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Evaluating the combined threat of climate change and biological invasions on endangered species

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ABSTRACT

Climate change and invasive species are two major biodiversity threats expected to provoke extinctions of many species in the future. This study evaluates the joint threat posed by climate change and two invasive species: the zebra mussel (*Dreissena polymorpha*) and the signal crayfish (*Pacifastacus leniusculus*), on the distribution of two endangered freshwater species: the depressed river mussel (*Pseudanodonta complanata*) and the white-clawed crayfish (*Austropotamobius pallipes*), at the scale of Europe. We expected the native species to experience a gradual contraction over time in their geographic range size, while the invasive species would maintain or increase their spread; therefore, their overlap would increase, further threatening the conservation of the native species. To test these three hypotheses, ensemble species distribution models (SDMs) were calibrated with current distributions and projected onto present and 2050 future climatic scenarios. In agreement with our expectations, the 2050 scenarios suggested *D. polymorpha* may strongly benefit from climate changes (increase of 15–20% in range size), while the depressed river mussel would experience a considerable loss (14–36%), the overlap between both mussels increasing up to 24%. Although both crayfishes were predicted to be negatively affected by climate changes, the contraction was more severe for the invasive *P. leniusculus* (up to 32% decrease in range size). Moreover, the overlap between both crayfishes decreased by 13–16%, which may reduce the pressure upon the native *A. pallipes*. This study illustrates how SDMs can assist in management of endangered species over large spatial and temporal scales by identifying current and future areas of shared bioclimatic suitability and potential refugia.

1. Introduction

Climate change and invasive species are acknowledged as two of the most important causes of biodiversity loss in freshwater ecosystems (Sala et al., 2000), and they are expected to provoke major species extinctions in the near- and long-term future (Thomas et al., 2004). Under changing climatic conditions species are forced to adapt or to change their geographical range tracking climatic changes, and certainly many species migrations have already been documented in a variety of habitats (e.g. Parmesan and Yohe, 2003; Thuiller et al., 2004). In comparison with native species, invasive species are more likely to adapt to the new climatic conditions because they are usually abundant, tolerate a broad range of climatic conditions, cover wide geographic ranges and have highly competitive biological traits (Hellmann et al., 2008). This will intensify the joint threat posed by climate warming and invasive species on native populations. While major efforts have been devoted to the study of climate change and invasive species separately, their combined impacts on the native fauna have rarely been assessed (e.g. Walther et al., 2009; Ward and Masters, 2007). This lack of explicit combined analysis of risk makes it difficult for science to inform effective prevention of species invasion and conservation of native fauna and flora (Bradley, 2010). Consequently, forecasting the simultaneous response of invasive and native species to climate changes is of vital importance to both increase our understanding about species dynamics and promote adaptive management of the areas at highest risk of invasion.

To approach this issue, we investigated the potential response to climate change of two pairs of invasive-native species. We chose as representative two of the most harmful and widespread freshwater invasive species in Europe: the zebra mussel (*Dreissena polymorpha*, Pallas 1771) and the signal crayfish (*Pacifastacus leniusculus*, Dana 1851). Both of them are included into the list of 100 worst invaders in Europe (DAISIE European Invasive Alien Species Gateway, http://www.europe-aliens.org/). Amongst the various species potentially affected by these two invaders we selected the depressed river mussel (*Pseudanodonta complanata*, Rossmässler 1835) and the white-clawed crayfish (*Austropotamobius pallipes*, Lereboullet 1858), both of them included in the IUCN Red List of Threatened species (www.iucnredlist.org).

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D. polymorpha is frequently competitively dominant over native freshwater fauna, especially mussels by impeding the correct opening and closure of the valves, hampering its movement and burrowing, or directly competing for space and resources (Karatayev et al., 1997). Amongst freshwater mussels affected by the *D. polymorpha*, *P. complanata* is considered rare or endangered in most of the European countries where it is present (e.g. McIvor and Aldridge, 2007; Skidmore et al., 2010) and is classed as ''near threatened'' in the Red List of the IUCN (Van Damme, 2011). In addition to biofouling, water pollution, river impoundment, lack of fish hosts and habitat loss have seriously affected the distribution of *P. complanata* in Europe, which has disappeared from approximately 30% of its historical sites in Great Britain (Killeen et al., 2004). Under a scenario of increasing temperatures, experimental studies have shown a widening of the spawning season of *D. polymorpha*, beginning earlier in spring and finishing later in fall (Griebeler and Seitz, 2007), as well as enhanced growth in fall (Thorp et al., 1998), both of which suggest a positive effect of climate change on the spread of this mussel. *P. complanata* may show a comparatively lower capacity of adaptation to climate changes because of its relatively slow growth and low fecundity (Aldridge, 1999; McIvor and Aldridge, 2007). Although its potential response to increasing temperatures has not been yet studied, some authors have suggested other species such as the pearl mussel (*Margaritifera margaritifera*) may benefit from slight increases in temperature and flood frequency in northern latitudes, though they are generally expected to decline as a result of extreme climatic events including droughts and floods (Hastie et al., 2003). Many native freshwater mussels are also susceptible to changes in the abundance and distribution of their host fishes, which are necessary for their reproduction and dispersal. This is not the case for *D. polymorpha*, which reproduces via planktonic larvae and can disperse considerable distances (Borcherding, 1991), which may further increase the competitiveness of *D. polymorpha* under a climate change scenario.

P. leniusculus is native to western North America and was introduced in Europe for aquaculture (Lewis, 2002). It competes for space and resources with native crayfishes and is the main vector of the fungus *Aphanomyces astaci* (Alderman et al., 1990). This disease has caused large-scale mortalities amongst indigenous crayfish populations, particularly the white-clawed crayfish (*A. pallipes*), whose populations have been reduced by 50–80% in France, Italy and England (Füreder et al., 2010). Consequently, the species is included in the IUCN Red List as ''Endangered'' (http://www.iucnredlist.org). Results from tolerance experiments have shown that optimum temperature for the growth of both crayfishes ranges between 20 and 25 °C, while temperatures above 33 °C are lethal (Firkins, 1993). However, *P. leniusculus* has a greater overall thermal tolerance and can not only survive and grow under conditions unsuitable for *A. pallipes*, but will also grow faster (Firkins, 1993). Climate change is therefore likely to favour *P. leniusculus* but negatively affect *A. pallipes*, which may imply the promotion of *A. astaci* transported by the signal crayfish. In addition, the inherent resistance capacity to environmental stress and high plasticity of the fungus may promote its spread (Desprez-Loustau et al., 2007).

While studies exist on the impacts of invasive species such as *D. polymorpha* and *P. leniusculus* on native populations, no study to date has explored the potential shift in these species' geographic ranges related to climate changes at a European scale. Considering their broad thermal tolerance and invasion ability, we predict the two invasive species to maintain or increase their range of distribution, most probably towards northern latitudes (hypothesis 1). On the other hand, the two native species are likely to present a contraction in their geographical niche due to their generally lower phenotypic plasticity (hypothesis 2). Although not necessarily, such combination may result in greater overlap between both species further threatening the conservation of the native species (hypothesis 3). This study assumes that the modelled range of distribution of species is proportional to their realized (i.e. occupied) niche and therefore changes in the modelled range (such as increases, decreases or range shifts) are likely to be reflected in the realized niche of the species. We also assume that where both species overlap the invasive species will have a greater competitive advantage, hindering if not preventing completely the setting and spread of the native species. To test these predictions, ensemble Species Distribution Models (SDMs) were calibrated with each of the species' current distribution in Europe and projected onto present and future scenarios (2050 A and B scenario families, IPCC, 2000). The ultimate aim of this study is to support ecosystem management by anticipating future shifts in the distribution of native and invasive freshwater species over large spatial and temporal scales.

2. Methods

2.1. Data compilation

The four species' global occurrence was obtained from the Global Biodiversity Information Facility (GBIF, http://www.data.gbif.org/, last accessed April 2012), the United States Geological Survey (www.usgs.gov), the IUCN Red List of threatened species (www.iucnredlist.org) and a literature search to fill in gaps in distribution (e.g. Arbačiauskas et al., 2011; Bondar et al., 2005; Bossenbroek et al., 2007; Gallardo and Español, 2011; Karatayev et al., 2003; Nakata et al., 2010; Trichkova et al., 2007; Van der Velde et al., 2010). Data consisted of presence-only locations representative of the current range of the four species. For instance *D. polymorpha*, a freshwater mussel of Ponto-Caspian origin, is now widely distributed in Europe and the east part of North America; whereas the largest populations of *P. complanata* are found in the North of Europe (UK, Finland, the Baltic countries), being also present in France and rivers draining in the Black Sea (http://www.iucnredlist.org/details/18446/0). On the other hand, *P. leniusculus* native distribution comprises the northeast of America, from British Columbia in Canada to in California, Idaho, Oregon, and Washington, and has been introduced throughout Europe and Japan (http://www.iucnredlist.org/details/153648/0). In contrast, the distribution of *A. pallipes* is restricted between Spain in the south-west, Scotland in the north and Montenegro in the east (http://www.iucnredlist.org/details/2430/0). Duplicate records were removed from the database to allow only one occurrence per pixel of 5 arcmin (ca. 4×4 km), the resolution of environmental variables used as predictors (see below). Such filtering of occurrences using a coarse grid has been shown to reduce the spatial bias and clustering of data, thereby resulting in more robust models (Rodriguez-Castaneda et al., 2012).

Data on bioclimatic variables was obtained from WorldClim (Hijmans et al., 2005, available at http://www.worldclim.org, last accessed July 2010) at a 5 arcmin resolution (ca. 4×4 km). Eight bioclimatic factors were selected based on preliminary exploratory analyses (Pearson correlation $r < 0.80$), including: annual mean precipitation (annualPP) and temperature (annualT), temperature seasonality (Tseason), maximum temperature in the warmest month (maxT), minimum temperature in the coldest month (mint), precipitation of the driest month (PPdriest) and precipitation seasonality (PPseason) (bioclimatic data correspond to means for the 1950–2000 period). In this study, we assumed that air temperature is directly related to water temperature, a non-linear relationship that has been demonstrated before (e.g. Stefan and Preud'homme, 1993). However, we acknowledge that other factors such as water