restoration has to re-instate or at least mimic traditional disturbance events and management schemes, since the total lack of human interference may allow succession to vegetation types other than the desired target.

The starting conditions most often found are:

- Vegetation damaged through anthropogenic pollution (e.g. agricultural fertilization, industrial and mine remnants or atmospheric nitrogen deposition).
- Strongly-disturbed sites, such as quarries and mining areas
- Formerly diverse semi-natural vegetation altered through abandonment
- Former intensively used croplands

In the current issue, only one paper evaluates effects of restoration measures after anthropogenic pollution, three papers deal with the restoration of heavily disturbed sites, and three are dedicated to the restoration of species-rich communities after abandonment. In contrast, five papers deal with the restoration of vegetation on former cropland. When we look at limiting factors there is a pronounced thematic bias: only one paper is dedicated to abiotic site conditions and only three to management issues, whereas eight studies investigated seed and/or micro-site limitation.

In most of the latter studies, species were introduced and their performance evaluated with respect to provenance, disturbance regimes or micro-site preferences. This marks a new trend: in the 2003 special feature 'Restoring plant communities' in AVS by Van Diggelen & Marrs (2003) only two papers explicitly dealt with the introduction of plant species or even entire communities in restoration; the majority of contributions focused on management issues and the role of spontaneous succession in ecological restoration. The shift towards issues of dispersal, seed and micro-site limitation in restoration ecological research is also reflected by recent review papers (e.g. Kiehl et al. 2010).

Long-term effects of liming on the vegetation of softwater lakes

Acidification of weakly buffered softwater lakes by atmospheric deposition has been one of the most severe environmental problems in southern Scandinavia since the 1970s (Bobbink et al. 1998). To counteract acidification, liming of lakes has been a common restoration practice, often leading to strong eutrophication and an almost complete change in aquatic vegetation. In a 15-year study with lime application on experimental plots in a softwater lake, Lucassen et al. (2012) show that even small doses of lime lead to the mitigation of carbon dioxide limitation and excessive growth of isoetid plants with an increasing risk of up-rooting during storm events. The study clearly demonstrates that measures aiming at the restoration of former biogeochemical conditions may have unexpected and unwanted side effects, even in the long term.

Re-vegetation of quarries and mining sites

The acceleration of primary succession at strongly disturbed sites is a classical problem in vegetation restoration. Two papers on this topic tested how, under Mediterranean-climate conditions with pronounced summer drought, the establishment of native target species can be enhanced and accelerated by improving abiotic site conditions or by selecting particularly favourable micro-sites. In an experimental approach, Soliveres et al. (2012) showed that late-successional Mediterranean woody species are facilitated by the addition of water and nutrients, whereas early successional species are inhibited, probably through increased competition by herbaceous vegetation. The authors therefore recommend bringing late successional species to nutrient-rich patches with high availability of water and nutrients, and the use of pioneer species in the surrounding nutrient-poor and drier matrix. In a similar approach Ballesteros et al. (2012) introduced native species of a highly specialized Mediterranean gypsum flora to

experimental plots in a gypsum quarry with different soil and surface treatments. Vegetation development was restricted to sown plots and seedlings did best in treatments that were improved with gypsum spoil or organic material. The results are clearly indicating the prevalence of both, seed and micro-site limitation. In a sowing experiment in a lignite mine site in Central Germany, Kirmer et al. (2012) compared the performance of a high-diversity seed mixture of regional provenance with a species-poor mixture of commercial grass cultivars for 6 yr. In terms of relevant functions such as biomass production and ground cover protection against erosion, the species-rich regional mixture performed similarly well or even better than the species-poor mixtures of grass cultivars. The results clearly demonstrate that the re-vegetation of bare slopes can go hand in hand with biodiversity targets, such as the recreation of species-rich vegetation with locally adapted native species.

Restoration of semi-natural habitats after abandonment

Three papers in this issue deal with the problem of restoring semi-natural grassland after cessation of mowing or grazing. All these studies come from the Baltic state Estonia where, as in many other regions of Eastern Europe, large-scale abandonment of peripheral agricultural land had started in Soviet times and was further accelerated after the transition to a market economy. Since the country joined the EU, there have been considerable efforts to restore open habitats of high biodiversity value such as calcareous grasslands, wet meadows and coastal marshes. With a thorough analysis, Kalamees et al. (2012) showed that the persistent soil seed bank in overgrown calcareous alvar grasslands has a restoration potential that is much higher than found by previous studies, even after 25 and 50 yr of abandonment. In Baltic coastal grasslands overgrown with reeds Sammul et al. (2012) documented the impact of re-introduced grazing on species composition, biomass production and soil properties. Standing crop and nutrient content in biomass changed relatively quickly towards those of continuously grazed stands, whereas the floristic composition reacted more slowly, especially in terms of target species abundances. Surprisingly, soil properties remained in the range of abandonment, indicating a risk of rapid re-development towards tall reeds if grazing intensity is reduced. In a similar approach, Metsoja et al. (2012) analyzed the effect of resumed mowing on meadows of different flooding duration after more than 20 yr of abandonment. Restoration management resulted in an increase in species richness, compositional changes and higher evenness in all studied communities. After 10 yr of restoration management, clear floristic indicators of man-

agement intensity could be identified. All three studies clearly show that without interventions into abiotic site conditions such as nutrient status and hydrology, and with a largely preserved species pool restoration prospects are particularly favourable even after decades of abandonment. Agro-environmental schemes could be much more efficient and successful under such favourable preconditions than those common in many intensively used agricultural landscapes of Western Europe under raised productivity and with depleted species pools (e.g. Kleijn et al. 2001).

Establishment of near-natural vegetation on former cropland

Five papers in this special issue deal with the restoration of vegetation on former cropland. Remarkably, only one paper has a focus on spontaneous natural succession as an option for restoration. Jírová et al. (2012) documented vegetation development on 58 oldfields, initially surveyed in 1975, in a peripheral limestone mountain area in the Czech Republic. Spontaneous succession after 30 yr had led either to deciduous woodlands on deeper soils or species-rich shrubby dry grasslands on shallow limestone soils. The study clearly demonstrates that spontaneous natural succession works well on fallows within areas of small-scale low-intensity agricultural management with a patchy distribution of habitats and well preserved species pools in close proximity to restoration sites. In many other more intensively used agricultural landscapes of Central and Western Europe, dispersal limitation has been identified as one of the most serious obstacles to the restoration of desired target communities on former cropland (Bakker et al. 1996; Donath et al. 2003). Consequently, four papers in this special issue deal with the introduction of species to former cropland via sowing or hay transfer. The studies presented here range from small-scale experiments to restoration projects at landscape level.

The paper by Mitchley & Jongepierová (2012) reports data from long-term monitoring of sowing experiments aiming at the restoration of species-rich mesic grasslands in the Czech Republic. The results clearly demonstrate lasting benefits of diverse regional seed mixtures whereas there was relatively poor establishment of target species in the natural regeneration treatments, most often from neighbouring sowing treatments. However, even sown strips were still far from fully representing the desired target vegetation. The poorest results were obtained in commercial grass seeding treatments, most obvious due to strong competition by sown grasses.

Another approach was followed by Lengyel et al. (2012) in a grassland restoration project in the Hungarian Hortobágy Puszta, aiming at the restoration of loess steppes

and alkali grasslands on 760 ha of former cropland. Due to the vast area under restoration they could not afford applying diverse seed mixtures for cost and logistic reasons. Furthermore, weed suppression and early integration of farmers as users of the newly established grasslands were of crucial importance. Therefore, species-poor mixtures of dominant grasses were applied to initiate grassland restoration. After 5 yr, basic functional and structural requirements, such as weed suppression, dominance of perennials, ground cover and biomass production for agricultural purposes were achieved. There was also a constant increase in the number and cover of target species, although overall species composition still differed strongly from ancient reference grasslands.

In the steppe of La Crau in south-eastern France, where obtaining an adequate seed mix is currently not possible and where gathering hay can be challenging and expensive, Coiffait-Gombault et al. (2012) decided to test the effect of sowing three foundation species to trigger restoration. As plant colonization from surrounding patches of the target community is extremely slow in this Mediterranean area, the authors then sowed four subordinate species and monitored their establishment where foundation species had previously been sown, as well as on areas where the soil was just harrowed. Subordinate species established better where the foundation species had been sown and when grazing was maintained through the restoration process.

In contrast to the previous study, Schmiede et al. (2012) tried to establish entire plant communities in the floodplain of the river Rhine by transferring hay from donor sites with well-developed flood-meadow target vegetation to species-poor grasslands on former crop fields. A particular emphasis was given to the effect of various intensities of sward disturbance on recruitment success from the transferred hay. Diaspore transfer with hay proved to be potentially very successful with more than 100 allocated target plant species. Establishment success was least successful in undisturbed plots, clearly demonstrating the poor accessibility of closed swards and need for heavy disturbances to enhance seedling recruitment.

Perspectives

The current issue clearly reflects that species introduction and establishment has become a major issue in restoration ecological research. Given the ongoing depletion of species pools and increasing dispersal limitation especially in intensively-used agricultural landscapes of Western and Central Europe (Bakker & Berendse 1999; Kleijn et al. 2001), and ambitious targets of a green infrastructure by EU environmental policy aiming at the restoration of 15% of near-natural habitats to improve ecological functioning and biodiversity in European cultural landscapes (European

Commission 2009), this topic might become even more important in fundamental and applied ecological research. Further impetus can be expected from new national and international legislation aiming at the exclusive use of regional seed provenances in restoration and landscape design. In this context, the question 'How local is local' (McKay et al. 2005) is an urgent and still widely unsolved question since in most plant taxa the kind and degree of local adaptation is virtually unknown (Hufford & Mazer 2003). The provision of sound scientific knowledge and practical guidelines for the introduction of species in the course of restoration measures remains a vital challenge for the future.

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