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Beneficial effects of restoration practices can be thwarted by climate extremes

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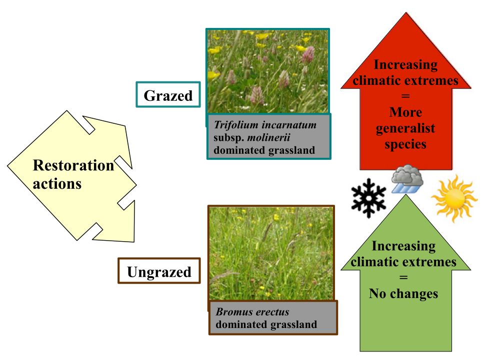
HIGHLIGHTS

- The interaction of climate extremes and grazing thwarted restoration success.
- Synanthropic species took advantage, in grazed site, of the increasing climate extremes.
- Endemic species decreased with an increase of heavy rainfall events.

GRAPHICAL ABSTRACT



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ABSTRACT

The impacts of climate extremes on species, communities and ecosystems have become critical concerns to science and society. Under a changing climate, how restoration outcomes are affected by extreme climate variables is a largely unknown topic. We analyzed the effects of experimental factors (grazing and sowing of native species), extreme climate events (intense precipitation and extreme temperatures indexes) and their combination on the restoration progress of a dry, calcareous grassland in Tuscany (Italy) with a 1 year before/15 years continuous annual monitoring after, control/impact (BACI) experiment. Grazing had a beneficial effect on the diversity of the grassland, while sowing had a limited impact. The climatic index that most affected the entire plant community composition was the number of very heavy precipitation days. The interaction of grazing and extreme climatic indexes had a significant detrimental effect on restoration outcomes, increasing the cover of synanthropic and Cosmopolitan-Subcosmopolitan generalist species and decreasing the cover of more valuable species such endemic species. In the richest grazed plots, species richness showed a lower sensitivity to the average precipitation per wet day but in grazed site, restoration outcomes can be negatively influenced by the intensification of precipitation and temperature extremes. In a context of progressive tropicalization of the Mediterranean area, to assist managers setting achievable restoration goals, restoration practitioners should consider that climate extremes might interfere with the beneficial effects of restoration practices.

1. Introduction

The increase in the frequency and magnitude of climate extremes is a well-accepted feature of forecast alterations to the global climate

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(IPCC, 2007). How climate extremes affect species, communities and ecosystems has become critical to science and society (Jentsch et al., 2011; Smith, 2011; Lloret et al., 2012; Hoover et al., 2014; Chelli et al., 2017; De Boeck et al., 2017) but several effects on biodiversity, as the implications for ecological restoration, are still unknown (Harris et al., 2006). For example, it is acknowledged that restoration outcomes can be driven by biotic and abiotic factors (Stuble et al., 2017).We know that the effect of rainfall on species cover in serpentine grassland depends on the rate of disturbance, and that extreme climate events, such as *el Niño* cycles, contribute to the invasion of non-native species (Hobbs et al., 2007). We also learned that grazing and drought interact, to determine resistance to invasion by perennial grass communities (Han and Young, 2014) and that mowing and drought have different effects on diversity of xeric and mesic communities (Maalouf et al., 2012). Nevertheless, how climate variables, such as extreme temperatures or heavy rain, interact with the progress of restoration practices is a largely unexplored topic.

The evaluation of restoration success is often undermined by the lack of clearly defined restoration goals, the scarcity of shared methods for measuring restoration efficacy and by a chronic absence of monitoring, as demonstrated for grasslands (Waldén and Lindborg, 2016). The methodological shortcomings in monitoring are accompanied by the tendency of ecologists to study vegetation change and attribute it to individual causes when, instead, the study of multiple causes and effects and their interactions is essential to understanding, managing and restoring ecosystems more effectively (Hobbs et al., 2007; Stuble et al., 2017). In this context, long-term data become increasingly important to interpreting patterns of response on entire community composition or species distributions and to measure the long-term restoration success (Hobbs et al., 2007).

Grasslands are particularly important for the diversity of small-scale vascular plants (Butaye et al., 2005; Dengler et al., 2014) since semi-natural, temperate grasslands host the world record on the number of taxa in 1m^2 (Wilson et al., 2012). The conservation of calcareous grassland communities is strongly advocated for, due to their capacity to support high biodiversity as well as rare and/or endangered species (Willems, 2001). However, changes in land use have resulted in a substantial decline in the extent and ecological quality of semi-natural grassland communities, over the past two decades across Europe (van Dijk, 1991; Bakker and Berendse, 1999; Critchley et al., 2004; Ridding et al., 2015). Restoration activities have been undertaken in many sites to improve the habitat conditions and increase the area to prevent any further losses of their ecological services and value (Waldén and Lindborg, 2016). Maccherini and Santi (2012) using a long-term (10 years), Before/After-Control/Impact experiment (BACI) showed that different restoration practices substantially affect the structure and composition of a calcareous grassland. After 10 years of observation, the perennial grass *Bromus erectus* and the annual legume *Trifolium incarnatum* subsp. *molinerii* were the species most influenced by restoration measures: grazed plots were dominated by *T. incarnatum* subsp. *molinerii,* an annual Euri-Mediterranean species typical of ex-arable and arable land, while the perennial *B. erectus,* a Paleotemperate species typical of grasslands, dominated ungrazed plots (Maccherini and Santi, 2012).

The Mediterranean Basin is considered a climate change hotspot sensitive to global warming (Giorgi and Lionello, 2008). In Italy, during the last 55 years, extreme temperature indices showed a general warming trend for the entire peninsula (Toreti and Desiato, 2008; Chelli et al., 2017) and in future decades heavy rainfall and summer heat waves are expected (ISAC-CNR, 2009). In Tuscany, precipitation indices showed a negative trend (years 1955–2010) in the number of wet days, associated with an increase in the contribution of heavy rainfall events to total precipitation (Regione Toscana, 2012).

Under a climate change scenario, characterized by an intensification of extreme climate episodes, after 5 years from the study focusing on restoration strategies (Maccherini and Santi, 2012), we used a *1 year before - 15 years after continuous annual* control-impact (Before/After-Control/Impact) experiment to investigate how experimental factors and extreme climate events affect the restoration of a dry, calcareous grassland. Specifically, we tested the following questions: do climatic extremes interact with experimental factors (grazing and sowing)? If so, how do they interact? Which group of species is more resistant to the influence of experimental factors and/or climatic extremes?

2. Materials and methods

2.1. Study area

The experiment was carried out in close proximity to the summit of Monte Labbro (42°49′13"N, 11°31′33″E), Tuscany (Italy), a predominantly calcareous massif on the Uccellina-Monte Amiata ridge (Lazzarotto, 1993). The area is included in a Site of Community Importance/Special Protected Area (SCI/SPA, "Monte Labbro and Upper Albegna Valley"). The summit area (1193 m a.s.l.) has been grazed for centuries, mostly by sheep, with human traces dating back to the Bronze Age (Pistoi, 1989). From the 1960s onwards, the grazing pressure decreased, triggering the secondary succession of semi-natural grasslands into increasingly dense scrublands. The area is characterized by a mosaic of community types, including well preserved, semi-natural, dry, calcareous grasslands with few or no shrubs, overgrown grasslands, dense scrublands with *Prunus spinosa*, *Rubus ulmifolius* and *Cytisus scoparius*, and woodlands with *Acer campestre* and *Acer monspessulanum*. In the period comprising late summer of 2000 to early spring 2001, the laborers manually cut all shrubs (except all individuals of *Juniperus communis* and some of *P. spinosa, Rosa canina* and *Crataegus monogyna*, for faunistic conservation purposes; for more details see Maccherini et al., 2007, 2014; Maccherini and Santi, 2012).

We located the experimental plots in a cleared overgrown pasture (before cutting, *Prunus spinosa* covered 80%), grazed by donkeys, which were reintroduced into the area few years before restoration management; the site is occasionally grazed by sheep, hares and cattle. Stock density (0.5 ha^{-1} yr^{-1}) did not change during the years of observation.

2.2. Experimental design, measurements and climate data

We conducted a 1 year before/15 years after-control/impact experiment (BACI), with continuous monitoring because this design overcomes the problem of attributing changes to an impact rather than natural variability (Stewart-Oaten et al., 1986). In fact, to conclude that the observed changes in restored site (Impact site) were determined by restoration actions (i.e. experimental factors), it's necessary to compare the plant composition of the restored sites with degraded areas, similar to the restored ones, which were not manipulated or managed (Control site). This comparison allows us to take into account and measure the natural variability among sites in the absence of disturbance (Chapman and Underwood, 2000; Benedetti-Cecchi and Osio, 2007). In this context, the restoration measures (i.e. grazing and sowing of native species, the experimental factors) are the source of disturbance and the effects of the restoration are defined as the differences in community composition between the two levels of factor grazing and sowing.

We tested the effects of grazing (two levels: grazed and ungrazed) and the sowing of native species (two levels: sown, non-sown) on restoration of a calcareous grassland communities. We established, in spring 2001, a randomized, block design in an area with a dense cover of *P. spinosa* (80%) that was cut in the early spring of 2001. The area lies on a moderately steep slope (15°) with a south-west aspect. Four 3 × 5 m experimental plots were established in each of four blocks stratified on elevation. In the summer of 2001, we harvested seeds from a reference grassland community, in the study area (Maccherini et al., 2007). Individual plots in each block were randomly assigned to one