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Freshwater biodiversity under climate warming pressure: Identifying the winners and losers in temperate standing waterbodies

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ABSTRACT

Climate warming is affecting the biodiversity all around the world, resulting in the expansion or contraction of the geographical range of species, and leading to colonisation (winners) and extinction (losers) events in ecosystems. It is crucial for the conservation of biodiversity to identify these potential winners and losers.

We focus here on small standing waterbodies in Switzerland and on five taxonomic groups: vascular plants, snails, beetles, dragonflies and amphibians. We first assessed the sensitivity of each species to climate warming through their thermal preferences, using current altitudinal and latitudinal distribution, as a surrogate for temperature. We then evaluated the resilience of species to perturbations through five ecological and biogeographical criteria applicable to the perturbation "warming": dispersal ability, degree of habitat specialisation, geographical extent in the study area, future trend in geographical extent, and future trend of habitat availability for species.

Potential winners and losers of a warming climate could be quantified through their thermal preferences. The proportion of potential losers ranged from zero species for snails to 33% of the regional species pool for dragonflies. The set of potential winners was much larger, ranging from 53% for amphibians to 61% for dragonflies. A multimetric index combining the five resilience criteria enabled the further prioritisation of the species along a gradient of extinction risk.

This potential threat from climate warming is not reflected by the current Red Lists of dragonflies and amphibians, suggesting that conservation management could gain from a complementary label indicating the degree of sensitivity to warming.

1. Introduction

The Earth's climate is predicted to become warmer during the 21th century with global average increases in temperature of 1.8–4 °C, and it has already warmed by 0.74 °C over the 20th century (IPCC, 2007). In addition, there is no longer any doubt that climate warming has drastic effects on biodiversity. Indeed, it is affecting the geographical range of species and the composition of communities all around the world (reviews in McCarty, 2001; Walther et al., 2002). An increase in species richness under the influence of climate warming is expected in alpine areas according to the well-known decline in species richness with increasing altitude (see review from Rahbek (1995)), for both terrestrial (e.g. Herzog et al., 2005; McCain, 2005) and aquatic taxa (e.g. Lods-Crozet et al., 2001; Jones et al., 2003; Jacobsen, 2004). Moreover, several studies have predicted that climate warming will induce an increase in local species richness in different ecosystems, from montane and subalpine forests (Kienast et al., 1998) to small temperate waterbodies (Rosset et al., 2010). Some long-term datasets have already confirmed this predicted trend. For example, the species richness of terrestrial plants has been reported to increase during the last century in permanent plots situated on alpine-nival summits (e.g. Grabherr et al., 1994; Vittoz et al., 2009). These observed or predicted increases in taxonomic richness are the consequence of changes in species composition. Indeed, as it has occurred over geological time scales in response to a changing climate, many taxa will shift their geographical range and move into regions where climate is more suitable, while others will fail to do so and will suffer extinction. Therefore, in a given region (and in a given ecosystem), taxa can become extinct ("the losers"), while at the same time colonisations by new taxa can occur ("the winners"). An increase in taxonomic richness is observed when the colonisation events are more frequent than the extinction events. The ability of taxa to adapt to the changing climatic conditions (e.g. Ashley et al., 2003) would make this balance even more complex.

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The geographic range of many taxa has already been observed to shift towards regions where their climatic suitability is increasing, and this is likely to be the response of most species (e.g. Parmesan et al., 1999; Parmesan and Yohe, 2003; Hickling et al., 2006). However, some taxa will not be able to track the changing climate and are at risk of extinction. Estimates of the number of these taxa differ greatly between regions and between taxa: from only a few percent (e.g. Levinsky et al., 2007) to almost 80% (e.g. Thomas et al., 2004) of the regional species pool. Freshwater biodiversity, in particular, is highly vulnerable to climate change, with extinction rates matching or exceeding those suggested for better-known terrestrial taxa (Heino et al., 2009).

Besides these quantitative estimates, it is essential to identify the species which are at risk of extinction in order to design targeted action plans for conservation. The use of species-specific criteria related to ecology, life-history or geographical distribution is frequent in extinction risk assessments independent of climate changes (e.g. Keith, 1998; O'Grady et al., 2004; Kotiaho et al., 2005; Mattila et al., 2008). Investigation of such criteria to detect taxa which are the most extinction-prone because of climate warming is more recently emerging (e.g. Ott, 2001; Heikkinen et al., 2010; Williams et al., 2010; Graham et al., 2011): several species-specific criteria have been related to the sensitivity of species to global changes in climate, such as thermal preferences, dispersal ability, geographical extent, population trend and degree of habitat specialisation (Ott, 2001; Beaumont and Hughes, 2002; Thuiller et al., 2005a; Broennimann et al., 2006; Jiguet et al., 2007; Calosi et al., 2008; Vittoz et al., 2009). Furthermore, the combination of these criteria could enhance the effects of climate change on species. Travis (2003) demonstrated that habitat specialists with poor dispersal abilities or suffering from habitat loss will be more affected by climate change than other habitat specialists.

The present study assess the sensitivity to climate warming of species from five taxonomic groups (vascular plants, beetles, snails, dragonflies and amphibians) living in small standing waterbodies (ponds or wetlands) in Switzerland. Ponds were used as an ecosystem model because: (i) their small size and relatively simple communities make them attractive model systems for research (De Meester et al., 2005), (ii) freshwater systems respond strongly to physical environmental changes, such as climate change (Heino et al., 2009), (iii) ponds are predicted to increase in species richness in response to warming (Rosset et al., 2010). The present investigation aims to detect the potential winners and losers involved in this local species enrichment, with the final aim of providing baseline information to prioritise conservation measures towards the species most at risk of extinction. Specifically, we will evaluate the sensitivity of each species to warming through two successive and complementary approaches. The first approach investigates the thermal preferences of species using altitudinal and latitudinal distributions as a surrogate for temperature. This will allow to quantify the number of species in four distinct groups of winners and losers: two groups of potential losers at risk of extinction (cold and cool thermal specialists), and two groups of potential winners (warm thermal specialists and thermal generalists). A second approach takes into consideration the resilience of species to perturbations, and therefore their ability to track the climate warming; it is used for groups for which sufficient ecological and biogeographical knowledge is available, i.e. for Odonata and Amphibia. This second approach aims to prioritise further the species from each of the four groups along a gradient of extinction risk. The method uses a multimetric index, with five criteria describing the resilience of species to a "warming" perturbation: the dispersal ability, the degree of habitat specialisation, the geographic extent in the study area, the future trend in geographic extent and the future trend of habitat availability for species.

2. Methods

2.1. Study area

Switzerland is an outstanding model for investigating climate issues and particularly the sensitivity of species to climate warming. Indeed, this country covers a large range of altitudes (210–2760 m above sea level), and therefore a large range of thermal conditions (mean annual air temperatures from −2 °C to 12 °C). Despite its small size (41,000 km^2), Switzerland includes many standing waterbodies with an estimated 32,000 ponds (defined here as waterbodies between 100 m^2 and 5 ha in surface area) and 360 lakes.

2.2. Study taxonomic groups

Five taxonomic groups were investigated: aquatic vascular plants, aquatic Gastropoda, aquatic Coleoptera (larvae and adults), Odonata adults and Amphibia. These represent heterogeneous groups in terms of their systematic classification (vascular plants, invertebrates and vertebrates), but also in terms of their life cycle, i.e. amphibiotic (Odonata, Amphibia) vs. aquatic (plants, Gastropoda, Coleoptera), and of their colonisation abilities, i.e. passive (plants, Gastropoda) vs. active (Coleoptera, Odonata, Amphibia).

For each taxonomic group, only species dependent on pond habitats for an important part of their life cycle were investigated; therefore running water species were discarded. For vascular plants in particular only aquatic species, as defined by their humidity index scores, were investigated (for details and full species list see Oertli et al., 2002).

Information concerning these five taxonomic groups came mainly from large national databases available in Switzerland for the period 1990–2007 (databases from the Swiss Centre for fauna cartography CSCF, the Swiss Centre of floristic network CRSF). More than 60,000 species records were available. These species records came from different sources: research projects, volunteer records, species inventories or museum records. The scientific validity of all species records was rigorously verified by experts before their inclusion in the databases.

2.3. Methodological approach for the identification of potential winners and losers

Species-specific criteria related to ecology or geographical distribution were used to assess the sensitivity of species to warming through two successive and complementary approaches. The first approach investigated the thermal preferences of species, using knowledge of their altitudinal and latitudinal distribution as a surrogate for temperature in order to classify species into distinct groups of winners and losers. The second approach takes into consideration the resilience of species to perturbations, and therefore their ability to track the climate warming, in order to prioritise further the species from each of the groups identified through the first step along a gradient of extinction risk.

2.4. Thermal preferences of species

Thermal preferences of species were investigated with the final aim to quantify the number of species in two groups of losers: the cold thermal specialists and the cool thermal specialists, and in two groups of winners: the warm thermal generalists and the warm generalists. The underlying assumption is that species with restricted thermal ranges, in particular in cold or cool temperatures are potential losers and that species with ranges restricted