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Application of species distribution models for protected areas threatened by invasive plants

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ABSTRACT

Local species distribution models (SDMs) were constructed for three of the most harmful invasive alien plant species (*Fallopia* spp., *Solidago* spp. and *Heracleum mantegazzianum*) in the Kokořínsko Protected Landscape Area (Czech Republic), using Natura 2000 habitat types and other environmental conditions as predictors for the SDMs. Presence or absence data (recorded by field mapping) was entered into the SDMs and used to predict the potential distribution of particular species. Here, we critically evaluate the accuracy of the models and assess their applicability for natural resource protection. Variables such as habitat and soil type tend to dictate the current distribution of *Solidago* spp., while distance from roads and water corridors and elevation are important for *Fallopia* spp. distribution. For *Solidago* spp., 'generalised boosted models' and 'generalised additive models' were considered the most suitable algorithms. For *Fallopia* spp., however, the predictive power of the models tended to be weak, while the number of localities was too low for SDMs in the case of *H. mantegazzianum*. The number of initial localities containing invasive alien species was an important factor for making significant predictions of potential distribution. In general, the predictive power of the models was too low when using less than 10 localities; for good predictive power at the local scale, we suggest that at least 100 localities/100 km^2 are used.

1. Introduction

Recent research has shown that the number of alien plant taxa in Central Europe has increased continuously over the last two decades (Pyšek, Chytrý, Pergl, Sádlo, & Wild, 2012), resulting in a significant threat to biodiversity (Stohlgren et al., 2011). Given these changes, special attention should be given to the study of invasive alien species (IAS) in protected areas as biological invasions have been highlighted as one of the most important global drivers of biodiversity loss (Foxcroft, Pyšek, Richardson, & Genovesi, 2013). In particular, it is vitally important to identify those regions most at risk of invasion and local species that may be vulnerable to such invasions (Hulme et al., 2014; Thalmann et al., 2015). While detection of newly invaded localities is difficult at a local scale and almost impossible over larger areas, early detection of invasive plants followed by their prompt elimination remains the optimal management approach for protected areas (Iacona, Price, & Armsworth, 2014).

Previous studies have shown that the spread of invasive species is dependent on the presence of suitable habitat (Chytrý et al., 2008; Lonsdale 1999), specific disturbance regimes or the availability of free resources such as nutrients (Davis, Grime, & Thompson, 2000). Habitats and vegetation types harbouring the highest proportion of alien species are generally those with a high level of disturbance or fluctuating resource input (usually nutrients, though sometimes also water or light; Bímová, Mandák, & Kašparová, 2004; Pyšek et al., 2012). Indeed, in the Czech Republic, arable land, areas with annual synanthropic vegetation, trampled habitats and anthropogenic tall-forb stands have been shown to support the highest number of IAS (Chytrý, Pyšek, Tichý, Knollová, & Danihelka, 2005). The spread of alien plants into natural habitats is highly influenced by the presence of trails or access roads (Otto et al., 2014) and the number of visitors to protected areas (Allen, Brown, & Stohlgren, 2009; Lonsdale 1999; Padmanaba & Corlett 2014; Pickering & Mount 2010). Furthermore, factors such as timber harvesting (which opens up the canopy, allowing light penetration) increase the range of species that can grow and increases the chances of alien plants invading.

Effective eradication of invasive species represents a serious challenge for land managers. As such, planning for regional treatment and budgeting funds for management of these areas requires

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an understanding of the invasion process across protected areas. At present, however, data on presence and spread of invasive species are often incomplete (Guisan & Thuiller 2005; Hobbs & Humphries 1995). Species distribution data are useful for identifying the different types of habitat potentially threatened by IAS in the study area (Chytrý et al., 2008; Dullinger, Kleinbauer, Peterseil, Smolik, & Essl, 2009; Lososová et al., 2012; Pyšek et al., 2012). In combination with data on primary spreading vectors (e.g. roads, trails and water corridors [see above]) and local environmental conditions (Guisan & Zimmermann 2000), such data can be used to construct species distribution models (SDMs; Thuiller, Lafourcade, Engler, & Araujo, 2009) using Geographic Information System (GIS) software and statistical tools. These SDMs allow the prediction of new areas threatened by potential invasion (Dullinger et al., 2009; Guisan & Zimmermann 2000).

Here, we provide an evaluation of (a) SDMs constructed using different statistical approaches and (b) the spectrum of environmental variables at a local spatial scale, for three IAS with a high likelihood of invading a protected landscape area (PLA) in the Czech Republic. We have used Natura 2000 habitat types, Consolidated Layer of Ecosystems, soil types, and elevation as the main environmental predictors for determining the spread of invasive species. Natura 2000 habitat types provide unique information about environmental conditions, vegetation cover, type of management, and the degree of degradation of the site (Pěknicová, Petrus, & Berchová-Bímová, 2015), and thus could be a useful predictor for IAS spread (Chytrý, Kučera, & Kočí, 2001; Guth & Kučera 2006). Using a combination of such knowledge with the best available models, we were able to develop a methodology for the prediction of invasive species-spread and in turn prioritize the management of IAS. Our research strategy was based on the following hypotheses: (1) applicability of SDMs as a tool for land and nature managers will depend on the number of localities; (2) SDMs will prove useful for early detection of IAS in small protected areas (SPAs); and (3) Natura 2000 habitats will be one of the main predictors of IAS invasion.

2. Materials and methods

2.1. Data collection

The Kokořínsko PLA (Fig. 1) in the north of the Czech Republic lies in a hilly region with deep sandstone valleys, boreo-continental pine forest and extensive wetlands (Mikulec & Antoušková 2011; NCA 2015). Distribution (presence/absence) data for three *Fallopia* taxa (*F. japonica* var. *japonica*, *F.* × *bohemica* and *F. sachalinensis*), two *Solidago* spp. (*Solidago canadensis* and *S. gigantean*) and *Heracleum mantegazzianum* were collected between June and September 2013 over an area covering approx. 100 km^2. For each of the above, the exact location and area invaded was recorded using a Global Positioning System (GPS, U.S. Air Force, United States of America) unit and the habitat type recorded based on the Habitat Catalogue of the Czech Republic (Chytrý et al., 2001). We then selected the key environmental variables considered crucial for the plant's distribution based on: soil type; Natura 2000 habitat type; land cover (Consolidated Layer of Ecosystems); distance from water corridor; elevation (average elevation); slope (average slope); precipitation (annual precipitation); and, distance from roads and main trails (Table 1). Distances from roads and water corridors were calculated using Python scripting in ArcGIS.

2.2. Species description

The five IAS focused on in this survey are all on the Black List of alien species found in the Czech Republic (Pergl et al., 2016), are presently distributed in the research area and their ecological requirements are well known (Pyšek et al., 2012; Slavík, Štepánková, & Štěpánek, 2004). Moreover, both *F. japonica* and *H. mantegazzianum* are recorded on the list of 100 worst European invasive species (DAISIE 2015).

Staff of the Kokořínsko PLA have been recording presence of *H. mantegazzianum* and *Fallopia* taxa since 2000 (2000–2015). As *S. canadensis* and *S. gigantea* usually occurred together in the 50 × 50 m grid squares, they were mapped together as one taxa group. Both species have similar habitat preferences (Pyšek et al., 2012), growing mainly in disturbed habitats along roads and railways (Weber 1998), at forest edges, along riverbanks, in abandoned fields and pastures and grassy and urban areas (Walck, Baskin, & Baskin, 1999). *Solidago* species were never eradicated from the Kokořínsko PLA and recent mapping has shown distribution of both species increasing. The distribution of *H. mantegazzianum* has been expanding for some time, though it has been eradicated from some localities in the PLA. This species primarily invades nutrient-rich sites in semi-natural grasslands, forest edges and anthropogenic habitats. It is also able to establish in nutrient-poor habitats such as peaty meadows or in the acidic soils of forest clearings. It often occurs near linear landscape elements, such as river corridors or roads (Thiele & Otte 2006). All three *Fallopia* taxa have similar ecological requirements in terms of moisture and nitrogen, and are frequently found in relation to human settlements, e.g. in abandoned gardens, garden centres or parks (Bímová et al., 2004; Pyšek et al., 2012).

2.3. Data processing and species distribution modelling

GPS data for presence/absence of IAS were uploaded as a shapefile layer in GIS ArcMap v. 10.3. A 0.5 m buffer zone was created around each IAS presence point and the edge coordinates of continuous populations were connected in order to create a vector polygon shapefile. The vector layer of presence/absence data for each taxon was then transformed into a raster layer based on a 50 × 50 m grid square covering the Kokořínsko PLA research area. Zonal statistics were then used to assign a value for each of the environmental variables used (soil type; distance from water corridor and roads; elevation; slope; annual precipitation; Natura 2000 habitat layer; land cover). As a result, each raster cell in the final grid contained unique information on taxon occurrence (presence/absence [response variable]) and local environmental variables (see above).

Using a species distribution modelling approach, we formatted an attribute table of presence/absence data for the three taxa in combination with local environmental variables, thereby allowing predictions of potential distribution of the species in the Kokořínsko PLA. The attribute table was formatted using an ensemble forecasting approach as implemented in the BIOMOD2 package in R (R Development Core Team, 2013; version 3.1.1.). This approach combines predictions of several modelling techniques into one ensemble prediction. Here, we test the predictions of six distribution modelling algorithms (see Guisan & Zimmermann 2000), i.e. Generalised Linear Models (GLM), Generalised Boosted Models (GBM), Generalised Additive Models (GAM), Classification Tree Analysis (CTA), Artificial Neuron Networks (ANN) and Multiple Adaptive Regression Splines (MARS). The True Skill Statistic (TSS), Relative Operating Characteristic (ROC) and Cohen's Kappa Statistic (KAPPA) were then used to evaluate the species distribution models produced (Allouche, Tsoar, & Kadmon, 2006; see CAWRC 2015 for a detailed description of each; all statistical procedures were rescaled to provide a perfect score of 1). When using ROC, index values range from 0 to 1, with 0.5 indicating weak predictive power; while for TSS and KAPPA, values range from −1 to 1, with 0 indicates no predictive power. After evaluating the best models for *Fallopia*