Predictive mapping of *Elyna myosuroides* under climate change scenarios in the Swiss Alps – programmed local extinction

Thomas Gross

University of Basel, Institute of Botany, Section Plant Ecology
Basel, Switzerland

Abstract

Global change has developed from a hypothesis to a well-documented fact. One of its major components is the global, regional and local change of mean annual temperatures accompanied by further changing climatic factors such as rainfall, evapotranspiration and others. Based on two different socio-economic climate change scenarios, the distribution changes of *Elyna myosuroides* was projected by the end of the century in the region of Zermatt, Switzerland. *E. myosuroides* is of special interest in the context of rising temperatures, since organisms have been documented to evade higher temperatures by migrating the range upward in elevation and this model species is already inhabiting high elevation exposed locations. Using species distribution models the aim of this study is to develop predictive maps of occurrence of the model species under the two climate change scenarios A1 and B1 (Intergovernmental Panel on Climate Change, IPCC) by the end of this century. The resulting predicted distribution constitutes a severe decline in suitable habitat, leading to at least localized extinction of *E. myosuroides* in the region of Zermatt.

Key words: *Species distribution; Modelling; Species extinction; Species Distribution Models; Geographic Information System; Climate change scenarios*

Introduction

Global change, especially the rise of mean temperatures, has been widely studied and been acknowledged not only as a major future threat but as an already developing reality. One of the major underlying causes for climatic and therewith connected global changes is the rapid increase of greenhouse gases in the atmosphere, most notably CO_2 (IPCC 2007). As a response to changing temperatures, organisms may adapt to the new climatic conditions, migrate to suitable conditions (e.g., Davis and Shaw (2001)) or go extinct. Not only is it unclear, if species are able to adapt or migrate quickly enough to keep up with the rate of climate change, but also is limitation of suitable space an issue, especially in high alpine species.

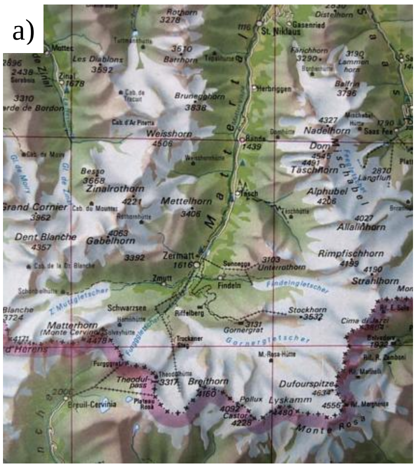
Of special interest for the modelling of predicted species distribution are therefore species which are already by their natural distribution at the boundary of inhabitable ecosystems such as high alpine plants which may not be able to shift their occurrence patterns to higher elevations as a result of a warmer climate. One such plant species is *Elyna myosuroides*, which is a tussock-building grass that occurs on high alpine wind-exposed mountain ridges (Steiner and Pierre 2003). Using predictive modeling techniques, the expected distribution of *E. myosuroides* by the end of the century was mapped under the two socio-economic global change scenarios A1 and B1 described by IPCC (Intergovernmental Panel on Climate Change; IPCC (2000)).

Materials and methods

Study area and model species

Data analysed in this study originate from field sampling carried out in the area of Zermatt in the Western Swiss Alps. The elevation of the domain ranges from 1500 to 4600 m and sampling plots ranged from 1500 to 3300 m (Fig. 1a-b). The model species *Elyna myosuroides* forms dense tussocks and can be found on wind-exposed and in winter often snow-free ridges. It can grow on calcareous and more acidic substrates (Steiner and Pierre 2003).

a)



b)

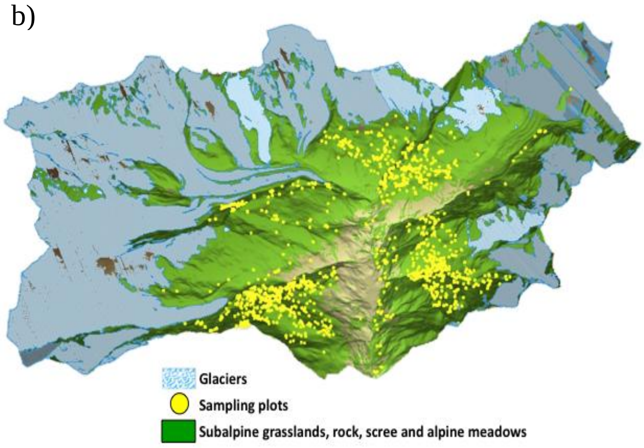


Fig. 1a: Map of the region of Zermatt. **Fig. 1b**: Location of sampling plots respective to broad ecosystems of the area of Zermatt.

Topographic and climatic predictors

Prior to calibrating the model a wide array of geographic and climatic variables (Table 1) were analysed using PCA (Principal Component Analysis) to detect correlations between variables and to chose the best predictors for the presence of *E. myosuroides*. Subsequently, the set of predicting variables found to be the best combination for the geographic and climatic factors as well as the physiological requirements of the studied species were used for further analysis.

Tab. 1: Topographic and climatic variables included in the PCA (Principal Component Analysis)

Code	Definition
elevation	Elevation given by a DEM (Digital Elevation Model)
tavey	Annual temperaure (°C)
tave_smr	Summer temperaure (°C)
tave_win	Winter temperature (°C9
gdd3	Growing-degree day (10* °C*day)
mtc	Minimum temperature of the coldest month
precy	Yearly sum of precipitation
prec_smr	Summer sum of precipitation
prec_win	Winter sum of precipitation
etpty	Potential. evapotranspiration (mm) calculated with the Jensen-Haise empirical formula (take temperature and solar radiation as inputs)
pety	Simulated yearly the potential. evapotranspiration (mm) with the PREVAH model
mindy	Averaged daily atmospheric H2O balance for the year (10*mm/day)
mind68	Averaged daily atmospheric H_2O balance for the summer (10*mm/day)
snowcover	Simulated yearly snowcover(mm) with the PREVAH model
slope	(°)
srady	Yearly sum of the monthly mean daily global radiation [$kJ/mm^2/day$]
topopos	Topographic position index (neg. value = concave)

Climate change scenarios

Two different climate projections based on socio-economic scenarios described by the IPCC (2000) were used for the period from 2011 to 2100: A1 and B1. A1 is the most severe climate change scenario of IPCC (therein referred to as “A1F1”) which assumes a “business as usual” socio-economic development without major efforts to reduce emission of greenhouse gases and for which an increase of approximately 7.7°C in average temperature has been predicted for the study area. B1 is a more moderate scenario with an increase of approximately 4.5°C (details of the projection of the socio-economic scenarios in Engler, Randin et al. (2009)).

Species distribution model and spatial projection

Four different modelling techniques were fitted for the model species: GLM (Generalized Linear Models), GAM (Generalized Additive Models), GBM (Generalized Boosting Models) and RF (Random Forest). Topographic and climatic variables were used as predictors for the presence or absence of the species (response variable). For the calibration of GAMs and GLMs a binomial distribution was assumed and for predictor selection followed a stepwise procedure based on the Akaike Information Criterion (AIC; Akaike 1973).

Using ensemble techniques, the distribution of *E. myosuroides* was modelled using present and predicted future climatic conditions. From the initial distribution yielded by the model, unsuitable areas for growth of E. (e.g., urbanized areas, streams, roads) were masked.

Results

Selection of predicting variables

All geographic and climatic variables specified in Table 1 were analysed using a PCA (Principal Component Analysis) regarding their predictive power and correlations between variables (Fig. 2). Subsequently, the variables were used to calibrate models using GLM, GAM, RF and BM approaches. Based on the visual analysis of plotted response curves of the respective initial models, variables which showed truncated responses were not included in the final model. This approach suggested the inclusion of the variables etpty, pety and srady in the final model.

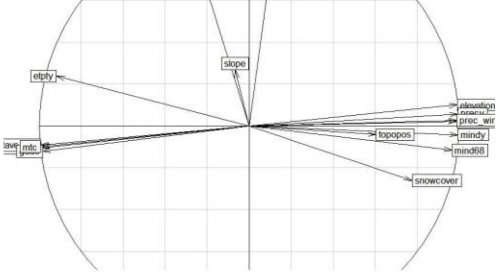


Fig. 2: PCR correlation circle including all geographic and climatic variables.

Current and predicted future distribution

Fig. 3a provides an overview of the current distribution of *E. myosuroides* in the study area based on the mapped field sampling results. The results of the ensemble projection of the species range in Zermatt indicate a big reduction already under the less severe climate change scenario B1 (Fig. 3b). As expected from the habitat requirements of the species, an upward trend along the elevation gradient is expected and it is likely that the species will not find suitable habitats at lower elevations. For the “business as usual” scenario A1 (Fig. 3c), an almost complete extinction of *E. myosuroides* is expected for the region of Zermatt. It is also evident that under the A1 scenario only very little colonization of new habitats at higher elevations may be expected (green areas in Fig. 3c).

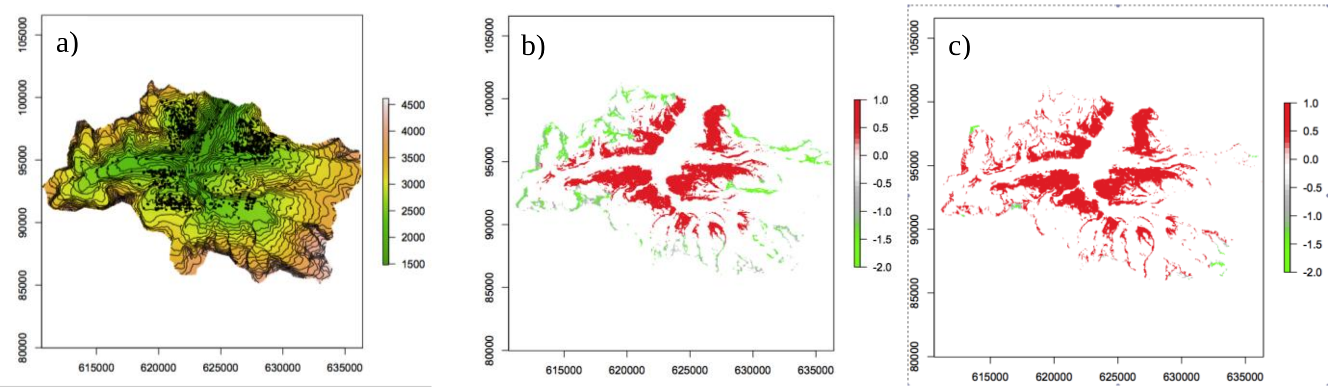


Fig. 3. a) Map of the region of Zermatt with the current distribution of *E. myosuroides* (black circles = sample plots where species present, colours = elevation in m a.s.l.). **b)** and **c)** Predicted distribution of *E. myosuroides* under climate change scenario B1 and A1, respectively. Colours indicate extinction patterns from 1 = complete extinction to negative numbers = range expansion.

Discussion

E. myosuroides is commonly found on high elevation on wind-exposed ridges. If we assume that this model species will move its range upward as an evasion to higher average temperatures, we cannot take this as a survival guarantee for this species. Research questions which may provide guidance toward the prediction of survival odds of species do not only include the possible rate of adaptation or evasion (e.g., if the species is able to shift its range at least as quickly as climate changes) or whether the species is able or not to move beyond barriers (i.e. dispersal capabilities) but also the question if there will be enough available suitable habitat at all.

Even in the present simplistic case not assuming dispersal barriers the results suggest a drastic reduction in distribution of *E. myosuroides* even under the more optimistic B1 scenario (Fig. 3b). For the more severe scenario A1 (Fig. 3c), it is unlikely that the species will survive in the study area under more realistic conditions. Furthermore, under the A1 scenario the upward range expansion of *E. myosuroides* is very limited and only very few high altitude patches (green areas in Fig. 3c) will meet the criteria for the survival of the model species. Thus, if “business as usual” prevails, it’s a programmed extinction of *E. myosuroides* by the end of this century in Zermatt.

References

Davis, M. B. and R. G. Shaw (2001). "Range shifts and adaptive responses to Quaternary climate change." Science **292**(5517): 673-679.

Engler, R., C. F. Randin, et al. (2009). "Predicting future distributions of mountain plants under climate change: does dispersal capacity matter?" Ecography **32**(1): 34-45.

IPCC (2000). Emissions Scenarios. UK., Cambridge University Press.

IPCC (2007). Climate change 2007: The physical science basis. Contribution of Working Group I to the Fourth Assessment, Cambridge Univ. Press.

Steiner, A. J. and H. Pierre (2003). Die Vegetation der Gemeinde Zermatt: Beiträge zur geobotanischen Landesaufnahme der Schweiz: Bd 74. Germany, vdf Hochschulvlg.