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Establishment success of 25 rare wetland species introduced into restored habitats is best predicted by ecological distance to source habitats

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ABSTRACT

In response to ongoing local extinction of species and the current biodiversity crisis, the number of reintroduction programs aiming to establish new populations of rare species in the wild has increased. However, only a small proportion of these programs has been planned and monitored scientifically and comparative multi-species studies are missing in this context. Therefore, the relative importance of factors involved in reintroduction success is poorly known. In 2007, we assessed population growth since introduction as a measure of establishment success of 25 wetland species (rare or extinct in the wild nationwide) and a total of 50 populations in Switzerland that had been introduced at seven restored sites with apparently adequate environmental conditions between 1997 and 2005. We related establishment success to 32 life-history traits of these species obtained from the BiolFlor database, to initial number of introduced plants (propagule pressure with 1–130 individuals introduced per population), and to the ecological distance between source sites and restored sites based on vegetation records. Our results clearly showed the importance of close ecological similarity between source and introduction sites for successful establishment of wetland species into restored pond habitats. In contrast, neither life-history traits nor propagule pressure were related to establishment success in our study. Based on our results, we strongly recommend enforcing ecological studies prior to reintroduction to accurately assess the suitability of restored sites. To unambiguously assess the key determinants of successful establishment, future reintroduction programs should be set-up according to experimental designs.

1. Introduction

Decline and extinction of species are natural phenomena (Levin, 2000). However, they have dramatically sped up during the last centuries due to human activities, and resulted in the current biodiversity crisis (Leakey and Lewin, 1995). It has been estimated that currently 13% of the world's plant species are threatened with extinction (IUCN, 2002), and this percentage is even higher for many local floras. In Switzerland, for example, 32% of all vascular plant species are listed as threatened in the Red List (Moser et al., 2002). Clearly, mitigating the rate of local species extinction is a major objective of conservation biologists.

It is undisputed that species decline is caused by extrinsic factors such as habitat alteration due to human activities and other components of global change. Therefore, in response to the dramatic loss of plant species, the disciplines of reintroduction biology and restoration ecology have emerged during the last decades (Armstrong and Seddon, 2008). Many reintroduction programs have been set-up worldwide with the aim of establishing new populations of rare species in the wild. The success of these programs can now be evaluated. Seddon et al. (2005) recently published an analysis on taxonomic bias in reintroduction projects using records of the International Union for Conservation of Nature (IUCN) reintroduction specialist group. They showed that of the 699 reintroduction projects 30% concern plant species while 61% concern vertebrates and only 9% invertebrates. The apparent under-representation of plant-reintroduction projects compared with vertebrates may partly reflect that few results of these projects have been published. For example, in France there have been many plant-reintroduction trials but only four have been published (Bottin et al., 2007 and references therein). In Switzerland, several reintroduction programs of rare plants were carried out, but very few scientific publications have described their results yet (Galeuchet and Holderegger, 2005).

To improve the success rate of projects on reintroduction of rare plant species, we require knowledge on the factors determining establishment success (Pavlik et al., 1993). Therefore, we urgently need to evaluate the success of reintroduction trials. A factor that is likely to contribute to reintroduction success is the number (and

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genetic diversity) of plants introduced at a site. In the literature on invasive alien plants, which might also provide insights into determinants of rarity (Bright and Smithson, 2001; van Kleunen and Richardson, 2007), this introduction effort is better known as propagule pressure, and it has been suggested that this might be the most important determinant of establishment success (Lockwood et al., 2005). If the initial pool of introduced individuals does not have sufficient genetic diversity, the plants may suffer from genetic problems (Colas et al., 1997; Hufford and Mazer, 2003; Kirchner et al., 2006). Indeed, limited genetic diversity is frequently associated with reduced fitness (Leimu et al., 2006), and could result in population extinction.

Other potential determinants of reintroduction success that have not received much attention in conservation biology are intrinsic species traits, such as the capacity for vegetative reproduction and the breeding system (Fischer and Stöcklin, 1997; Murray et al., 2002). Furthermore, extrinsic environmental factors are likely to be important for establishment success (Montalvo and Ellstrand, 2001; Jusaitis, 2005; Bottin et al., 2007; Lawrence and Kaye, 2009). Even among habitats that from an expert-based point of view all look adequate for reintroduction there may be environmental differences important for the long-term success of reintroduction. In addition to absolute habitat quality of a restoration site itself, one might expect that species are most likely to establish in sites that are relatively similar to the source sites of the introduced plants in ecological terms. To the best of our knowledge, however, no study has evaluated yet the roles of introduction effort, intrinsic species traits and the extrinsic environment on establishment success of many rare species in one single study.

Most reintroduction programs focus on a single species, and use only one or a few reintroduction sites. Consequently, it is often impossible to elucidate the determinants of failure or success of such programs. Moreover, none of the few comparative studies with multiple species evaluated the role of intrinsic traits of species on their establishment success (Jusaitis, 2005; Guerrant and Kaye, 2007). We used a unique set-up of experimental reintroduction in the wild of 25 wetland species that are extremely rare or even extinct in the wild in Switzerland. Between 1997 and 2005, these species were introduced at seven restored sites in the Seeland region of Switzerland, where these species used to occur before most of the wetland sites in this region were converted into agricultural land. A total of 50 populations were studied in the field and demographical and ecological surveys were made in 2007. We addressed the following questions: (1) Does the number of introduced plants explain the success of population establishment? (2) Do biological traits of species explain the success of population establishment? (3) Does ecological similarity between source and target habitat explain the success of population establishment? We use the results of our study to make recommendations for future reintroduction projects.

2. Materials and methods

2.1. Introduction history and sites

The Seeland region, 30 km west of the city of Bern, used to have many natural wetland habitats. In the last centuries, most of these natural habitats have been converted into cultivated fields, and nowadays the region is a major provider of vegetables. One decade ago, the Swiss Foundation for Landscape Conservation allowed the local association Habitat Network "Grosses Moos" to restore some patches of wetland habitat within this agricultural landscape. At seven locations, ponds, ranging in size between 25 and 1700 m^2, were created 500 m–5 km apart from each other (Table 1). The sites were created between 1996 and 2002, and then rapidly colonized by common wetland species such as *Phragmites australis*, *Juncus effusus* and several *Carex* species. The vegetation was mown annually and removed, thereby repeatedly creating open patches suitable for the establishment of competitively weaker plants.

Table 1
Compilation of the number of species introduced at each site and the number of species which succeeded ($\log \lambda \geqslant 0$) or failed ($\log \lambda < 0$) to establish at the site.

Site	Number of species introduced	Number of species successfully established	Number of species that failed to establish
Baumschulmoos	1	1	0
Fräschels	5	4	1
Heumoos	9	4	5
Krümmi	11	6	5
Pré aux Boeufs	6	5	1
Staatmoos	1	1	0
Stierenbeunden	17	3	14
Sum	50	24	26

To further speed up the restoration process, 1–17 rare wetland species were introduced at each site (25 species in total; Table 1). The first introductions of six populations were done in 1997, followed by 23 populations in 2000, five populations in 2001, three populations in 2002, 12 populations in 2004 and one population in 2005. For more than half of the species, the plant material used for introduction was first pre-cultivated in ex-situ populations in the Botanical Garden of Bern. For the other species, individuals were taken directly from natural source populations. Introduction at the restored sites was performed by planting 1–130 (median = 6) individuals either in a limited area in the middle or along the edges of the pond depending on the configuration of the site. One of the two introduced populations of *Blackstonia acuminata* (the one still existing in 2007) was started from seeds instead of from planted individuals.

2.2. Study populations and success of establishment

The reintroduction project included a total of 50 introduced populations (representing 25 species) and 14 sites of still existing source populations (Table 2). To assess the establishment success of the introduced populations, we visited all 50 introduced populations in the summer of 2007. We recorded the sizes of the populations by counting all individuals or by estimating the total number of individuals when the population consisted of >100 individuals. For three species (*Eleocharis acicularis, Pilularia globulifera* and *Marsilea quadrifolia*) for which the size of the initial population had been estimated as surface cover (m^2), we also estimated surface cover in 2007. The establishment or demographical success (λ) was estimated as.

$$\log \lambda \sim [(\log(1 + \text{popsize}_{2007})) - (\log(1 + \text{popsize}_{\text{initial}}))]/\text{year}$$

Here, popsize_{2007} is the population size in 2007, $\text{popsize}_{\text{initial}}$ is the initial population size at introduction, and *year* is the number of years since introduction. For the introduced population of *B. acuminata* started from seed in 2000, λ was calculated using as initial population size the number of individuals counted at a census in 2004. We added one to census population sizes when estimating λ in order to also take loss of populations into account.

2.3. Vegetation records, ecological distance and biological species traits

To assess the similarity in habitat conditions of introduced populations and their source populations, we did vegetation records in both types of populations. For the populations still existing in 2007, we recorded all plant species present in an area of 2 m^2 around the target species. Nine of the introduced populations were