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Effects of management regimes and extreme climatic events on plant population viability in *Eryngium alpinum*

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ABSTRACT

Extreme climatic events like the 2003 summer heatwave and inappropriate land management can threaten the existence of rare plants. We studied the response of *Eryngium alpinum*, a vulnerable species, to this extreme climatic event and different agricultural practices. A demographic study was conducted in seven field sites between 2001 and 2010. Stage-specific vital rates were used to parameterize matrix population models and perform stochastic projections to calculate population growth rates and estimate extinction probabilities. Among management regimes, spring grazing and land abandonment decreased vital rates and population growth, while autumn grazing and late mowing had positive effects on population viability. The 2003 heatwave reduced fecundity rates and survival rates. Only spring grazed sites presented considerable extinction risk. Stochastic projections showed that an increased frequency of 2003-like events may exacerbate extinction risk, but extinction probability depends mainly on land management regimes. To better conserve *E. alpinum* populations, we recommend conversion of presently spring grazed and abandoned sites to late mowing or autumn grazing.

1. Introduction

Extreme climatic events can negatively affect plant population dynamics and increase extinction risk in threatened species (Marrero-Gomez et al., 2007; Maschinski et al., 2006). Increased temperature extremes and severe drought induce significant stress to plants, which can lead to increased mortality rates (McDowell et al., 2008; Saccone et al., 2009; Yordanov et al., 2000) and reduced photosynthetic rates and reproductive performances (Chaves, 1991; Epron and Dreyer, 1993; Schulze, 1986; Yordanov et al., 2000). Europe has undergone an extremely dry and hot summer in 2003 (Meehl and Tebaldi, 2004; Schär et al., 2004; Zaitchik et al., 2006), which resulted in exceptional human mortality (Le Tertre et al., 2006), decreased ecosystem productivity (Ciais et al., 2005; Reichstein et al., 2007), loss in crop yield (van der Velde et al., 2010) and increased plant mortality (Saccone et al., 2009). Such reductions in plant survival may compromise the persistence of vulnerable plant populations and increase their risk of extinction. A temperature anomaly such as that registered in 2003 had never been observed in the last 140 years (Schär et al., 2004). The occurrence probability of such an extreme event can nonetheless increase with global climate change as a result of the greater between-year variability in meteorological conditions and an increase of mean temperatures (Meehl and Tebaldi, 2004; Schär et al., 2004).

Many Alpine plant species can be found in sites that were historically used as pastures for grazing by domestic animals or meadows harvested by farmers. Current management strategies in Alpine ecosystems still include seasonal mowing or grazing, but with varying frequency, intensity and timing, and absence of management is also common. These new management regimes can lead to changes in plant community structure (Jantunen et al., 2007; Stammel et al., 2003) and to an increase of extinction risk for the most vulnerable species (Brys et al., 2004; Jantunen et al., 2007; Lennartsson and Oostermeijer, 2001; Marage et al., 2008). Populations can exhibit different vital rates and population growth rates between sites subject to different management strategies and characterized by variable ecological conditions. Some management conditions might not allow rare and protected plant species to persist and are incompatible with their conservation.

The objective of this work was to study the population dynamics of *Eryngium alpinum*, a rare Alpine perennial plant threatened

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by changes in land use (Cherel and Lavagne, 1982; Gaudeul and Till-Bottraud, 2003, 2004, 2008; Gillot and Garraud, 1995), in relation to: (i) the effects of the 2003 heatwave and (ii) the effects of management regimes. Field data were collected between 2001 and 2010 in seven sites submitted to various management regimes and survival, flowering and fecundity rates were measured for plants of different life stages: seedlings, juveniles, vegetative adults and reproductive adults. Through statistical analysis of vital rates and demographic modeling, we were able to predict how a 2003-event will increase the extinction risk of populations and to identify the best management regimes for the conservation of this species.

2. Materials and methods

2.1. Species, study sites and management regimes

E. alpinum L. (Apiaceae) is a perennial, rare species. Its distribution area extends over the Alps (France, Italy, Switzerland, Austria, Croatia) between 1300–2500 m (Cherel and Lavagne, 1982). The species is present in open sunny but relatively humid habitats; restricted to hayfields and avalanche corridors. The species is protected by the Bern convention, the European Habitat Directive of Natura 2000 (Wyse-Jackson and Akeroyd, 1994), the French Red List of protected species and it is considered vulnerable by IUCN (Gillot and Garraud, 1995). The threats are mainly due to human activities such as cutting for commercial use (flower bouquets) and land use change (from late hay harvest to spring grazing, or abandonment leading to land closure by forest). Flowering occurs from mid July to mid August. Mature fruits (schizocarpous diachenes) fall near the mother plant at the end of August and seeds germinate in the spring.

Two regions were studied: the Pralognan region (Pralognan la Vanoise, Savoie, France) is located in the "aire d'adhésion" of Vanoise National Park and the Fournel region (L'Argentière la Bessée, Hautes Alpes, France) is located in the "Vallon du Fournel-les Bans" Natura 2000 site and the "aire d'adhésion" of Ecrins National Park. The two regions are located approximately at the same elevation (1500 m) but in contrasting situations: Pralognan is in the Northern Alps on a steep East-facing slope while Fournel is in the Southern Alps on a mild North-facing slope. Respectively three (DES, BER and BOU in Fournel, located 1–5 km apart) and four (PRA, PRB, PRC and PRD in Pralognan, located less than 100 m apart) different sites were studied. Three permanent rectangular plots, located less than 5 m apart and measuring between 4 and 20 m^2, were set up for annual census in each site. In the two regions, the National Parks are testing various management practices to limit or even reverse the population decline observed due to agricultural abandonment (Table 1). These management practices are based on local traditional and present uses of mountain prairies.

Table 1
Management regimes in the seven sites.

Region	Site	Management regime
Fournel	DES	Autumn grazing: 1800 sheep (306 LU[a]; 7.1 ha, 43 LU/ha) for 1 week around the 10th of September and for 2 weeks between the 1st and the 15th of October
	BER	Late mowing (after the 15th of August)
	BOU	Spring grazing: 800 sheep (136 LU on 3.0 ha, 45 LU/ha) for 10 to 15 days between the 5th and the 15th of June
Pralognan	PRA	Abandoned
	PRB	Late mowing every other year
	PRC	Late mowing every year
	PRD	Spring + autumn grazing: 40 heifers and occasionally some cows (24 LU, 2.2 ha, 11 LU/ha) from the 1st of June to the 1st of July and from the 1st of September to the 10th of October

[a] Livestock unit (LU) coefficients were 0.17 for sheep and 0.6 for heifers (Conseil Fédéral Suisse, 1998).

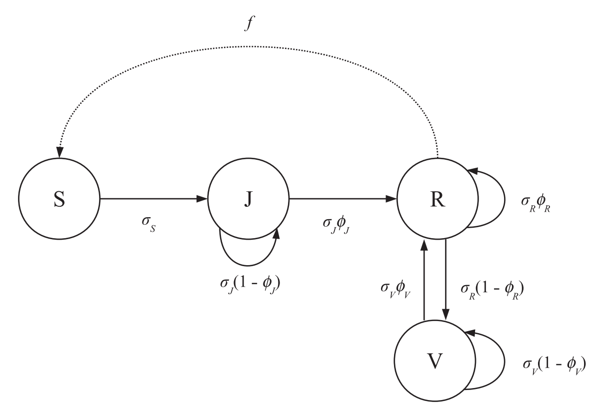

Fig. 1. Life-cycle of *E. alpinum*. S, seedlings; J, juveniles; V, vegetative adults; R, reproductive adults; σ_i, survival rate; ϕ_i, flowering rate; *f*, fecundity rate.

2.2. Life cycle and data collection

The life cycle of *E. alpinum* was subdivided into four biological stages (Fig. 1). Seedlings (S) are small plants younger than one year. Juveniles (J) are older than one year and have not yet flowered in their life. Reproductive adults (R) are plants bearing one or more inflorescences. Vegetative adults (V) do not bear inflorescences but have already flowered in their life. Seedlings become juveniles in one year, while juveniles and adults can remain in the same stage for more than one year or make a transition to another stage.

For the first 2 years of survey (2001 and 2002), juveniles and vegetative adults were distinguished on the basis of morphological traits (number of basal leaves and length of the longest petiole). An individual was considered juvenile when it bore less than four leaves and when the longest petiole measured less than 20 mm, otherwise it was classified as a vegetative adult. These criteria had to be slightly modified for BOU, where spring grazing results in enhanced vegetative growth and plants have more leaves (juveniles identified as individuals bearing less than ten leaves with the longest petiole measuring less than 20 mm).

In each permanent plot, plants were individually tagged and their presence/absence and biological stage were scored every year from 2001 to 2010, leading to a dataset including nine annual transitions, the first one being 2001–2002 and the last one being 2009–2010. Stage-specific annual survival rates σ_i were defined as the proportion of plants surviving from one census to the next one. Stage-specific flowering rates ϕ_i were defined as the proportion of surviving plants that make the transition to the reproductive adult stage. The annual fecundity rate *f* for year *t* was defined as the ratio of the number of seedlings emerging in year *t* + 1 over the number of reproductive adults in year *t*, assuming equilibrium between seed immigration and emigration among plots and no seed bank. Seed immigration and emigration rates between plots were likely equivalent because plots were located in areas of uniform density; moreover, fruits disperse by gravity over a few decimetres from their mother plant (Gaudeul and Till-Bottraud, 2004). As the number of seedlings was only recorded since 2003, seedling survival rate in the 2001–2002 and 2002–2003 transitions and fecundity rate in the 2001–2002 transition were not available. No reproductive adult was observed in BOU in 2008, so survival and flowering rates for the reproductive adult stage could not be estimated. Since census was performed in July, the effect of the 2003