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Impact of climate warming – Upslope shift in the distribution of a land snail species in the Swiss National Park

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Abstract

Predicted biological responses to climate warming are changes in phenology and polewards shifts or upslope displacements of the distribution of species. National parks are ideal for investigating effects of climate warming because protected landscapes allow us to examine long-term responses to climate change without confounding effects of land use changes and disturbances by human activities. We investigated changes in the upper elevational range of the land snail *Arianta arbustorum* by repeating historical records from 1916– 1917 on nine mountain slopes in the Swiss National Park in 2011–2012. We found that the upper elevational limit for snail populations has risen on average by 164 m in 95 years, accompanying a 1.6 ºC rise in mean annual temperature in the investigation area. The higher temperature results in a longer activity period of the snails and in an upslope shift of the vegetation. On some slopes we found that the snails have already reached natural barriers (vertical rock walls with no soil) preventing any further upward dispersal. Thus, on many mountains further upslope dispersal may be hindered by the lack of suitable habitat. To our knowledge, this is the first evidence for an invertebrate species with low dispersal capacity ascending to higher elevations in the Alps in response to climate warming.

Keywords

Arianta arbustorum, climate warming, dispersal, elevational distribution, gastropod, habitat requirement, land snail.

Introduction

Recent climate warming induces physiological and ecological responses in plants and animals throughout the world, apparent in the phenology and distribution of species (PARMESAN 2006). Alpine areas belong to those regions expected to experience above average warming with continued global climate change (BENISTON 2003). Indeed, there is increasing evidence that the range of plants and animals are moving in response to recent climate warming towards higher elevations (GRABHERR et al. 1994; WALTHER et al. 2005; LENOIR et al. 2008). In this way the organisms escape the increased temperature. However, responses to climate warming in mountain areas have so far predominantly been studied in animals with good dispersal capacities such as birds (e.g. MAGGINI et al. 2011) and butterflies (e.g. WILSON et al. 2007). Species with poor dispersal abilities, sedentary lifestyles, and specialized habitats are assumed to be potentially the most vulnerable to effects of climate warming (PARMESAN 2006). Terrestrial gastropods are among the poorest active dispersers in the animal kingdom. Numerous gastropod species have narrow habitat requirements and react sensitive to changes in environmental conditions and disturbances (NEKOLA 2010).

BÜTIKOFER (1920) investigated the gastropod communities in the Swiss National Park (SNP) in the Eastern Alps and presented detailed information on the upper elevational limit of the land snail *Arianta arbustorum* (Linnaeus, 1758) on twelve mountain slopes in the years 1916–1917. SNP is a strict nature reserve with no human disturbance or land-use change since 1914. Thus, any change in the distribution range of a species in the SNP is not confounded by human activities. We resurveyed the same mountain slopes after 95 years to examine whether there is a shift in the upper elevational limit of *A. arbustorum* in relation to changes in temperature and precipitation measured in the SNP during this period.

Materials and methods

Study species

Arianta arbustorum is common in moist habitats of northwestern and central Europe, living in the lowlands and mountainous areas reaching elevations up to 2700 m a.s.l. in the Alps. The upper elevational limit of the species is determined by the length of the snow-free period and habitat characteristics (BAUR 1986). On mountain slopes, *A. arbustorum* can be continuously distributed over large areas or occur in small, relatively distinct populations. Individuals become sexually mature at 2–4 years, and adults live another 3–5 years (maximum 14 years; BAUR &

RABOUD 1988). During winter, the snails hibernate in leaf litter or buried in the soil. Mean dispersal of adult snails averaged 12 m per year in an alpine grassland with coarse scree (BAUR 1986).

Study area and temperature measurement

The Swiss National Park (SNP) was established in 1914 in the Eastern Alps, Switzerland (46° 39' N, 10° 12' E). As a strict nature reserve (category Ia; IUCN/WCMC 1994), its main targets are ecosystem protection without any influence of humans or domestic animals, and scientific research. There is no habitat and wildlife management, and public access is permitted only on marked paths in summer months. The SNP measures 170.3 km^2 and includes an elevational range from 1215 to 3180 m a.s.l. Forests cover 32% of the park area, alpine grasslands 20%, waters 1% and rocks and scree fields 47%. Dolomite is the dominant bedrock.

In Buffalora, situated at the edge of SNP at 1968 m a.s.l., temperature and precipitation were constantly measured since 1917. The mean July temperature is 9.9 °C (average from 1961–1990), the mean annual temperature –0.3 °C, and the mean annual precipitation 902 mm (METEOSWISS 2012). All mountain slopes examined were situated within a distance of 16 km from the weather station in Buffalora.

Snail monitoring

BÜTIKOFER (1920) surveyed the mollusc fauna in the newly established SNP and its surroundings in the years 1916–1917, paying particular attention to the upper elevational limit of *A. arbustorum*, whose shells can relatively easily be found. BÜTIKOFER (1920) presents a map (scale 1 : 150 000) and descriptions of the sites where the uppermost individuals of *A. arbustorum* were found on 12 mountain slopes.

We repeated his survey in August 2011 and in June and August 2012. We subdivided each slope in 10-m elevational bands. Depending on the topography, the breadth of the elevational bands varied between 15 m (in gullies) and 400 m (on homogeneous slopes). Beginning at the slope's base, two or three persons searched carefully for individuals of *A. arbustorum* in the lowest elevational band. If a living individual or an empty shell was found, we recorded both its geographical coordinates and elevation using a GPS receiver (Garmin, Geko 201, Romsey, U.K.), and continued to search in the next higher situated elevational band. This procedure was repeated until we did not find any snails in five successive bands. We defined the upper elevational limit as the elevation where the last snail was found. In the case of empty shells, at least one living individual had be found within an elevational range of 10 m. For each slope, we also assessed the mean inclination based on maps (scale 1 : 25 000) and aspect using a compass.

We excluded three slopes examined by BÜTIKOFER because of dangerous access to the site (one case) or the site of former snail occurrence was not described in enough detail (two cases). Hence, we resurveyed nine of the twelve mountain. Using the geographical coordinates, we draw small-scale distribution maps of snail individuals found on each slope and compared the current distribution with the upper altitudinal limit recorded in 1916–1917.

Results

Mean temperature increased by 0.16 °C per decade in the SNP over the past 95 years. In contrast, the amount of annual precipitation did not change over the period considered.

On the nine mountain slopes examined, the upper elevational limit of *A. arbustorum* raised 146 m (s.e. = 27 m; range 5–250 m) in the past 95 years (paired *t*-test, $t = 5.42$, $n = 9$, $P = 0.006$). On one slope, where a shift of 5 m was found, the upper distribution range of the snail had already reached the foot of vertical rock walls of mountain Piz Murters in 1916, preventing any further upslope dispersal. If data from this slope are removed from the analysis, the upper elevational limit for snail populations has risen on average by 164 m. In the recent survey, individuals of *A. arbustorum* were found to have reached natural barriers (vertical rocks wall) preventing further upwards dispersal on two slopes. Upslope extension of snail distribution was larger on south to south-east exposed slopes (mean ± s.e. = 233 ± 8 m) than on north to north-east exposed slopes (122 ± 18 m; unpaired *t*-test, $t = 4.50$, d.f. = 6, $P = 0.0041$). However, upslope extension of snail distribution was not influenced by the inclination of the slope (Pearson correlation: $r = -0.25$, $n = 9$, $P = 0.53$).

Discussion

The present study provides meteorological evidence for recent warming in SNP, and shows that this trend is accompanied by a significant upslope range extension of the land snail *A. arbustorum*. On all but one mountain slope, we found an increase in upper elevational limit of *A. arbustorum* compared to the data collected 95 years earlier by BÜTIKOFER (1920). The exception can be explained by the presence of a geographical barrier preventing further upslope dispersal in the past decades. The observed magnitude of elevational range shift of *A. arbustorum* clearly exceeds any potential measurement uncertainty due the use of different types of altimeters in the past and present. BÜTIKOFER (1920) also provided evidence for the occurrence of a few other alpine snail species at higher elevations on the slopes examined. This indicates that BÜTIKOFER (1920) may not have underestimated the upper elevational limit of *A. arbustorum* in 1916–1917. Considering the mean dispersal distance of 12 m per year measured in tagged *A. arbustorum* on mountain slopes (BAUR 1986), an upslope range extension of 62 to 250 m as recorded in the present study is feasible over a period of 95 years.

National parks are ideal for investigating effects of climate warming because protected landscapes allow us to examine long-term responses to climate change without confounding effects of land use changes and disturbances by human activities. SNP is a strict nature reserve with no human disturbance or land-use change since 1914. Thus, the rise in the upper elevational limit of *A. arbustorum* cannot be explained land-use changes or human activities.

Global warming is influencing most natural systems on Earth, but the impact on high elevation ecosystems is especially pronounced. The European Alps are perhaps the best-endowed mountain system in terms of climatological and environmental data. The warming experienced in the Alps, while synchronous with the global warming, is of far greater amplitude than in the lowlands and reaches up to 2 ºC for individual sites (BENISTON et al. 1997). Similarly, in Buffalora at the edge of SNP, an increase of 1.6 ºC was recorded. Climate change in this region is characterized by an increase in minimum temperatures of about 2 ºC, and a more modest increase in maximum temperature, but no change in precipitation data, resulting in a prolonged period of vegetation growth.

Shifts at the upper edge of elevational range agree with the hypothesis of an upslope trend to escape rising temperatures. This is also the most widely used explanation for the recorded plant species' shifts on mountain peaks in the European Alps (GRABHERR et al. 1994; CAMENISCH 2002) and in Scandinavia (KULLMAN 2002). Climate is the major factor limiting plant species richness at high elevations. Elevational shift over the last century varied in plant species from 46 to 532 m (mean 258 m) on mountain slopes in the Upper Engadina, 40 km west of SNP (WALTHER et al. 2005). Similarly, the Ibex (*Capra ibex*) shifted its activity range 250 m upslope in the SNP in the past 70 years (R. Haller, personal communication). Our results confirm the elevational range shift in another group of organism that has so far not been examined.

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