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Exploring the compass of potential changes induced by climate warming in plant communities

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ABSTRACT

New models are required to predict the impacts of future climate change on biodiversity. A move must be made away from individual models of single species toward approaches with synergistically interacting species. The focus should be on indirect effects due to biotic interactions. Here we propose a new parsimonious approach to simulate direct and indirect effects of global warming on plant communities. The methodology consists of five steps: a) field survey of species abundances, b) quantitative assessment of species co-occurrences, c) assignment of a theorised effect of increased temperature on each species, d) creation of a community model to project community dynamics, and e) exploration of the potential range of temperature change effects on plant communities.

We explored the possible climate-driven dynamics in an alpine vegetation community and gained insights into the role of biotic interactions as determinants of plant species response to climate change at local scale. The study area was the uppermost portion of Alpe delle Tre Potenze (Northern Apennines, Italy) from 1500 m up to the summit at 1940 m.

Our work shows that: 1) unexpected climate-driven dynamics can emerge, 2) interactive communities with indirect effects among species can overcome direct effects induced by global warming; 3) if just one or few species react to global warming the new community configuration could be unexpected and counter-intuitive; 4) timing of species reactions to global warming is an important driver of community dynamics; 5) using simulation models with a limited amount of data in input, it is possible to explore the full range of potential changes in plant communities induced by climate warming.

1. Introduction

Evidence of changes in high-latitude and alpine plant communities due to ambient warming over recent decades have been reported in observational studies (Capers and Stone, 2011; McManus et al., 2012; Callaghan et al., 2013). Studies investigating the consequences of future climate warming on species distributions often apply the assumption that species respond to climate change in individual ways (Tylianakis et al., 2007, 2008; Baselga and Araújo, 2009; Meineri et al., 2012; Casazza et al., 2014). However, all plant species are embedded in complex networks of interactions with other organisms, and the ways in which changes to species combine across the whole community may be often unclear, largely because of difficulties in quantifying such complexity (McCann, 2007). The stress gradient hypothesis states that positive interactions are more common in abiotically stressful habitats (Bertness and Callaway, 1994). Previous studies have shown that facilitation is promoted under different environmental constraints (Choler et al., 2001; Tirado and Pugnaire, 2005). Facilitations tend to be more common in plant communities in more extreme environments (Liancourt et al., 2005; Brooker et al., 2008). There is evidence that interactions can shift from facilitation in colder environments to competition in warmer environments (Callaway et al., 2002). Furthermore, the responses are not always linear over time, as shown for vascular plants (Hollister et al., 2005; Alatalo and Little, 2014) and also for bryophytes and lichens (Alatalo et al., 2015).

The indirect effects induced by global warming and the complex feedbacks that exist among species indicate that species-specific predictions are not necessarily consistent with those of the

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community (Ferrier and Guisan, 2006; Suttle et al., 2007; Tylianakis et al., 2007; Ferrarini, 2013). Biotic interactions may complicate the wide-scale control that the environment has on species distribution (Suttle et al., 2007; Dorji et al., 2016) and local interactions may become increasingly important for species range dynamics in the future (Brooker et al., 2007). This is particularly true for mountain areas, where local climates diverge from that of the region (Trivedi et al., 2008).

Very few of the most commonly-used models deal explicitly with complex temperature-induced interactions among species. A more complete understanding of the effects of global warming scenarios on communities necessarily requires some kind of scaling from climate-species interactions to the whole interaction network (McCann, 2007). Thus single-species studies should be expanded to include a more general multi-species assessment, based on the synthesis of individualistic models (Ellis et al., 2007). However, changing individual species models to account for complex biotic interactions is challenging since such models are highly sophisticated, data-demanding and require detailed knowledge of ecological processes that is usually unavailable for most species (Araújo and Luoto, 2007).

Here we propose a new community model to simulate direct and indirect effects of global warming on species abundances in plant communities. The proposed methodology aims to tackle some important limitations of common approaches, since it: a) can deal with an unlimited number of plant species, b) takes into account complex biotic interactions among species, c) can be applied at fine spatial resolution, and d) is parsimonious since it requires a limited amount of data. We applied this community model to explore a number of possible climate-driven dynamics in an alpine vegetation community, and to gain insights into the role of biotic interactions as determinants of plant species response to climate change at local scale.

2. Materials and methods

2.1. Study area and field sampling

The study area (barycentre coordinates: 1,630,335 E; 4,885,562 N; 124.68 ha) was the uppermost portion of Alpe delle Tre Potenze (Northern Apennines, Italy) from 1500 m up to the summit at 1940 m (Fig. 1).

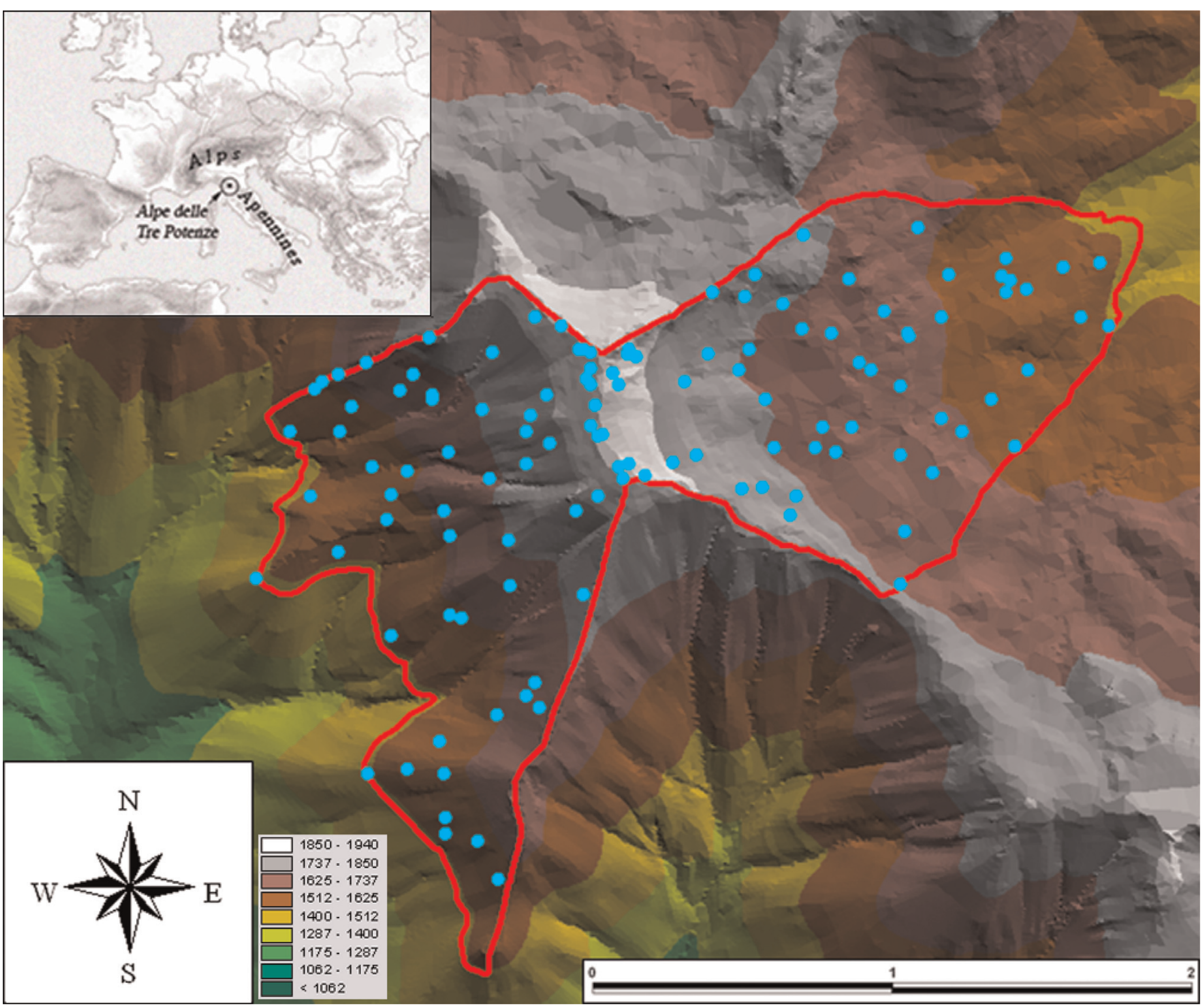

Fig. 1. Sampling plots (blue points) within the study area (red polygon) overlying the 3-D topographical model of the study area. The scale bar is expressed in km. The numbers in the legend refer to meters above sea level. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)