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The impact of human trampling on a threatened coastal Mediterranean plant: The case of *Anchusa littorea* Moris (Boraginaceae)

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ABSTRACT

In a 5-period study (2007–2011) we examined the effects of human trampling on the last remaining population of *Anchusa littorea* on its sandy coastal habitat in Sardinia. This species, considered extinct in the wild for several years, was casually rediscovered in a small population at Is Arenas (SW Sardinia). We monthly monitored six trampled and six un-trampled permanent plots, mapping individuals and recording their size and reproductive variables. Trampled and un-trampled plots showed significant differences with respect to plant density, plant size and reproductive performance (flowers and fruits production) of *A. littorea*. This study demonstrated that human trampling represents a severe threat to the conservation of this species that can be appreciated as a keystone species with concern to human trampling effects on coastal dune plants. In case of *A. littorea* urgent measures should be undertaken to protect this unique remnant population in the dune system of Is Arenas. In particular, tourist paths should be redirected and confined to others areas in order to promote the natural expansion of *A. littorea* in its original habitat. A possible integrated strategy for the conservation and management of the species consists in a combination of *in situ* and *ex situ* measures.

Introduction

Coastal development by men has resulted in widespread modification of sandy ecosystems across the globe (Coombes et al., 2008; McLachlan and Brown, 2006; Nordstrom, 2000). In such ecosystems anthropogenic changes began at least two centuries ago (Nordstrom, 2000) and are predicted to intensify over the next few decades (Brown et al., 2008). Coastal sandy habitats are extremely sensitive to all forms of disturbance, including those connected with recreational tourism (Kutiel et al., 1999; Pickering and Hill, 2007), and human trampling is rated by among the most severe factors impacting sandy shores (Brown and McLachlan, 2002; Andersen, 1995; Kutiel et al., 2000; Lemauviel and Rozé, 2003). Human trampling, which often affects ecosystems of high conservation value (Andrés-Abellán et al., 2006; Bowles and Maun, 1982), is an integral part of the problems of conservation management of natural areas (Gallet and Rozé, 2001, 2002; Kutiel et al., 1999; Rossi et al., 2009).

Studies about effects of human trampling have mostly examined the characteristics of vegetation and soils that have been walked over, and compared these to un-trampled areas (Hamberg et al., 2010; Lemauviel and Rozé, 2003; Rickard et al., 1994; Rossi et al., 2006, 2009; Santoro et al., 2012). Several studies have analyzed the effects of human trampling specifically on dune ecosystems (e.g., Hylgaard, 1980; Hylgaard and Liddle, 1981; Kelly et al., 2003; Kerbiriou et al., 2008; Lemauviel and Rozé, 2003; Santoro et al., 2012). Moderate to high human trampling intensity can decrease plant diversity, cover, and productivity, whilst soil compaction increases (Andersen, 1995; Kutiel et al., 2000). The impact of trampling also varies between habitats. Notably shifting and semi-stabilized dunes may recover from damage more rapidly than stabilized sand dunes (Kutiel et al., 1999).

The problem of the human alterations of coastal habitats is very widespread along the Mediterranean basin as a result of urbanization, industrialization, and tourism activities (EEA, 1999), so that these habitats range among the most endangered environments in Europe (van der Meulen and Salman, 1996). However, few studies have focused on the effects of human trampling on Mediterranean sandy coastal ecosystems (Comor et al., 2008; Kutiel et al., 1999, 2000). Although for threatened plants the impact of tourism is particularly severe (Pickering and Hill, 2007), to our knowledge, the effect of human trampling on threatened plants growing on coastal sandy dunes has yet to be accurately assessed in Mediterranean coastal habitats.

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Fig. 1. Area of *A. littorea* population at "Is Arenas" locality (Arbus, SW-Sardinia). In the map the footpath that crosses the area of population is clearly be seen.

This paper describes the results of a long-term assessment on the effect of human trampling on *Anchusa littorea* Moris (Boraginaceae), a threatened endemic plant growing only on coastal dunes in southwest Sardinia (Fig. 1). Sardinia is a major centre of diversity and endemism for *Anchusa* in the Mediterranean area, with seven allopatric endemic *taxa*, four of them [*A. littorea*, *A. sardoa* (Illario) Selvi & Bigazzi, *A. crispa* Viv. subsp. *crispa* and *A. crispa* Viv. subsp. *maritima* (Vals.) Selvi & Bigazzi] occurring in coastal habitats (Bacchetta et al., 2008). These *taxa*, which are facing an increasing anthropogenic pressure on their habitats in coastal ecosystems, all are considered to be in a precarious conservation status (Bacchetta et al., 2008; Coppi et al., 2008). Quilichini and Debussche (2000) suggest that for *A. crispa* strong tourism pressure (in form of human trampling) on coastal dunes during the summer months is the most serious threat. Long-term data sets describing the natural population dynamics of *A. littorea* were lacking before the present investigations, and the biology and ecology of this species is still poorly investigated.

Until the seventy years of the previous century, the plant was distributed in several coastal systems of the Sardinia (S'Ena Arrubia, Terralba, Marina di Arbus, Piscinas, Is Arenas, Sant'Antioco and San Pietro – Bacchetta et al., 2008; Valsecchi, 1980). However, since it was not found during field investigations for over 25 years, *A. littorea* was considered extinct in the wild (Bacchetta and Pontecorvo, 2005). Bacchetta et al. (2008) casually rediscovered a small population of *A. littorea* at the Is Arenas locality (Arbus, SW Sardinia; Fig. 1). The site is frequented for recreation purposes by local people and it is crossed by a footpath; for this reason, human trampling has been suggested as an important threat for this population (Bacchetta et al., 2008).

Human trampling can be studied in two ways, from a conservation point of view or as a site management tool, and thus the aims of this study were: (1) to evaluate the effects of trampling on the *A. littorea* density, and (2) to evaluate the effects of trampling on its reproductive output, in order to suggest management recommendations for the conservation of the species and to characterize in general effects of trampling on plants in Mediterranean coastal dune habitats.

Materials and methods

Study species and site

A. littorea is an annual herb, with a small basal rosette. Each plant develops one or several cymes, with small tubular flowers. Corolla is light blue or white and the small mericarps are light grey-brown. The flowering period is from March to May and partially overlaps with the fruiting season, which is from April to July (Bacchetta et al., 2008; Valsecchi, 1980).

A. littorea grows in ephemeral herbaceous vegetation on dune systems of siliceous sand, in the discontinuities of *Juniperus macrocarpa* Sm. micro-forest. This plant community consists of several endemics, such as *Linaria flava* (Poiret) Desf. subsp. *sardoa* (Sommier) A. Terracc., *Phleum sardoum* (Hackel) Hackel, *Silene nummica* Vals. and other interesting annual plants, such as *Malcolmia ramosissima* (Desf.) Thell., *Brassica tournefortii* Goun and *Polycarpon alsinifolius* (Biv.) DC. (Bacchetta et al., 2008). In March 2007, the *A. littorea* population consisted of 371 individuals, with 131 reproductive plants, over a surface of c. 2800 m^2 (Fenu and Bacchetta, 2008).

The site of the investigated population (Fig. 1) is located in the Is Arenas dune systems, one of the most important and well-preserved coastal systems of Sardinia, which spreads to *ca.* 5 km inland. Geologically, the area mainly consists of Holocene sandstones and aeolian sands forms which present irregular heights, ranging from 10 to 80–90 m a.s.l. (Annino et al., 2000).

Available climate data from the nearest weather station (Montevecchio, *ca.* 12 km) indicate a typical Mediterranean annual pattern of temperature and precipitation with a large dry summer (from late May to late September).

Data sampling

From 2007 to 2011 the population of *A. littorea* was monthly monitored from March to July during the same time (around the 10^{th} of each month) by placing randomly twelve permanent plots of 1 m × 1 m; the corners of the plots were marked by aluminium