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Will charophyte species increase or decrease their distribution in a changing climate?

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ABSTRACT

Most charophyte species are threatened across Europe. Understanding their current and future distribution is a challenge for their conservation. We looked for species distribution models (SDM) and for increasing or decreasing species occurrence under a future climate scenario in Switzerland. Firstly, we modeled the occurrence of charophyte species in 1402 Swiss localities using presence–absence data and environmental variables (waterbody size, mean July temperature, July precipitation, soil calcium carbonate content and proportions of land used by agriculture and forest cover in the catchment area and in the surroundings). We used generalized additive models (GAM) to analyze the data. Secondly, based on the models, we predicted the occurrence of the species in 21,092 localities listed in Switzerland. Thirdly, we applied a climate scenario to our models (2 °C mean July temperature increase and 15% reduction in July precipitation) and predicted species occurrence under these new conditions. Twelve charophyte species were modeled successfully. The major driver of species distribution was the waterbody size, followed by climate and land-use variables. We detected predicted impacts of climate changes on the species occurrence and identified the potential winners and losers. About half of the species are predicted to become losers; they colonize the littoral zone of lakes. Other charophytes are potential winners; the majority of them colonize small waterbodies.

1. Introduction

Historical analyses of charophyte distribution in Western Europe have shown the disappearance of several species and the decline of rarer ones (Simons and Nat, 1996; Auderset Joye et al., 2002; Korch et al., 2008; Baastrup-Spohr et al., 2013). This observation has led to evaluation of the degree of species extinction risk in several European areas. The Red Lists all indicate a high degree of threat for many charophyte species at national or regional level (for example Stewart and Church, 1992; Blazencic et al., 2006; Gärdenfors, 2010; Auderset Joye and Schwarzer, 2012).

A reduction of the risks to which charophytes are exposed requires improving our knowledge of their ecology. Here, we attempt to fill a gap by modeling the species distribution and predicting their occurrence currently and in a changing environment.

Species distribution modeling (SDM) is currently viewed as a way to assess species habitat, and as a tool for the management of endangered or invasive species (see Guisan et al., 2013). The assumption of SDM is the prediction of entire, or potential, spatial distribution of a phenomenon by relating sites of known occurrence with environmental variables characterizing those sites and all other sites (Guisan and Thuiller, 2005; Elith and Leathwick, 2009; Hijmans and Elith, 2013).

Here, we utilize such a method to model the charophyte species distribution using climate (temperature, precipitation) land-use (% agriculture and forest), waterbody size and soil calcium carbonate content as predictors. We expected that these environmental predictors would drive the charophyte species distribution at the scale of the country.

The following steps were carried out: (1) random selection of localities and field record of species occurrence over the whole country; (2) extraction of environmental predictor values at the species locations and at all listed locations from spatial databases; (3) modeling and prediction of species occurrence across Switzerland using presence–absence data (step 1) and environmental values (step 2); (4) prediction of species occurrence under a future climate change using models obtained in step 3.

Climate, in combination with other variables can explain the main vegetation patterns around the Earth (McArthur, 1972; Ellenberg, 1988). Under recent climate changes, shifts in species

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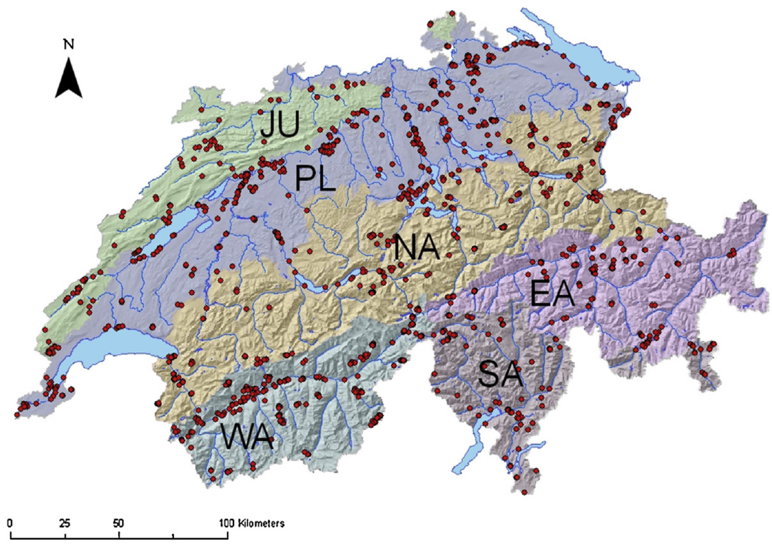

Fig. 1. Distribution of the 1402 localities within the 6 main biogeographical Swiss regions (Gonseth et al., 2001). JU = Jura Mountains, PL = Plateau, NA = Northern Alps, WA = Western Alps, EA = Eastern Alps, SA = Southern Alps.

distribution ranges have been observed across a wide diversity of taxonomic groups over all continents (Parmesan and Yohe, 2003; Walther, 2010). This is also likely to be case for charophyte species. Thus, we applied a climate scenario to address the way the species may be impacted by future environmental changes. The climate change in Switzerland predicts an increase of temperature and a decline in summer rainfall (CH2011, 2011). We hypothesized that the impact of warming and drought on freshwater organisms could be negative for some charophyte species and positive for others.

2. Methods

2.1. Study area

Switzerland (46° 57′ 04″ N 7° 26′ 19″ E – 41,285 km^2) has a variety of landscapes and habitats with the Alps acting as a separation line. The climate conditions vary regionally due to the mountainous influence; from an intra-alpine dry and continental climate regime in the Western and Eastern Alps to an oceanic climate at low-elevation (Plateau) and high elevation (Northern Alps, Jura Mountains). The Southern Alps are dominated by relatively mild and dry winters and warm humid summers. During the hottest month (July), the range of the mean monthly temperature varies from 2.7 °C (Arctic) to 21.9 °C (Mediterranean) according to altitude (Zimmermann and Kienast, 1999; MeteoSuisse, 2013). July rainfall exhibits important spatial variations and ranges from 359 mm to 2594 mm.

More than a third of the Swiss territory is used for agriculture and another third is covered with forest. Lakes, rivers, unproductive vegetation and surface areas without vegetation cover about a quarter of the territory. Urbanization which used to occupy 7% of the land is now growing quickly to the detriment of agriculture (OFS, 1992/1997).

2.2. Charophyte species data

The aquatic ecosystems of the country were investigated with the main objective of evaluating the extinction risk of the charophyte species growing in Switzerland (Auderset Joye and Schwarzer, 2012). Sites to be explored in the field were selected from a stratified sample of 21,092 aquatic ecosystems represented by ponds (45%), lakeshore segments (10%) and breeding sites for amphibians of national importance (45%). The stratification of the set of 21,092 localities was based on biogeography (6 regions), altitude (6 classes; Fig. 1) and the proportion of agricultural land used in the catchment area (3 categories). The localities finally chosen for investigation were randomly selected from the dataset with a double constraint: selecting at least 4 sites in each of the 108 strata. The sites were selected within historical sites (when existing) known to have harbored charophytes in the past. Lastly, 1402 localities were surveyed during 4 years (2006–2009). Only 387 localities were colonized by charophyte species during this fieldwork. The data analyzed here included presence/absence for the 20 species recorded in the 1402 localities (Table 1).

2.3. Selection of environmental predictors

A conceptual framework based on the ecophysiological and biophysical processes that govern the relationships among species and their environment can be used to choose potential environmental variables that describe species distributions (Austin, 2007). This framework recognizes indirect, direct and resource variables. Temperature and rainfall are considered as direct variables, while resource variables are those which are consumed by organisms, e.g. nitrogen for plants (Austin and Smith, 1989; Guisan and Zimmermann, 2000). This conceptual general model works for terrestrial plants but rainfall, for example, acts indirectly through water-level changes and their consequences (light, temperature) on aquatic plants.

Predictors were carefully chosen from the GIS available variables (at 25 m resolution) which were considered to have a high potential to explain charophyte species distribution. They belong to four domains: climate, rock type, land-use and waterbody size. For each domain we designated a subset of one or several candidate explanatory variables. The variables finally selected show relatively low correlation to each other (Table 2). In order to avoid problems of collinearity between predictors we restricted their number to 8 (Table 3).

Climate variables were preferred to altitude because they are more direct and known to constraint species distribution. We chose mean temperature and July precipitation as the most representative predictors for climate because charophyte species are strongly influenced by high temperature and droughts (Casanova and Brock,