Ecological Engineering 95 (2016) 828–838

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng

Population dynamics of the endangered shrub *Myricaria germanica* in a regulated Alpine river is influenced by active channel width and distance to check dams

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ARTICLE INFO

Article history:
Received 20 March 2016
Received in revised form 1 June 2016
Accepted 16 June 2016
Available online 5 August 2016

Keywords:
German tamarisk
Demography
River restoration
River sediment
Biodiversity conservation
Natura 2000

ABSTRACT

Despite its high conservation and indicator value, there is a lack of information on the long-term dynamics of *Myricaria germanica* (L.) Desv. (German tamarisk), and of factors affecting its population density and viability. Here we studied the dynamics of adult and juvenile *M. germanica* at 19 sites during a seven year period (2009–2015) along a 30 km long stretch of an Italian Eastern Alpine river, by assessing a set of anthropogenic and geomorphological factors. Adult (239–571 individuals) and juvenile (62–292 individuals) population numbers showed no significant difference between years, and a remarkably uneven distribution among sites. Yet, several remnant populations have declined or disappeared in recent years and a few populations have increased. We found a positive effect of the width of the active channel on adult and juveniles plants. This means that anthropogenic river narrowing is a leading cause of the decline of the species along river banks. For juveniles, abundance also decreased with distance from downstream check dams. We conclude that in the regulated river studied, the conservation of *M. germanica* appears to be possible not only as a result of natural flow dynamics, but also at an artificial sediment storage area upstream of a check dam with a semi-natural river dynamic that maintains favourable riverine habitats. Our results are useful in a decision-making framework for the conservation of *M. germanica*, for river restoration and for flood protection in alpine valleys.

1. Introduction

Natural rivers are complex and dynamic ecosystems characterized by variable biological and morphological channel structures (Richards et al., 2002; Tockner and Stanford 2002). Naturally braided rivers and their fluvial processes are characterized by a dynamic equilibrium between sediment accumulation and sediment erosion, which generates multichannel fluvial systems where sediment supply, intermittent water discharge, and bank erosion create an ever-changing mosaic of landform types (Tockner et al., 2006). In the last two centuries, natural river dynamics and morphology have been greatly modified by river control methods. A reduction in width, anastomisation and sediment transport reduction, a decrease in the ground water table and the loss of ecological connectivity are among the most negative consequences. Species typical of pioneer stages have decreased rapidly or are becoming extinct (Müller and Scharm, 2001). Natural erosion processes have been suppressed below dams, thus reducing the regeneration of pioneer species and favouring an unidirectional succession towards lower diversity (Ward and Tockner, 2001). Furthermore, channelization is having severe effects on riverine biological communities because it homogenizes habitat structure, leading to the loss of ecological niches (Meyer et al., 2013). As a result, the maintenance and restoration of hydro-geomorphic dynamics in rivers are currently considered of fundamental importance to develop a habitat mosaic and habitat features capable of supporting a variety of organisms (Gumiero et al., 2013; Ravazzolo et al., 2015).

Alpine rivers host a natural flora adapted to ecotonal environmental conditions between water bodies and the floodplain, recurrently changed by fluvial processes (Camporeale et al., 2013). Riparian vegetation is a vital component of the alpine biome, because it provides breeding, resting and foraging sites for many wildlife species (Banner and MacKenzie, 1998). Riparian vegetation protects the banks against erosion (Tal et al., 2004), contributes to hyporheic water filtering and influences runoff (Tabacchi et al., 2000). Like in other regions, the natural dynamic state of most

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http://dx.doi.org/10.1016/j.ecoleng.2016.06.066
0925-8574/

alpine streams, which sustains a diversity of successional stages, has been disrupted by anthropogenic disturbances (Ward and Tockner, 2001). Riparian ecosystems of the Alps are now among the most endangered and have been increasingly subjected to channelisation, gravel extraction and flow regulation (Müller, 1995). Nonetheless, intermediately-disturbed Alpine rivers can display an unusually high heterogeneity of woody species (Sitzia et al., 2015).

Pioneer communities can be used as representative indicators not only of the hydrogeomorphic functionality of a river but also of the suitability of restoration actions, in terms of habitat diversification and increase in riparian species richness (Dufour et al., 2007). Plants found in the amphibious zone of the riparian ecosystem are adapted to harsh habitat conditions by reducing their growth rate and by taking advantage of the low availability of water and nutrients; these plants are termed stress tolerators (Grime, 1979). Müller (1995) defined these species as 'stress-strategists', i.e. species that cannot live in habitats other than alpine floodplains such as the pioneer perennial shrub *Myricaria germanica* (L.) Desv. (German tamarisk). *M. germanica* can grow as old as between 21 (Schweingruber et al., 2007) or 70 years (Frisendahl, 1921), but plants in the wild are usually eradicated within 15 years by periodical flooding or are outcompeted by plants of later succession stages (Lener et al., 2013). This species is therefore physiologically and morphologically adapted to stochastic events, either floods or droughts. Physiological adaptations include dispersal by wind and water, quick germination, high re-sprouting capacity even when buried by debris, and continuous summer blooming. The small leaf surface reduces evaporation, and the flexible branches and deep and dense root system prevent dislodging and promote drought resistance (Müller, 1995, 1998). *M. germanica* exhibits a mixed-mating system, in which both outcrossing and selfing occur (Werth and Scheidegger, 2014). Long distance dispersed seeds make this species adapted to temporal isolation (Müller, 1995, 1998). However, seed germinability declines fast and the seed bank is not persistent in the soil (Müller and Scharm, 2001; Lener et al., 2013). To summarise, the biological traits of *M. germanica* make it a good indicator of natural riverine conditions, and its presence ensures that other habitats of conservation interest are in the vicinity, i.e. it is considered a keystone and flaghship species (Kudrnovsky, 2013).

The Alpine distribution of *M. germanica* used to be wide ranging, from lowland floodplains to mountainous riparian habitats (Kudrnovsky, 2013). In the last 150 years, its habitat extent has been constrained considerably by flow regulation with embankements, check dams and pollution, and eutrophic conditions favouring the development of competitive shrub layers, which outcompete the stress-strategist *M. germanica* (Müller, 1995; Kudrnovsky, 2013). Therefore, *M. germanica* is considered an endangered species in several national and regional red lists (e.g., Korneck et al., 1996; Rossi et al., 2013), even if it has not yet been assessed by the IUCN red list (IUCN, 2015). *M. germanica* is the dominant species of the *Salici-Myricarietum* pioneer association (Moor, 1958), which develops on gravel bars in braided alpine rivers in the temperate zone of Europe and Asia, on periodically flooded sites with silt containing fine moist sand. This association is listed in Annex I of the Habitats Directive under the 3230 code "Alpine rivers and their ligneous vegetation with *Myricaria germanica*" (European Commission, 2013) and, as such, requires protection within the Natura 2000 network of the European Union. It is also classified as endangered by the IUCN red-list of ecosystems (Essl, 2013).

M. germanica can reproduce easily by cuttings or seeds (Koch and Kollmann, 2012), but translocations have shown variable success rates (Michielon and Sitzia, 2015). The reintroduction of this species has recently been the subject of projects of national and international interest, such as in Austria (e.g., Feichtinger and Gumpinger, 2012), Germany (e.g., Koch and Kollmann, 2012), Switzerland (e.g., Rieben, 2009) and Italy (e.g., Zanichelli, 2001).

The decline of this species of high conservation value is generally explained by the disruption of the river dynamic, but the role of specific anthropogenic and geomorphological determinants have not yet been quantitatively assessed. Therefore, the objective of this study was to identify factors that affect the long-term population dynamics and viability of *M. germanica*. To address this objective, we surveyed the number of adult and juvenile individuals of *M. germanica* over a seven year period (2009–2015) along a 30 km stretch of the Avisio River, a South-Eastern Alpine river where several remnant populations have declined in recent years. From each population site we measured the presence and intensity of several geomorphological and anthropogenic factors. Our hypotheses were that; (i) adults and juveniles are decreasing steadily in number of individuals with time, and (ii), variability in population size is explained by riparian ecosystem variables and the occurrence of engineering works, mainly check dams and artificial sediment storage areas.

2. Methods

2.1. General description of the study area

The study area is situated within the borders of the Avisio River catchment basin, located in Trentino, in the Italian Eastern Alps (Fig. 1).

The 91.5 km long Avisio River is one of the most important tributaries of the Adige River. The Avisio drainage basin area is 940 km^2 in size, with the highest elevation at 3343 m a.s.l., including the Fassa Valleys, the Fiemme Valleys and the Cembra Valleys, and a small part of the Pinè Plateau. The Avisio River originates at Lake Fedaia (2028 m a.s.l.) from the Marmolada glacier, flows from NE to SW, and enters the Adige River at Lavis (195 m a.s.l.), where it forms a vast alluvial plain. The river has an average gradient of 2% (Autorità di Bacino del Fiume Adige, 2008). The geological structure of the basin is mainly characterized by the effusive system formation of the Permian porphyry (porphyric Atesina platform) and by sedimentary formations of the Triassic, while the valley floor presents Quaternary sedimentary cover (Vardabasso, 1930). From a morphological aspect, the Avisio Valley represents three distinct areas: the Fassa Valley upstream of Predazzo, characterized by higher altitudes (>1000 m a.s.l.), the Fiemme Valley downstream of Predazzo, wider and of lower elevation, and the Cembra Valley, a deep and narrow gorge.

The climate is continental, with a Mediterranean influence in the most south-western part. The Avisio River is characterized by a pluvio-nival flow regime. Over the last 25 years (1986–2010), the average discharge was 5.9 m^3 s^{-1} at Soraga in the Fassa Valley, 12.9 m^3 s^{-1} at Cavalese in the Fiemme Valley, and 5.5 m^3 s^{-1} (this lower value is caused by hydropower utilization) at the river mouth (Bortolotti F., pers. comm., Mar 16, 2010).

2.2. The decline of Myricaria germanica

General changes in the suitability of habitat conditions for *M. germanica* can be divided into three periods. The first period occurred from the end of the Little Ice Age to 1950s, and enhanced fluvial and morphological activity in the Avisio River, particularly between 1750 and 1900, like in many other alpine streams of the Alps (Rumsby and Macklin, 1996). This, coupled with low forest cover and little river manipulations, resulted in the high availability of sediment and a wide active channel. The shrubby riparian vegetation was poor due to intense animal grazing (Comiti, 2012) and firewood collection. These conditions likely resulted in arrested ecological succession of riparian vegetation, favouring *M. germanica*. The second period occurred in the 1950s when sediment-rich