Short Communication

The effectiveness of plant conservation measures: the *Dianthus morisianus* reintroduction

Donatella Cogoni, Giuseppe Fenu, Erica Concas and Gianluigi Bacchetta

Abstract The plant *Dianthus morisianus* Vals. (Caryophyllaceae) is endemic to Sardinia. The Autonomous Region of Sardinia funded a conservation project for this species because it is one of the most threatened plant on the island. The project comprises in situ and ex situ research and experimental projects, such as the construction of protective fences and reintroduction. Juvenile plants, germinated from 200 seeds collected over 2 years and propagated without horticultural treatment, were reintroduced in November 2010. The surviving 113 plants were reintroduced 150 m from the natural population and were monitored monthly. Two years later the survival rate was > 95%, and the fruit yield per plant was higher than that recorded in the natural population. This research emphasizes the importance of identifying an appropriate microhabitat for plant reintroduction. The use of juvenile plants aided the success of the reintroduction and reduced the mortality rate; the knowledge of the species biology, in particular the critical stage of their life cycle, is a crucial factor in plant reintroduction.

Keywords Endemic flora, *Dianthus morisianus*, Mediterranean islands, reintroduction, Sardinia

The reintroduction of plants (the controlled placement of plant material into a natural or managed area; Godefroid et al., 2011) is a relatively recent development and a potentially important tool for conservation. The rationale for reintroduction is the establishment of new or augmentation of existing populations to increase the survival prospects of a species (Pavlik, 1996). IUCN (1998) encourages reintroduction as a strategy to prevent the extinction of plant species. The potential of reintroduction to contribute to the recovery of threatened species is significant, and is enhanced when part of integrated conservation activities (Albrecht et al., 2011).

Dianthus L. (Caryophyllaceae) is one of the most differentiated plant genera in Europe, characterized by several endemic taxa in the Mediterranean area (Valente et al., 2010). In Sardinia eight endemic species of *Dianthus* have been recorded (Bacchetta et al., 2010), four of which are narrowly distributed; among these, *Dianthus morisianus* Vals., the only psammophilous species of the genus in the Mediterranean basin and with only one population, on the Portixeddu coastal dune system in Buggerru, south-west Sardinia (Fig. 1), is one of the most threatened plants on the island (Bacchetta et al., 2012).

D. morisianus is a perennial herb characterized by numerous woody stocks, erect stems and a basal rosette with thin and linear leaves. The stems bear terminal multi-flowered heads; the calyx is characterized by lanceolate teeth and the colour of the corolla is pink. The flowering season is from early May to late June, and ripe fruits can be found during June–July (Bacchetta et al., 2010). This plant grows on stabilized dunes at the edge of *Juniperus* spp. micro-forests and scrub dominated by *Cistus* spp.

The natural habitat of *D. morisianus* has been strongly modified by human activities, causing habitat loss and fragmentation: there are several settlements in the species' habitat and since 1950 much of the dune system has been afforested to stabilize the dunes and halt the movement of sand inland. The small size of the population and the limited seedling recruitment make *D. morisianus* potentially prone to extinction, and it is categorized as Critically Endangered on the European (Bilz et al., 2011) and Global Red Lists (Fenu et al., 2011). The Autonomous Region of Sardinia funded a conservation project for *D. morisianus* because it is one of the most threatened plant on the island (Bacchetta et al., 2012). The project comprises in situ and ex situ research and experimental projects, such as the construction of protective fences (Fenu et al., 2012) and the reintroduction described here.

Detailed knowledge of a species' ecology and reproductive biology is required prior to reintroduction (IUCN, 1998). Preliminary research focused on the ecology of *D. morisianus* and the level of human disturbance in its habitat. These surveys facilitated the identification of a suitable area c. 150 m from the natural population (Fig. 1), in a protected site, managed by public administration (EFS, Ente Foreste della Sardegna); conservation of threatened plants is more practicable on legally protected than on private land (e.g. Ali & Qaiser, 2011). The chosen site was most likely a part of the species' former range and had not been greatly altered by human activities.

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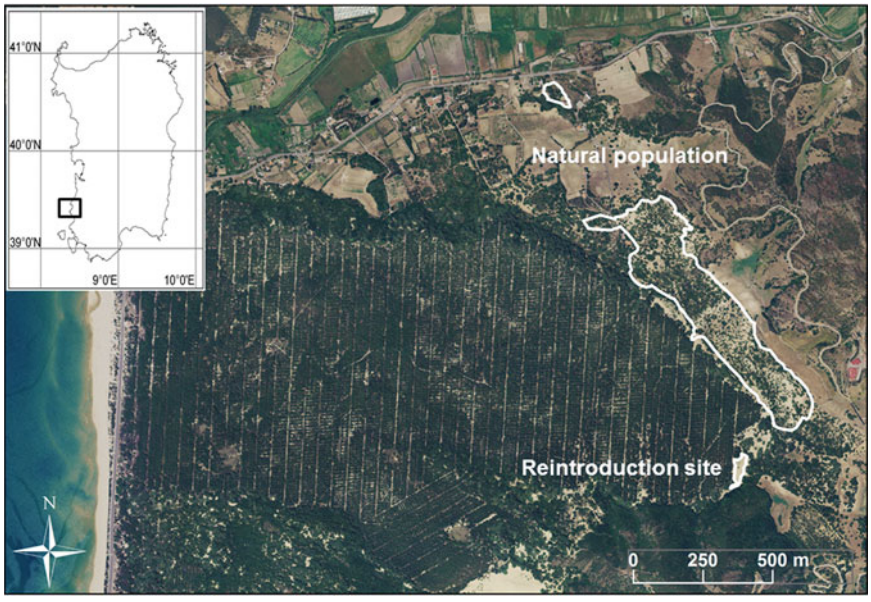

FIG. 1 Locations of the natural population and the reintroduction site for the threatened *Dianthus morisianus* on the Portixeddu dune system; the extent of the natural population is c. 17.5 ha, in two areas, of 17 and 0.5 ha. The rectangle on the inset indicates the location of the main map in Buggerru, south-west Sardinia.

Reintroduction success is greater when using material originating from multiple populations (Vergeer et al., 2005) but this is not possible when working with a narrowly distributed species. Seedlings germinated from seeds collected in different years were therefore used to facilitate the inclusion of some genetic diversity. Fruits were collected from the wild population in 2008 and 2009, by sampling 50 mature plants in each year. Seedling emergence and establishment are the most critical stages in the life cycle of *D. morisianus* (Cogoni et al., 2012) and therefore juvenile plants were used for the reintroduction. In a laboratory 200 seeds (100 per collection) were sown and incubated at the optimal germination temperature (15 °C; Cogoni et al., 2012). Subsequently, all the seedlings (92 and 94 for the first and second sowing, respectively) were placed in pots with sand collected in the species' habitat. Successful growth requires adaptation to environmental conditions and thus propagation requires hardening, to decrease the stress of planting out and increase survival (Aguraiuja, 2011); accordingly, no horticultural treatments were adopted. In November 2010 the 113 surviving plants (50 and 63 from the first and the second sowing, respectively) were reintroduced to the chosen site. The plants were placed in nine groups at a mean distance of c. 15 m from each other (Plate 1); the location of each group was determined by the availability of suitable microhabitats. The plants were then monitored monthly.

A key measure of the success of a plant reintroduction is the survival rate, the transplants ability to flower and set fruit, and the recruitment of new individuals (IUCN, 1998; Menges, 2008; Godefroid et al., 2011). The survival rate was high, with few plants dead in the first year and those remaining were alive after 24 months (Table 1). Forty and 65% of the plants became reproductive in the first and second years, respectively. The mean number of fruits per plant was 3.84 ± SE 2.48 and 7.97 ± SE 7.11 in the first and second years, respectively (Table 1), higher than that in the natural population (2.60; D. Cogoni et al., unpubl. data). The number of seedlings produced by the reintroduced plants (87; Table 1) is higher than recorded in the natural population, where seedlings comprise 9.95% of the population (D. Cogoni et al., unpubl. data). This is an important indicator for measuring reintroduction success, because recruitment is severely limited by summer drought in Mediterranean type ecosystems (Herrera, 1992).

PLATE 1 Reintroduction of *Dianthus morisianus* in the Portixeddu dune system, in collaboration with the staff of EFS (November 2010).

As far as we are aware there have been few reintroductions of plants on coastal dune systems in the Mediterranean Basin. Survival to the first summer is a key factor for measuring the success of a plant reintroduction

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TABLE 1 Summary of the total number of seedlings of *Dianthus morisianus* reintroduced, in nine groups, on the coastal dunes of south-west Sardinia (Fig. 1, Plate 1), and the number of dead plants, mortality rate, percentage of flowering and fruiting plants, mean number of fruits per plant, and the number of new seedlings in each of the first 2 years.

	First year (2010–2011)							Second year (2011–2012)					
Group	No. of seedlings	No. of dead plants	Mortality rate (%)	Flowering plants (%)	Fruiting plants (%)	Mean fruits per plant ± SE	New seedlings (21 Jan. 2012)	No. of dead plants	Mortality rate (%)	Flowering plants (%)	Fruiting plants (%)	Mean fruits per plant ± SE	New seedlings (24 July 2012)
1	12	1	8.3	33.33	25.00	2.33 ± 2.31	3	0	0	63.64	63.64	7.43 ± 3.26	0
2	10	0	0	40.00	40.00	4.00 ± 2.45	7	0	0	40.00	40.00	4.75 ± 4.35	8
3	9	0	0	66.66	66.66	4.50 ± 1.52	9	0	0	88.88	88.88	15.25 ± 13.17	12
4	15	0	0	46.66	46.66	3.14 ± 1.95	25	0	0	86.66	73.33	10.18 ± 6.15	22
5	15	0	0	40.00	33.33	3.60 ± 2.07	1	0	0	80.00	66.66	7.60 ± 6.33	0
6	6	0	0	33.33	33.33	1.50 ± 0.71	0	0	0	83.33	66.66	4.00 ± 3.46	3
7	20	2	10.0	25.00	25.00	3.20 ± 2.77	0	0	0	55.55	50.00	4.44 ± 3.09	1
8	16	0	0	56.25	56.25	5.78 ± 3.27	47	0	0	56.25	62.50	7.80 ± 6.09	41
9	10	1	10.0	40.00	30.00	2.67 ± 1.15	0	0	0	70.00	33.33	3.67 ± 2.52	0
Total	113	4	3.5	41.59	38.94	3.84 ± 2.48	92	0	0	68.80	60.55	7.97 ± 7.11	87

(Ballesteros et al., 2012) and on this measure the reintroduction of *D. morisianus* has been effective. In this habitat a reintroduction in autumn allows the plants to stabilize before the summer drought, and using an appropriate microhabitat, something unique to each taxa, is a key feature for successful plant reintroduction (Menges, 2008; Reckinger et al., 2010). If a suitable microhabitat can be located management activities such as watering may not be needed in the early stages of a reintroduction (Aguraiuja, 2011).

There is a positive relationship between the number of reintroduced plants and their survival, and using larger plants generally improves the success of reintroductions and reduces the mortality rate (Reckinger et al., 2010; Godefroid et al., 2011). Demographic and genetic theories both predict that the persistence time of a population increases with its initial size (Robert et al., 2007), and the effects of demographic stochasticity is lower in populations with > 50 plants (Menges, 1991). Knowledge of the biology of a species, in particular the critical life-cycle stage for survival, is crucial for reintroduction planning (Maunder et al., 2004), and expertise in ex situ multiplication and cultivation procedures, for emulating natural conditions, is a prerequisite (Aguraiuja, 2011). All considered, reintroduction is generally a relatively high-risk, high-cost activity (Gorbunov et al., 2008). The reintroduction of *D. morisianus*, however, is an example of a low-cost project: the involvement of researchers, public authorities and local stakeholders was voluntary, and site management was not intensive. Although at this stage the project is positive for all proposed indicators (Menges, 2008; Godefroid et al., 2011) long-term monitoring is planned, to examine the ecological and economic viability of the restoration options adopted. We believe that this reintroduction project can serve as a model for the reintroduction of other threatened species of the coastal dunes of Sardinia and, more widely, of the Mediterranean area.

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Biographical sketches

Donatella Cogoni, Giuseppe Fenu and Erica Concas have a particular interest in conservation of the threatened endemic plants of Sardinia. Gianluigi Bacchetta carries out geobotanical analyses in the western Mediterranean. The group's research is focused on conservation biology, including the demography, reproductive and pollination biology and population genetics of narrow endemic plant species.

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