



Original Research Article

Prediction of climate warming impacts on plant species could be more complex than expected. Evidence from a case study in the Himalaya

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ARTICLE INFO

Article history:

Received 31 May 2013

Received in revised form 20 February 2014

Accepted 20 February 2014

Available online 23 March 2014

Keywords:

Climate change

Optimal reintroduction

Plant species conservation

Seed dispersal

Spatial simulation model

Threatened species

ABSTRACT

Many studies have investigated the possible impact of climate change on the distributions of plant species. In the present study, we test whether the concept of potential distribution is able to effectively predict the impact of climate warming on plant species.

Using spatial simulation models, we related the actual (current species distribution), potential (modelled distribution assuming unlimited dispersal) and predicted (modelled distribution accounting for wind-limited seed dispersal) distributions of two plant species under several warming scenarios in the Sagarmatha National Park (Nepal). We found that the two predicted distributions were, respectively, seven and nine times smaller than the potential ones. Under a +3 °C scenario, both species would likely lose their actual and predicted distributions, while their potential distributions would remain partially safe. Our results emphasize that the predicted distributions of plant species may diverge to a great extent from their potential distributions, particularly in mountain areas, and predictions of species preservation in the face of climate warming based on the potential distributions of plant species are at risk of producing overoptimistic projections.

We conclude that the concept of potential distribution is likely to lead to limited or inefficacious conservation of plant species due to its excessively optimistic projections of species preservation. More robust strategies should utilize concepts such as “optimal reintroduction”, which maximizes the benefit–cost ratio of conservation activities by limiting reintroduction efforts to suitable areas that could not otherwise be reached by a species; moreover, such strategies maximize the probability of species establishment by excluding areas that will be endangered under future climate scenarios.

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1. Introduction

Concern has escalated in recent years regarding the potential effects of climate change on species and ecosystems (Parmesan and Yohe, 2003; Gilman et al., 2010; Araújo et al., 2011). The IPCC (2007) remarked that future climate change is estimated to exacerbate the loss of species, especially of those taxa with strict climate requirements and limited migratory capabilities (Vittoz et al., 2009). Mountainous areas with cold, alpine climates have received particular interest in terms of changes in species distribution (Körner, 1999). Mountain ecosystems are susceptible to the impacts of a rapidly changing climate and provide interesting locations for the early detection and study of the

signals of climatic change (Beniston, 2003). Nogués-Bravo et al. (2007) predicted that mountainous areas will experience unprecedented rates of warming during this century, two to three times greater than the rate observed during the previous century. The midlatitude mountains of Asia are expected to show the greatest increase in average temperature among the mid-latitude mountain systems of the world (Nogués-Bravo et al., 2007).

Although few data are available for the Himalayas (e.g., Giam et al., 2010), several works have focused their attention on the impacts of climatic variation on the plants of other alpine areas (Thuiller et al., 2005; Parolo and Rossi, 2008). In a study of approximately 85 subalpine and alpine nonwoody plants in the Austrian Alps, Dirnböck et al. (2003) predicted that 40–50% of these species could become extinct due to climate change in the next 50 years. Guisan and Theurillat (2000) predicted that nearly 40% of the 63 alpine and nival plant species in their study could lose more than 90% of their suitable habitat. Reductions in distribution or extinction are particularly likely for species with

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weak dispersal capacity (Engler et al., 2009), while efficiently dispersed species have a greater chance of rapidly responding to climate warming (Vittoz et al., 2009).

The major limitation of these models is that they tend to ignore dispersal restrictions by referring to the potential distributions of plant species (Engler et al., 2009). In an ideal environment, a species is expected to occupy a geographical area that strictly corresponds to its potential niche, thus occurring everywhere that environmental conditions are suitable (Pulliam, 2000). In reality, this potential distribution is unlikely to be observed, and the realized distribution is reduced from the potential due to abiotic (e.g., topographic barriers) and biotic factors (e.g., competition) (Scherrer and Körner, 2011). Studies based on the assumption of universal dispersal (i.e., a species has unlimited dispersal, its future distribution being the entire projection of its potential niche; Thomas et al., 2001) might provide good approximations for plants with high dispersal ability, but they likely overestimate the future distributions of many other species. For example, in the alpine environment, wind is one of the major factor influencing seed dispersal (Tackenberg and Stocklin, 2008); parts of a plant's potential distribution may therefore remain uninhabited, despite their local suitability, as a consequence of dispersal limitations due to topographic barriers and wind behaviour (Pulliam, 2000; Parolo et al., 2008). While the unlimited dispersal assumption represents an optimistic best-case scenario, some studies have also provided a worst case no-dispersal scenario (Thuiller et al., 2005) to establish a lower bound for their projections. As noted by Bellard et al. (2012), this scenario is clearly convenient for practical purposes, but most species fall somewhere between these two extremes. In addition, the difference between these extreme projections can generate heavy uncertainties (Thuiller et al., 2004). Reducing these uncertainties requires the consideration of dispersal processes, but few studies to date have included dispersal limitations when projecting species distribution under climate change scenarios (Dullinger et al., 2004; Midgley et al., 2006; Engler et al., 2009).

Accordingly, this work has the following goals: (1) to emphasize the empirical (not theoretical) differences among the actual (realized), predicted (dispersal-restricted) and potential (dispersal-unlimited) distributions of plant species; (2) to propose a methodology based on spatial simulation modelling for the individuation of the predicted distributions of wind-dispersed species; (3) to quantify the deviation between plant species survival probabilities in the face of climate warming as estimated using both potential and predicted distributions; (4) to test our approach using two plant species in the Himalayan mountain system.

Overall, we aim to test if the concept of potential distribution is able to effectively predict the impacts of climate warming on the plant species in our case study. The answer to this question has great implications for conservation.

2. Study area and study species

The study area (Fig. 1) corresponds to the Khumbu Valley, which lies in the Sagarmatha National Park (SNP; northeastern Nepal, Solukhumbu District). Data on the climate of this region has been collected at the Pyramid Meteorological Station since 1994 (Bollasina et al., 2002; Diodato et al., 2011). The study area covers a 30.55 km² portion of the national park and ranges from 4907 to 5913 m a.s.l. in altitude. The area is divided into a lower alpine belt, dominated by shrubs of dwarf rhododendrons and prostrate junipers, and an upper alpine belt, dominated by *Kobresia pygmaea* mats and cushion plants such as *Anaphalis xylorhiza* and *Leontopodium monocephalum* (Miehe, 1989, 2008).

L. monocephalum Edgew. (Asteraceae) is a stoloniferous plant that forms off-white mats and is distributed in Tibet, India, Bhutan, Pakistan and Nepal, usually below 5500 m a.s.l. The species grows

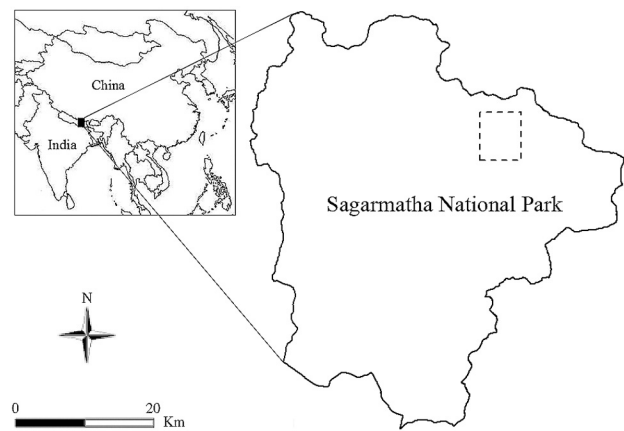


Fig. 1. Study area (dashed line; 30.55 km²) inside the Sagarmatha National Park (Nepal).

in alpine gravelly slopes and meadows (Chen et al., 2011) dominated by *K. pygmaea*. *A. xylorhiza* Sch.Bip. ex Hook.f. (Asteraceae) is a perennial plant with thickish rhizomes, numerous branches, hairy leaves in a basal rosette and flowering stems with five to ten capitula; its achenes are obovoid-oblong with a length of 1.5 mm. This species is distributed in South Tibet, North India, Bhutan and Nepal, usually below 5500 m a.s.l. The plant grows in alpine grasslands and areas with lichens (Chen et al., 2011), primarily on *K. pygmaea* meadows.

Both species have a vegetative period between April and November, bloom during the monsoon season (June–September) and produce wind-dispersed achenes during a dispersal period from September to November. These species were chosen because of their ecological, morphological and distributional characteristics. Both have good dispersal capacity due to the morphology of their achenes and are at the range boundaries of their southern distributions (Miehe et al., 2008). As shown by Lesica and McCune (2004), species at their range boundaries are among the most sensitive indicators of the effects of global warming.

3. Methods

3.1. Field sampling and basic statistics

Floristic surveys were conducted in autumn 2010. Although the field accessibility of these mountainous areas is very limited, we were able to collect at approximately 150 locations for each species with systematic, extensive sampling. The coordinates of each site were measured with a global positioning system (GPS) device using differential correction techniques to improve the accuracy of the data locations (error < 1 m). The actual species distribution (ACT) was estimated as the convex hull (area of the minimum convex polygon containing the sampled points; Graham, 1972) around the sampled points.

The climatic data (T° and winds) for the 2008–2010 period were provided by two Lsi-LASTEM automatic weather stations (AWS) maintained by Ev-K2-CNR located near the Pyramid Laboratory/Observatory (elevation: 5050 m a.s.l.) and atop Kala Pattar (elevation: 5585 m a.s.l.). Basic statistics were calculated for the temperatures of the vegetative period (April–November) and the wind speeds and directions (sampled at 2 m above the terrain) for the dispersal period of the two species (September–November).

3.2. Seed dispersal model

We built a mass-consistent wind flow model, similar to those of Davis et al. (1984) and Ross et al. (1988), which explicitly

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