Journal of Insect Science (2017) 17(1): 10; 1–7
doi: 10.1093/jisesa/iew102
Research article

Dynamics of Reintroduced Populations of *Oedipoda caerulescens* (Orthoptera, Acrididae) over 21 Years

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Subject Editor: Konrad Fiedler
*deceased 28 June 2013

Received 20 September 2016; Editorial decision 20 October 2016

Abstract

Conservation programs increasingly involve the reintroduction of animals which otherwise would not recolonize restored habitats. We assessed the long-term success of a project in which the Blue-winged grasshopper, *Oedipoda caerulescens* (L., 1758), was reintroduced to a nature reserve in Northwestern Switzerland, an alluvial gravel area where the species went extinct in the 1960s. In summer 1995, we released 110 individuals (50 females and 60 males) and 204 individuals (101 females and 103 males) into two restored gravel patches with sparse vegetation. We used a transect count technique to assess the population size of *O. caerulescens* in the years 1995–2004 and 2015–2016 and recorded the area occupied by the species. At both release sites, the populations persisted and increased significantly in size. Individuals that followed a newly created corridor established four new subpopulations. Seven years after reintroduction, *O. caerulescens* had reached a high abundance around the release sites and in the four colonized patches, indicating a successful project. At the same time, the dispersal corridor became increasingly overgrown by dense vegetation. Surveys 20 and 21 yr after introduction showed that the abundance of the Blue-winged grasshopper had strongly declined in the established subpopulations and moderately in the original release sites, owing to natural succession of the habitat and lack of disturbances, which reduced the area suitable for the species by 59%. Our study shows that reintroductions are unlikely to succeed without integration of long-term habitat management (in the present case maintenance of open ground).

Key words: habitat restoration, propagule size, reintroduction, succession

Restoration of a site, especially in highly fragmented landscapes, mostly benefits mobile generalist species (Samways 1994, Baur 2014). For less mobile species, reintroductions, i.e., the intentional movement and release of plants and animals inside their indigenous range from which they have disappeared, are an increasingly used tool to re-establish populations in restored habitats (IUCN/SSC 2013). Reintroduction projects frequently focus on keystone species related to particular functions in the ecosystem, or alternatively, on rare and/or endangered species, as well as charismatic species, which have public acceptance and receive financial support (Fischer and Lindenmayer 2000). The approach is valuable to rescue particular species from extinction, both at the local and global scale, and to increase local biodiversity (Harris and van Diggelen 2006, Thomas et al. 2009).

Invertebrates constitute a substantial proportion of both the biomass and species richness of ecosystems and play a significant role in ecosystem functioning (New 1995, Samways 2005). Invertebrate species become increasingly frequent reintroduction targets once the populations have become locally extinct (Bajomi et al. 2010, Swan et al. 2016). Examples of successful reintroductions were reported for Lepidoptera (Thomas 1989, Marttila et al. 1997), Orthoptera (Pearce-Kelly et al. 1998, Sherley 1998, Hochkirch et al. 2007) and beetles (Drag and Cizek 2015), although some projects were not successful (e.g., Wagner et al. 2005).

In this article, we assessed the long-term success of a project in which the Blue-winged grasshopper *Oedipoda caerulescens* (L., 1758) was reintroduced to a nature reserve, a locality where the species went extinct in the 1960s. The Blue-winged grasshopper is a xerothermophilous species living in stony and sandy habitats with sparse vegetation (Detzel 1998, Straube 2013). Matching habitat suitability is the crucial step in any reintroduction project. Suitable habitat should meet the candidate species' total biotic and abiotic needs through space and time and for all life stages (Samways 2005). The importance of habitat quality for population viability and patch occupancy dynamics has repeatedly been shown in diverse insect taxa (Baur et al. 2002, Fleishman et al. 2002, Franzén and

Nilsson 2010, Pasinelli et al. 2013). The long-term success of a reintroduction can be influenced by temporal changes in both habitat quality and the abundance of competitors and predators. In many cases, reintroduction success may also be affected by societal conditions, such as local public support and socio-political considerations (IUCN/SSC 2013).

Despite recent efforts to develop the science of reintroduction biology (Seddon et al. 2007, Armstrong and Seddon 2008), there is still no general and broadly accepted definition of reintroduction success (Robert et al. 2015). Long-term viability of the introduced population is the ultimate target of any translocation action. Here, population size can be used as a relevant indicator (although subject to considerable uncertainty) of the viability of the reintroduced populations and thus as a proxy for reintroduction success (Fischer and Lindenmayer 2000). An important issue is also the quantification of the roles of the various intrinsic, environmental and management factors on the reintroduction success of a species. Sarrazin (2007) proposed to split the dynamics of successful reintroductions into three main phases, namely establishment, growth and regulation, and to focus on the regulation phase to assess the ultimate success of any reintroduction action. The success criteria should, therefore, focus on the regulation phase during which population dynamics critically depend on the interactions among species and habitat characteristics to draw reliable conclusions about long-term population persistence (Robert et al. 2015).

The aim of our project was to re-establish viable populations of *O. caerulescens* at two sites in a nature reserve in Switzerland. The distribution of the Blue-winged grasshopper ranges from North Africa (Morocco) in the south, to Denmark and Southern Sweden in the north, and to Southwest Asia in the east. In Germany, *O. caerulescens* is considered in the Red List as near threatened (Maas et al. 2011), as it is in the Red List of Switzerland (Monnerat et al. 2007), and in both countries as elsewhere in Europe the species is protected by law. The causes of its decline and local extinction include the destruction and degradation of xerothermous habitats and the succession of secondary habitats (Detzel 1998, Schlumprecht and Waeber 2003, Grein 2010). Attempts to re-establish the Blue-winged grasshopper have had little success. In Lower Saxonia (Germany), reintroduction of *O. caerulescens* into various habitats was unsuccessful (NLWKN 2011).

In our study, the reintroduction was implemented following the IUCN guidelines for reintroductions and other conservation translocations (IUCN/SSC 2013). Key steps were the selection of the source population and the two reintroduction sites, the site preparation, as well as the population monitoring and site management in the years following reintroduction. We evaluated the reintroduction success by recording the number of grasshoppers using a standardized method over a period of 21 yr.

Materials and Methods

Study Species

In Central Europe, *O. caerulescens* occurs in stony grasslands with a significant amount of bare ground, in rock steppe, ruderal sites, gravel and sandpits and quarries (Ingrisch and Köhler 1998). Individuals show high site fidelity, staying usually within the same habitat patch (Altmoos 2000, Straube 2013). The Blue-winged grasshopper hibernates in the egg stage in the soil. Grasshoppers in the first nymphal instar appear in May or June, depending on weather conditions (Detzel 1998, Pfeifer et al. 2011). Individuals pass four to five nymphal instars before the first adults appear in the second half of July. The density of adults reaches a peak at the beginning of August, and individuals can be found until the end of October (Appelt and Poethke 1997). Grasses including *Lolium perenne*, *Dactylis glomerata*, and *Agropyron repens* and herbs such as *Rumex acetosella* and *Hieracium pilosella* are the preferred food (Merkel 1980).

Selection of Reintroduction Sites

Criteria used in the choice of the two reintroduction sites were 1) similarity of the habitats to that of remnant populations in terms of soil structure, cover and composition of vegetation, and climate; 2) avoidance of uncontrolled disturbance; and 3) accessibility for management. Reinacherheide, a 1.7 km-long and 300-m wide nature reserve (47° 29′ 50″ N; 7° 36′ 18″ E; elevation 280 m a.s.l.) situated 10 km south of Basel, Switzerland, was chosen. In this nature reserve *O. caerulescens* went locally extinct in the 1960s. The site of the source population (see Source Population) and the nature reserve are 20 km apart separated by unsuitable habitat. Both have similar climate, soils, and vegetation. In this region, the annual temperature averages 10.4°C and the annual precipitation is 780 mm (Meteo Swiss 2013). The nearest-situated recent population of *O. caerulescens* is approximated 10 km apart from the reintroduction sites.

History and Preparation of Reintroduction Sites

Major parts of the nature reserve Reinacherheide are situated on alluvial gravel (Eglin and Moor 1981). In the past centuries, the river Birs represented a natural, up to 700-m wide river system with branches and slow-flowing meanders associated with sand and gravel flats. In the section of the release sites, the Birs was transformed into a 30-m wide channel between 1847 and 1855 (Lüthi 2003). As a consequence, the riverbed deepened by 3 m. The alluvial gravel interspaced with patches covered by a thin layer of nutrient-poor, dry and sandy soil allowed the development of species-rich plant and invertebrate communities. In the 19th century, this area was alternatingly used as arable field with little yield, as building waste pit, as area for horse riding and sport with dogs and as a campsite. Already in 1908, botanists recognized the exceptionally high and unique plant diversity and demanded its protection (Lüthi 2003). Various surveys showed significant species loss among plants, butterflies and birds between 1920 and 1970 (Eglin and Moor 1981). In 1974, the core area (25.5 ha) was designed as the nature reserve Reinacherheide, mainly based on the argument that its gravel bed has a vital function for the clearing of ground water providing the drinking water supply for more than 50,000 people. The rules of the nature reserve prohibit recreational activities off the public tracks. Later the size of the nature reserve was increased to 39 ha. Nowadays, the nature reserve consists of a mosaic of riparian forest along the river Birs, gravel fields and areas of nutrient-poor, dry grassland, interspaced by bush rows and dry forests, entirely surrounded by settlement, and industrial areas (Lüthi 2003). In the west the reserve is bound by an outdoor swimming pool and a highway.

The area of the nature reserve is, however, not entirely protected against human impact. In the winter 1997/1998, a cable duct was laid running from south to north. As a compensation for the structural damage, the top soil was scraped down to the gravel pad in four areas (new patches C1, C2, D1, and D2 in Fig. 1), creating an early stage of succession, and the gravel patch of release site B was enlarged. Furthermore, the pipe trench was filled with sandy gravel (sections L1–L3 in Fig. 1), assuming that this 3-m wide belt may function as dispersal corridor. However, owing to the ongoing

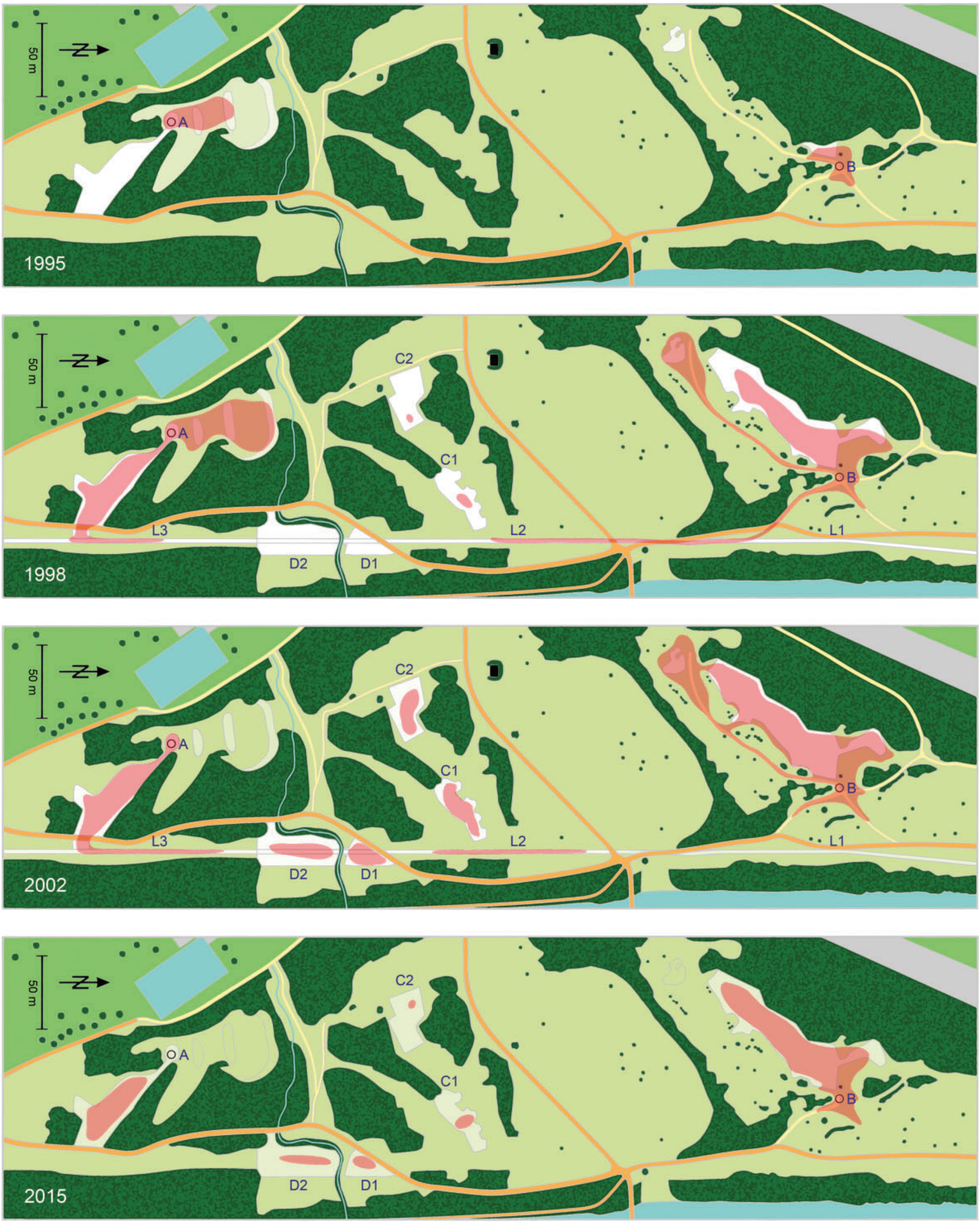

Fig. 1. Spatial distribution (in red) of *O. caerulescens* released in two sites (A and B) in the nature reserve Reinacherheide, Switzerland, in summer 1995. The maps show the area occupied by the grasshopers 3 w (1995), 3 yr (1998), 7 yr (2002), and 20 yr (2015) after reintroduction. In winter 1997/1998 four new gravel patches (C1, C2, D1, and D2) were created and a pipe trench crossing the nature reserve (L1–L3) was filled with sandy gravel. The pipe trench worked temporarily as dispersal corridor. In the west the reserve is bound by an outdoor swimming pool (upper left corner) and a highway (upper right corner), in the east by the river Birs. Gravel patches are indicated in white, forest in dark green, nutrient-poor, dry grassland in light green, and tracks in orange and trails in yellow.

atmospheric nitrogen deposition, this gravel belt was overgrown by vegetation within a few years.

Source Population and Release of Grasshoppers

O. caerulescens is still abundant at various sites in the embankment and floodplain of the river Upper Rhine (Coray 2000). Species-rich communities of xerothermophilous plants and invertebrates coexist on gravel and sandy soils of the Rhine island, which separates the navigable channel "Grand Canal d'Alsace" from the relatively natural remnant of the former river Rhine. Individuals of *O. caerulescens* were caught over a distance of 100 m along a gravel driveway above the embankment 1 km north of the hydroelectric power station of Kembs. Using an insect net, 110 individuals (50 females and 60 males) were caught on 31 July 1995 and released at site A (see below), and another 204 individuals (101 females and 103 males) were caught on 16 August 1995 and released at site B. Female and male grasshoppers were transported separately in two 13.5-liters buckets and released a few hours after being caught at the reintroduction sites. The source population was not adversely affected by the removal of 314 individuals as indicated by the very large population sizes observed in the succeeding years (G.H. Thommen, unpublished data).

Criteria for Success

Two criteria for success were set: 1) persistence of the two introduced populations for longer than 7 yr with likely ongoing persistence given continuity of habitat management; 2) establishment of new subpopulations in newly created habitat patches within 5 yr. The latter criterion was set assuming that filling the pipe trench with sandy gravel facilitates grasshopper dispersal. Using this corridor, individuals of *O. caerulescens* may colonize the newly created habitat patches in which the top soil was scraped down to the gravel pad in the winter 1997/1998.

Population Monitoring

A transect count technique was used to assess the relative population size of *O. caerulescens* in the potentially suitable areas around the release sites, the restored gravel areas and the sandy gravel on the covered pipe trench. These areas were slowly walked through following a zigzag line with a distance of 5 m between lines (Baur et al. 1996, Braschler et al. 2009). All adult females and males of *O. caerulescens* seen within a 1.5 m-wide strip were counted. Surveys were conducted between 10:30 and 17:00 h on warm sunny days. In each year, three surveys were done in August (exceptions with only one survey were the years 2003 and 2004).

The transect count technique used to assess population size of *O. caerulescens* reveals an estimate of the relative abundance in a particular patch. Resight data obtained in the days after release indicated that with this technique 20–33% of the individuals present might be recorded. The actual population sizes may therefore be three to five times larger than the relative abundances given in Table 2.

Post-Release Dispersal

Grasshoppers were released at one spot each in site A and B. Post-release dispersal of *O. caerulescens* was assessed after 4 and 19 d in site A and after 3 and 21 d in site B. Using the transect technique described earlier we recorded the positions of individuals on a map. Circles with radii of 6, 12, 18, 36, and 72 m and marked with small flags around the release points facilitated the mapping. The same procedure was used to assess the distances moved from the release points by the grasshoppers of the first (after 1 yr) and second generation (after 2 yr).

Table 1. Distance dispersed of *C. caerulescens* after release at two introduction sites in the nature reserve Reinacherheide, Switzerland

Release site	Time after release	Mean distance (m)	Maximum distance (m)	*N*
A	4 d	7.1	27	25
	19 d	8.9	54	20
	1 yr	35.3	54	23
	2 yr	52.3	80	59
B	3 d	6.1	27	23
	21 d	13.0	54	23
	1 yr	18.1	80	37
	2 yr	28.3	80	108

Mean and maximun distances are shown. *N* indicates the number of individuals resighted.

Habitat Quality

Habitat quality refers to the "ability" of the environment to provide conditions appropriate for individual and population persistence (Samways 2005). For reproduction, the Blue-winged grasshopper requires bare ground on sandy or stony soils, for feeding several grass and herb species. The most suitable conditions for reproduction are at a vegetation cover of around 50% (Lutz 1996). In our study, we considered the habitat suitable for *O. caerulescens* when the vegetation cover on a gravel patch was within the range of 25–75% (Warren and Büttner 2008). We derived the area of suitable habitat from satellite maps made in 2002, 2007, and 2013 (Google Earth 2016) using the pixel counting function in Adobe Photoshop (version 10.0.1). In 2016, we measured the area of suitable habitat in all patches occupied by the species in the field.

Statistical Analyses

Chi-square tests were applied to examine whether the initial dispersal direction was random. For this analysis, the positions of the recovered grasshoppers were assigned to four classes according to their dispersal direction (north, east, south, and west). Paired sign-test was used to assess changes in population size in the gravel patches between two periods. The relationship between the relative population size of *O. caerulescens* and the area of suitable habitat was examined using linear regression. Data analyses were performed in the R environment (version 3.2.2, R Development Core Team 2015).

Results

Post-Release Dispersal

Mean dispersal from the release points averaged 6.1 and 7.1 m at the two sites after 3 respectively 4 d and increased to 8.9 and 13.0 m after 19 respectively 21 d (Table 1). Initial dispersal direction was random in site B after 3 d ($\chi^2 = 6.39$, df = 3, $P = 0.09$), while in site A the grasshoppers showed a preference to move towards north and east ($\chi^2 = 15.80$, df = 3, $P < 0.01$). After 19–21 d, several grasshoppers had reached the edge of suitable habitat and their further dispersal was influenced by the shape of the habitat patch, resulting in non-random dispersal directions (site A: $\chi^2 = 10.00$, df = 3, $P < 0.02$; site B: $\chi^2 = 10.56$, df = 3, $P < 0.02$). One year after reintroduction, *O. caerulescens* had moved on average 35.3 m (site A) and 18.1 m (site B) from the release points. The corresponding values 2 yr after reintroduction were 52.3 and 28.3 m (Table 1).

Table 2. Relative population size of *C. caerulescens* (number of individuals observed per survey) in various habitat patches in the nature reserve Reinacherheide, Switzerland, in 1995–2004 and 2015–2016

Year	Habitat patch									Total
	A	B	C1	C2	D1	D2	L1	L2	L3	
1995	23.3 ± 1.7	23.0 ± 0.0	–	–	–	–	–	–	–	46.3 ± 1.7
1996	23.0 ± 1.2	30.7 ± 5.8	–	–	–	–	–	–	–	53.7 ± 4.9
1997	54.0 ± 4.5	92.0 ± 15.5	–	–	–	–	–	–	–	146.0 ± 20.0
1998	28.0 ± 10.6	63.7 ± 0.3	2.0 ± 0.6	0.3 ± 0.3	0.0	0.0	7.3 ± 3.3	0.0	0.7 ± 0.7	102.0 ± 10.3
1999	20.5 ± 9.5	95.7 ± 30.9	13.7 ± 1.5	10.3 ± 4.8	0.0	0.0	0.0	0.5 ± 0.4	0.0	140.7 ± 32.6
2000	12.7 ± 3.2	148.0 ± 16.8	5.0 ± 0.6	3.3 ± 0.3	0.3 ± 0.3	0.3 ± 0.3	0.0	1.0 ± 0.6	0.0	170.7 ± 16.7
2001	85.0 ± 6.6	251.3 ± 4.8	5.7 ± 1.2	1.7 ± 0.3	2.3 ± 0.7	2.3 ± 1.2	0.0	5.0 ± 2.3	7.3 ± 3.4	360.7 ± 8.1
2002	91.0 ± 13.0	228.0 ± 27.1	20.3 ± 8.4	14.3 ± 2.8	15.7 ± 2.0	15.3 ± 2.2	0.0	5.0 ± 1.5	8.3 ± 3.2	398.0 ± 37.3
2003	14 –	116 –	13 –	7 –	7 –	17 –	0	9 –	4 –	187
2004	65 –	208 –	17 –	9 –	9 –	20 –	0	15 –	78 –	421
2015	14.3 ± 1.2	93.3 ± 8.8	6.3 ± 0.7	1.7 ± 0.3	6.3 ± 0.9	4.7 ± 0.7	–	–	–	126.6 ± 7.8
2016	24.3 ± 2.9	61.7 ± 3.8	14.0 ± 1.5	3.3 ± 1.2	2.0 ± 0.6	7.3 ± 0.9	–	–	–	112.6 ± 9.0

Mean ± SE of 3 surveys per year are shown, except only 1 survey in 2003 and 2004. The patches C1, C2, D1, and D2 and the pipe trenchs L1, L2 and L3 were created in winter 1997/1998. L1–L3 were overgrown by 2015 and no longer contained suitable habitat.

Colonization of Newly Created Habitat Patches

In the first 2 years (1996–1997) after reintroduction, individuals of *O. caerulescens* spread over the entire gravel patches around the two release points (Fig. 1, Supp Fig. S1 [online only]). In winter 1997/1998, new patches of suitable habitat were created by scraping the top soil down to the gravel pad (patches C1, C2, D1, and D2 in Fig. 1, Supp Fig. S1 [online only]), and by filling the nature reserve-crossing pipe trench with sandy gravel (L1–L3 in Supp Fig. S1 [online only]). In summer 1998, individuals of *O. caerulescens* used the gravel cover of the pipe trench as dispersal corridor and colonized the newly created habitat patches C1 and C2, and in 2000 the patches D1 and D2 (Supp Fig. S1 [online only]). From 2001 onwards, the cover of the pipe trench was increasingly overgrown, reducing its function as dispersal corridor. In 2002, 7 yr after its reintroduction, the Blue-winged grasshopper had reached its maximum distribution in the nature reserve, and was established in six habitat patches, which were partly connected to each other.

Changes in Population Size

The relative population size of *O. caerulescens* increased in the patches A and B around the release sites, reaching a maximum after 6–7 yr (2001–2002; Table 2). Similarly, in the newly colonized patches (C1, C2, D1, and D2), the relative population sizes were largest in 2002 but decreased thereafter (Table 2). In all six patches, the relative population sizes were significantly smaller in the period 2015–2016 than in the period 2001–2004 (sign test, $P < 0.05$), with an overall decrease of 61% (patch A: 70% decrease, B 61%, C1 27%, C2 69%, D1 51% and D2 55%).

The relative population size of *O. caerulescens* (Y) decreased with decreasing area of the gravel patches (X in m^2) both in 2002 ($Y = 0.088X - 37.86$; $R^2 = 0.936$, $N = 6$, $P < 0.01$) and in 2016 ($Y = 0.038X + 0.86$; $R^2 = 0.953$, $N = 6$, $P < 0.001$).

Changes in the Area of Suitable Habitat

Serial satellite maps showed that the gravel patches became overgrown by progressive succession. In 2002, the year with the largest population sizes, the total area suitable for *O. caerulescens* in the six patches was 6,920 m^2 (Table 3). In 2016, the total area suitable was only 2,850 m^2, which corresponds to a reduction by 59%. The patches varied in reduction of suitable habitat, ranging from 40% in patch A to 95% in patch C2 (Table 3).

Table 3. Changes in the area of suitable habitat for *O. caerulescens* in six gravel patches in the nature reserve Reinacherheide, Switzerland, between 2002 and 2016

Gravel patch	Area (m^2)				Reduction
	2002[a]	2007[a]	2013[a]	2016[b]	2002–2016 (%)
A	1,340	960	960	800	40.3
B	2,930	2,680	2,250	1,530	47.8
C1	500	320	220	160	68.0
C2	735	410	55	40	94.6
D1	385	270	220	120	68.8
D2	1,030	770	410	200	80.6
Total	6,920	5,410	4,115	2,850	58.8

[a]derived from satellite maps (Google Earth 2016).
[b]measured in the field.

The pipe trenches (L1–L3) with sandy gravel functioned only a few years as dispersal corridor. Already in 2006, they were entirely overgrown and presented no longer a suitable habitat for *O. caerulescens* (Supp Fig. S1 [online only]).

Discussion

The movement and release of plants and animals is now an accepted conservation tool to re-establish new populations at sites where the species went extinct in the past (Seddon et al. 2014). Our study showed that the reintroduction of the Blue-winged grasshopper into the nature reserve Reinacherheide was successful if we consider only the first 6–8 yr after release. At both release sites the populations persisted and increased significantly in size, and individuals that followed temporary corridors established new subpopulations. However, the area of suitable habitat decreased over the duration of the study owing to natural succession and lack of disturbance, resulting in a significant decrease in population size in the following years, although the six populations still existed 21 yr after release.

Three factors might have contributed to the initial success of the reintroduction project. First, the suitability of the reintroduction site for the focal species is fundamental for any translocation project. Individuals should only be released in patches with high habitat quality. We assessed the habitat and vegetation structure of extant *O. caerulescens* populations and searched for release sites that provided similar conditions to the grasshoppers. However, habitat quality and the area of suitable habitat can change with time if there is a lack of disturbance resulting in progressive natural succession, as found in our study. A repeated monitoring of both the population size of the focal species as well as of the habitat quality is therefore essential. In the long-term, the suitability of a site needs to be considered at a range of spatial scales such as habitat size, availability of good habitat, and connectivity in the surrounding landscape, as it has been shown in the bush-cricket *Metrioptera roeselii* (Berggren et al. 2001).

Second, propagule size (the number of introduced individuals or the size of the founder population) is a key factor for reintroduction success. Releasing relatively large founder populations reduces the risk of negative effects of low genetic diversity and inbreeding, maintains the evolutionary flexibility of the introduced populations (Frankham et al. 2002), and reduces the risk of extinction due to demographic stochasticity (Lande 1993). We released 110 and 204 individuals in two sites at the beginning of the reproductive season in 1995. The founders could reproduce in the release sites in the first year and establish viable populations within a few years. In *M. roeselii*, introduction experiments revealed that a founder group of at least 32 individuals is required to establish a viable population with a high degree of certainty (Berggren 2001).

Third, the creation of four new habitat patches in the close surroundings allowed the establishment of new subpopulations. The pipe trench filled with sandy gravel functioned as dispersal corridor for a few years and thus was essential for the rapid colonization of the new patches. Six to seven years after reintroduction a metapopulation existed in the nature reserve Reinacherheide and the populations had reached their regulation phase, indicating the ultimate success of the reintroduction action (Robert et al. 2015). However, the gravel patches became increasingly overgrown over the years, which reduced both their size and suitability for *O. caerulescens*. On porphyritic hills in Germany, the presence of *O. caerulescens* in a habitat patch depended on patch size and patch isolation (Appelt and Poethke 1997). If patch size decreased, local extinction of the Blue-winged grasshopper became more likely. This can be explained by the relatively narrow habitat requirement of *O. caerulescens*. For successful reproduction, the grasshoppers need sparse vegetation and bare ground (Warren and Büttner 2008). Decreasing habitat size results in decreasing population size, which in turn enhances the risk of local extinction. The gravel patches are the only suitable habitat in the nature reserve and its surroundings. Natural recolonization from other populations outside the reserve is very unlikely given the distance to other populations. Although capable of flight, adult *O. caerulescens* are rather sedentary, with females more sedentary than males (Maes et al. 2006). The median dispersal distance has been recorded in the range of 5–47 m in suitable habitat (Appelt and Poethke 1997, Maes et al. 2006), but some individuals have been observed moving as far as 100 m (Detzel 1998), mainly following tracks (Straube 2013). Given the limited dispersal range, habitat connectivity is critical for the survival of the species. This can be achieved by maintaining a network of suitable habitat patches connected with dispersal corridors. In our case study, the habitat is threatened by the encroachment of woody plants and the expanding ground vegetation. It is therefore necessary to remove saplings and a part of the vegetation cover every 4 yr to mimic slight habitat disturbance and prevent natural succession of the gravel patches.

Conclusions

Our main conclusion is that reintroductions are unlikely to succeed without integration of habitat management. This is of particular importance in species living in habitats that are frequently disturbed or in early successional stages of habitats, because changes in vegetation cover affect habitat quality (Hodder and Bullock 1997). For the Blue-winged grasshopper, natural succession is a continuous threat in the reintroduction sites. Maintaining a network of suitable habitat patches is essential for the long-term persistence of *O. caerulescens* in this nature reserve and elsewhere. Furthermore, monitoring should not be stopped when the introduction is considered to be successful. Monitoring may also identify new threats to the introduced populations and allow adjustments of management actions.

Supplementary Data

Supplementary data are available at *Journal of Insect Science* online.

Acknowledgments

We thank Anette Baur, Brigitte Braschler, Hans-Peter Rusterholz and two anonymous reviewers for valuable comments on the manuscript and Ramona Melliger for helping to analyze satellite maps. Permits to reintroduce the Blue-winged grasshopper into the nature reserve Reinacherheide and to conduct research in the reserve were obtained from the Nature Conservation Authority of the canton Basel-Landschaft, Section Nature and Landscape, Liestal.

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