Journal of Environmental Management 131 (2013) 185–195

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Will climate change drive alien invasive plants into areas of high protection value? An improved model-based regional assessment to prioritise the management of invasions

J.R. Vicente [a,*], R.F. Fernandes [a], C.F. Randin [b], O. Broennimann [c], J. Gonçalves [a], B. Marcos [a], I. Pôças [a,d], P. Alves [a], A. Guisan [c,e], J.P. Honrado [a]

[a] CIBIO & Faculdade Ciências do Porto, Universidade Porto, Departamento Biologia, FC4, Rua do Campo Alegre S/N, 4169-007 Porto, Portugal
[b] Institute Botany, University Basel, Schönbeinstrasse 6, CH-4056 Switzerland
[c] Dépt d'Ecologie et d'Evolution, Univ. Lausanne, Bâtiment de Biologie, CH-1015 Lausanne, Switzerland
[d] Centro de Engenharia dos Biossistemas, Tapada da Ajuda 1349-017 Lisboa, Portugal
[e] Institute of Earth Sciences, University of Lausanne, Geopolis, 1015 Lausanne, Switzerland

ARTICLE INFO

Article history:
Received 25 March 2013
Received in revised form
5 September 2013
Accepted 14 September 2013
Available online 25 October 2013

Keywords:
Acacia
Combined predictive models
Connectivity analysis
Conservation value
Woody invasive plants

ABSTRACT

Species distribution models (SDMs) studies suggest that, without control measures, the distribution of many alien invasive plant species (AIS) will increase under climate and land-use changes. Due to limited resources and large areas colonised by invaders, management and monitoring resources must be prioritised. Choices depend on the conservation value of the invaded areas and can be guided by SDM predictions.

Here, we use a hierarchical SDM framework, complemented by connectivity analysis of AIS distributions, to evaluate current and future conflicts between AIS and high conservation value areas. We illustrate the framework with three Australian wattle (*Acacia*) species and patterns of conservation value in Northern Portugal.

Results show that protected areas will likely suffer higher pressure from all three *Acacia* species under future climatic conditions. Due to this higher predicted conflict in protected areas, management might be prioritised for *Acacia dealbata* and *Acacia melanoxylon*. Connectivity of AIS suitable areas inside protected areas is currently lower than across the full study area, but this would change under future environmental conditions.

Coupled SDM and connectivity analysis can support resource prioritisation for anticipation and monitoring of AIS impacts. However, further tests of this framework over a wide range of regions and organisms are still required before wide application.

1. Introduction

Over the past century, invasion by non-native species has rapidly increased, threatening ecosystems and economies worldwide (Richardson and Rejmánek, 2011). Invasions can alter the provision of ecosystem services (Le Maitre et al., 2011; Theoharides and Dukes, 2007) potentially promoting changes at several levels of conservation focus (Marchante et al., 2011). The continuous increase of human mobility acts as a key factor in the process of biological invasion by facilitating species migration and colonisation (Chytrý et al., 2008). Climate change also plays a key role in invasion processes through the stimulation of mechanisms that favour the proliferation of invasive species (Kleinbauer et al., 2010).

Protected areas are pivotal for the conservation of endangered ecosystems, habitats and species since they represent key areas to study the efficiency of several barriers (e.g. geographic barriers, and both environmental and biotic filtering; Richardson et al., 2000) to AIS invasions, and AIS impacts on native species (Pyšek et al., 2002). The Convention on Biological Diversity (CBD, 2010) considers

* Corresponding author. Tel.: +351220402790; fax: +351220402799.
E-mail addresses: jsvicente@fc.up.pt, xoaninha@gmail.com (J.R. Vicente), rui_fff@msn.com (R.F. Fernandes), christophe.randin@unibas.ch (C.F. Randin), olivier.broennimann@unil.ch (O. Broennimann), joaofgo@gmail.com (J. Gonçalves), brunoasmarcos@gmail.com (B. Marcos), ispocas@hotmail.com (I. Pôças), avoervas@gmail.com (P. Alves), antoine.guisan@unil.ch (A. Guisan), jhonrado@fc.up.pt (J.P. Honrado).

0301-4797/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jenvman.2013.09.032

protected areas as the cornerstone of biodiversity conservation but their importance and effectiveness vary across regions depending on human landscape management (Pyšek et al., 2002). One example of its applicability at an European scale is the Natura 2000 network that aims at ensuring the protection of important species and habitats in Europe (Opdam et al., 2009).

One problem with networks of protected areas is their static nature when related to species range and ecosystem changes (Pressey et al., 2007). In this context, AIS plants invading a protected area represent a serious concern due to their capacity to replace native flora and change ecosystem functions and properties (Pyšek et al., 2002). Once AIS are established, eradication is time consuming and expensive so preventing future invasions is considered the most cost-effective management approach (Genovesi, 2005).

In heterogeneous environments AIS occur in suitable patches that may be isolated from each other and connected through dispersal corridors (e.g. rivers, roads). It has been demonstrated that habitat connectivity offers preferential routes for the spread of AIS across landscapes (Minor et al., 2009; Proches et al., 2005). The anticipation of future invasions is, therefore, commonly regarded as an important conservation task (Bradley and Mustard, 2006; Theoharides and Dukes, 2007).

Species distribution models (SDMs) are widely used in ecology. Over the last decades, they have been increasingly used to identify key environmental variables driving AIS distribution (explanatory models *sensu* Shmueli, 2010; Guisan and Thuiller, 2005; Vicente et al., 2010) and to predict the potential distribution of AIS under current conditions and environmental change scenarios (Bradley and Mustard, 2006; Vicente et al., 2010, 2011). Also, SDMs have been particularly useful to predict areas of introduction in the invaded range (Broennimann et al., 2007). Furthermore, SDMs allow quick and cost-efficient assessments, because they are less complex to calibrate than mechanistic models.

Hierarchical approaches integrating environmental factors acting at different spatial scales may capture dimensions of species distributions that are ignored at a single scale, and thus can contribute to improve conservation planning (Minor et al., 2009; Pearson et al., 2004; Vicente et al., 2011). One example uses subsets of predictors (same extent and grain) classified *a priori* according to their scale of influence and to the ecological scales at which they are expected to operate (Vicente et al., 2011). When compared to models with unclassified predictors, projections of combined models contain a higher level of information about the relative importance of regional and local drivers of relevance for management (Vicente et al., 2011). Also, ensemble forecasting calibrated with different SDM techniques represents a significant improvement when compared to SDM calibrated with one technique (Thuiller et al., 2009).

SDM studies suggest that AIS distribution will likely increase in the future due to climate and land-use changes (Kleinbauer et al., 2010; Pyšek et al., 2002; Vicente et al., 2010, 2011). Priorities for AIS monitoring and management may however be set quite differently depending on the conservation value of the invaded areas (Blossey, 1999; Roura-Pascual et al., 2010). Regarding this, SDM predictions could support prioritisation of control, eradication and monitoring efforts.

In this paper we build on a proposed combined SDM framework (Vicente et al., 2011) coupled with range connectivity analysis to evaluate the current and future conflicts between AIS and protected areas. We illustrate the framework with the example of three Australian wattle (*Acacia*) species in a heavily invaded area of Northern Portugal. We finally related the predicted invasion risks with various potential drivers acting at different scales.

2. Methods

2.1. Study area and test species

2.1.1. Study area

The study area is located in the Northwest of the Iberian Peninsula and corresponds to the North of Portugal (Fig. 1), covering 21,515 km^2 in the transition between the Euro-Siberian and the Mediterranean biogeographic regions. Topographically this is a rather heterogeneous region, with an elevation ranging between 0 and 1545 m, resulting in marked variations of environmental conditions and land uses, expressed on a diversified vegetation cover. Geologically, the area is dominated by granite and schist, and therefore by acid soils. The climate varies from temperate Atlantic in the western areas to sub-continental Mediterranean in the eastern areas. Mean annual rainfall ranges from ca. 400 mm in the eastern valleys to over 2500 mm in the western mountain summits. About 25% of the area is covered by areas of conservation value, including several integrated areas in the Natura 2000 network of EU and national areas with legal protection (National Parks and Natural Reserves, natural monuments and protected landscapes) that are mostly within Natura 2000 areas. The North of Portugal is therefore fairly covered by nature protection regimes, but at the same time it is invaded by many AIS in a large diversity of habitat types (e.g. Vicente et al., 2010).

2.1.2. Test species

To illustrate our modelling framework, we chose three invasive woody plants introduced from Australia: *Acacia dealbata* Link, *Acacia melanoxylon* R.Br., and *Acacia longifolia* (Andrews) Willd. Australian *Acacia* species are important plant invaders emerging in many parts of the world, modifying vegetation structures and native species composition and otherwise affecting ecosystem functioning (Marchante et al., 2011; Richardson and Rejmánek, 2011). These plants were selected as test species on the basis of the following criteria: i) being aggressive invasive species in the region; ii) having partially similar habitat requirements; and iii) exhibiting the same general life strategy and invasiveness traits, e.g. production of large numbers of seeds, germination stimulated by fire, occurrence in dense populations, and exclusion of native species due to competition for resources (Lorenzo et al., 2010) and allelopathic ability (in *A. dealbata* and *A. melanoxylon*; Marchante et al., 2011).

The three species were reported as naturalised in Portugal in the 20th century, having been introduced mainly for ornamental purposes and control of soil erosion in mountainous and coastal areas (Almeida and Freitas, 2006), except for *A. melanoxylon*, which is also a forestry species. These three species are now common in forest areas, scrubland, along river margins (*A. dealbata*, *A. melanoxylon*) and sand dunes, as is the case of *A. longifolia* (Marchante et al., 2011).

The study area was first stratified based on the mean annual temperature (climate), bedrock type (geology) and percentage of forest cover, thus reflecting the major environmental gradients within the geographic region. The mean annual temperature and percentage of forest cover were each split into three classes by identifying the natural breaks in their distributions in ArcGIS (ESRI, 2010). Bedrock types were reclassified qualitatively as granitic rocks, schistose rocks, and all other types that have a limited distribution in the area. The study area was then stratified by combining these classes to generate 27 strata, of which 23 were represented in the area. This stratification was performed using the ArcGIS Spatial Analyst extension (ESRI, 2010). We then used an equal-stratified sampling design (as recommended by Hirzel and Guisan, 2002) to randomly select plots of 1 km^2 (corresponding