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Climate change will seriously impact bird species dwelling above the treeline: A prospective study for the Italian Alps

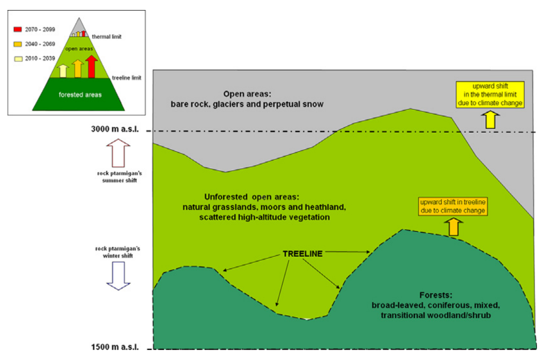
Alessandro Ferrarini [a], Juha M. Alatalo [b,*], Marco Gustin [a]

[a] BirdLife International - Lipu (Lega Italiana Protezione Uccelli), Conservation Department, Via Udine 3/a, I-43122 Parma, Italy
[b] Department of Biological and Environmental Sciences, College of Arts and Sciences, Qatar University, P.O. Box 2713, Doha, Qatar

HIGHLIGHTS

- Treeline rise is expected to reduce habitat suitability of alpine bird species.
- We built the first projection of climate-driven treeline rise in the Italian Alps.
- Treeline upshift will likely impact alpine bird species even in the near future.
- Impact will be only partly lessened by upward shift in the upmost thermal limit.
- The presented approach might promote similar studies elsewhere in the globe.

GRAPHICAL ABSTRACT



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ABSTRACT

High mountain systems are predicted to be especially vulnerable to the impact of climate change, with the climatically-constrained tree limit rapidly shifted upslope. In turn, the impact of upward treeline migration on mountain-dwelling bird species is expected to significantly reduce habitat suitability.

We developed the first projection of the expected climate-driven rise of the whole treeline (19,256 km) of the Italian Alps. The study area extends over 20,700 km^2, ranging over 550 km in longitude and 320 km in latitude. We then investigated how much the expected treeline rise will induce a) shrinking and shifting of the elevation range and b) loss in suitable habitat for the flagship species rock ptarmigan, an alpine bird species dwelling above the treeline and, similarly to many other alpine species, highly vulnerable to treeline rise. We also investigated the potential gain in suitable habitat for rock ptarmigan due to the climate-driven upshift in the uppermost thermal limit.

At lower altitudes (1500–1600 m a.s.l.), the average expected upshift in the current treeline resulted in 195, 274 and 354 m over the short (2010–2039), medium (2040–2069) and long term (2070–2099) respectively. Above 2400 m a.s.l., it was less than 30 m even in the long term. Overall, during the three climate periods the extent of suitable habitat for rock ptarmigan above the current treeline is projected to decrease by 28.12%, 38.43% and 49.11% respectively. In contrast, the expected gain in suitable habitat due to the shift in the uppermost thermal limit will be severely restrained by the limited surface extension in the top portion of the Italian Alps.

The presented approach can promote similar studies elsewhere in the globe, providing a regional perspective to the projection of climate change impact on bird species dwelling above the treeline.

* Corresponding author.
E-mail address: jalatalo@qu.edu.qa (J.M. Alatalo).

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1. Introduction

High mountain systems such as the Alps are predicted to be especially vulnerable to impacts of climate change (Feeley et al., 2011; Parmesan and Yohe, 2003) which may act as a potential driver towards mountain landscape transformation (Gottfried et al., 2012; Theurillat and Guisan, 2001) with adjustments that vary with topographical and climate conditions (Meshinev et al., 2000). The climatically-constrained tree limit (Körner, 1999), separating subalpine forests from alpine meadows, is expected to be rapidly influenced by the impact of climate change and shifted upslope (Holtmeier and Broll, 2005; Kullman, 2002). Significant shifts in the treeline have already been detected (Devi et al., 2008; Peñuelas and Boada, 2003). In Bulgaria, an upward vertical advance of 130–340 in *Pinus peuce* since 1970 has been reported (Meshinev et al., 2000), in Sweden an elevation rise of 120–375 m in several plant species has occurred in the past 50 years (Kullman, 2001).

In turn, the alpine treeline shift is a key subject for the conservation of mountain-dwelling bird species. The impact of upward treeline shift on alpine birds could be significant (Sekercioglu et al., 2008). Bird species dwelling in open areas above the treeline are in many cases highly sedentary, and have quite strict ecological requirements with regard to habitat selection. They are well adapted to these high mountain regions, thus their distribution is often limited to areas that encompass a narrow climatic niche (Revermann et al., 2012). While climate change was suspected to be a potential threat to alpine bird species only in few cases in previous studies (Storch, 2000; Storch, 2007), more recently it has been considered a major threat worldwide (Chamberlain et al., 2012; Chamberlain et al., 2016a, 2016b). Climate change poses a particular risk of extinction to alpine bird species for which elevation range and habitat availability are restricted (Chamberlain et al., 2013). For this reason, predicting how much climate change will likely shrink and shift the elevation range and decrease suitable habitats of alpine bird species due to climate-driven treeline rise can provide conservationists with useful elements to define management strategies for mitigating climate change impacts.

Most models of climate change impacts on biodiversity are only focused over a relatively long term (Chapman et al., 2014), and are therefore often perceived as being less relevant to current conservation problems. We therefore developed here the first projection of the expected climate-driven rise of the whole treeline in the Italian Alps over the short (2010–2039), medium (2040–2069) and long term (2070–2099). Treeline is operatively defined here as the line above any kind of forested area (coniferous forests, broad-leaved forests, mixed forests, transitional woodlands/shrubs), thus defining the boundary between the subalpine and the alpine vegetation zones. We then investigated how much treeline rise will likely induce a) shrinking and shifting of the elevation range and b) decrease in suitable habitat for the flagship species rock ptarmigan (*Lagopus muta helvetica*), an alpine grouse species occurring in isolated relict populations in the open areas (natural grasslands, bare rocks, sparsely vegetated areas and heterogeneous agricultural areas) between 1500 and 3000 m a.s.l. and, similarly to many other alpine species, highly vulnerable to treeline rise. The methodology presented here provides a way to promote similar studies on bird species dwelling above the treeline elsewhere in the globe.

2. Data and methods

2.1. Study species

The rock ptarmigan is present over a wide latitudinal range in Europe, North America and Asia, from 83°N in northern Greenland to less than 40°N in Japan (Storch, 2007) with a global population estimated at about 8000,000 individuals (BirdLife International, 2015). At global level, the rock ptarmigan is considered a least concern species, but in the EU countries it is included in Annex I of the EU Birds Directive (2009/147/CE), and recently it was classified as vulnerable in 27 EU countries (BirdLife International, 2015). In fact, it presents disjointed geographical distributions, with populations that are of great concern because of their small size and low genetic diversity (BirdLife International, 2015). The Italian alpine population of rock ptarmigan has been estimated to be about 5000–8000 pairs, with a decline of 20–30% in the 1980–2011 period (Nardelli et al., 2015). Thus it has been classified as vulnerable in the Red List of Italian birds (Peronace et al., 2012).

In wintertime, the rock ptarmigan moves to lower altitudes, being 1500 m a.s.l. the lowest altitude at which it has been found in the Italian Alps (Favaron et al., 2006; Scherini et al., 2003; Tucker et al., 1994). During the summertime, it moves up to 3000 m a.s.l., the uppermost thermal limit for this species in the Italian Alps (Favaron et al., 2006; Scherini et al., 2003; Tucker et al., 1994). Within this altitudinal range, the rock ptarmigan only dwells in open areas (natural grasslands, bare rocks, sparsely vegetated areas and heterogeneous agricultural areas) above the treeline, up to the glaciers and perpetual snow (Favaron et al., 2006; Nelli et al., 2013; Scherini et al., 2003; Tucker et al., 1994). The rock ptarmigan makes use of all mountainsides, although it has a preference for colder aspects in summer and warmer ones in winter (Cramp, 1988; Tucker et al., 1994). We employed these sources of information from the scientific literature to develop our projections of climate change impact on the rock ptarmigan for the whole Italian Alps. The whole conceptual framework employed in this work is depicted in Fig. 1.

2.2. GIS and climatic data

The study area corresponds to the portion of the Italian Alps above the lowest rock ptarmigan's altitudinal limit (i.e. 1500 m a.s.l.). It extends over 20,700 km^2, ranging over 550 km in longitude and 320 km in latitude (Fig. 2). We used a 1:25,000 landcover map updated to 2012, and a digital elevation model (DEM; horizontal resolution: 20 m) provided by the Italian Ministry of the Environment. Slope aspect and slope angle were calculated for each position in the DEM by taking local derivatives of elevation in the x and y directions. Slope aspect values were then grouped into 9 categories: flat areas (i.e. plane surfaces), N: 337.5°-2.5°, NE: 22.5°-67.5°, E: 67.5°-112.5°, SE: 112.5°-157.5°, S: 157.5°-202.5°, SW: 202.5°-247.5°, W: 247.5°-292.5°, NW: 292.5°-337.5°.

To represent baseline climate conditions, we used meteorological data for the period 1980–2009 calculated using ClimateEU, a package equivalent for Europe to ClimateWNA (Daly et al., 2008; Hamann et al., 2013). It provides climate data (based on the Parameter Regression of Independent Slopes Model interpolation method for precipitation and ANUSPLIN for temperature) for specific locations using latitude, longitude and elevation. Eight biologically-relevant candidate climate variables that are relevant in prediction of treeline elevation were selected: degree-days above 5 °C (growing degree-days; °C); degree-days below 0 °C (chilling degree-days; °C); mean annual precipitation (mm); mean warmest month temperature (°C); mean coldest month temperature (°C); summer heat:moisture index (°C mm^{-1}); number of frost-free days (unitless); annual snow precipitation (mm).

With regard to future climate data, the ClimateEU package downscales and integrates future climate datasets based on Intergovernmental Panel on Climate Change (IPCC) global change scenarios. In order to limit the modelling effort, following Hamann et al. (2015) and Isaac-Renton et al. (2014) we worked with an ensemble mean of all available model runs for the A2 emissions scenario. We preferred the A2 scenario since it is one of the marker scenarios developed by the IPCC. In addition, the A2 scenario is at the higher end (but not the highest) of the Fourth Assessment Report emissions scenarios, and if conservation strategies can be found for a larger climate change, then smaller climate changes of the lower end scenarios can also be faced. In fact, the current actual trajectory of emissions seems to better corresponds to a relatively-high emissions scenario (Soja et al., 2007). Following Fordham et al. (2011) and Isaac-Renton et al. (2014), we excluded poorly validated AOGCMs (MIROC3.2, MRI-CGCM2.3.2, MIROC3.2, IPSL-CM4, FGO-ALS-