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Plant invasion risk: A quest for invasive species distribution modelling in managing protected areas

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ABSTRACT

Preventing biological invasions in areas of conservation concern represents the most cost-effective strategy to minimize the impact of Invasive Alien Species (IAS) on native communities. In this context, invasive Species Distribution Models (iSDMs) are a sound tool for predicting invasion risk in protected areas. Although their potential to support invasive species managers is widely acknowledged, evidence of iSDMs providing actual conservation solutions is still scarce. With this work, we propose an iSDM-based methodology that accounts for the role of multiple invasion drivers to assess the risk posed by IAS in protected areas. Using a binomial Generalized Additive Model, we predicted the occurrence of a highly invasive plant in Mediterranean dune systems. According to the predicted IAS occurrence, we quantified the invasibility of protected sites inside the study area, classified each site in low to medium-high invasibility categories, and identified site-specific management perspectives. Our results encourage the use of iSDMs as a means of evaluating the risk posed by IAS in protected areas, and, at the same time, represent an attempt to fill the gap between theory and practice in conservation decision-making.

1. Introduction

A key topic in conservation biology is the preservation of natural areas with a concurrent reduction of time and costs needed for their conservation (Margules and Pressey, 2000). In 1992, the European Parliament promulgated the Habitat Directive (92/43/EEC) which aimed to "…contribute towards ensuring biodiversity through the conservation of natural habitats and of wild fauna and flora in the European territory…" by means of specific measures such as the establishment of a functional system of protected areas (PAs), namely the Natura 2000 network (EEC, 1992). This network is composed of Sites of Community Importance (SCIs) and Special Protection Areas (SPAs), in which European conservation strategies are implemented for maintaining plant communities and wildlife species at a "favourable conservation status".

Nowadays, the Natura 2000 network constitutes one of the most valuable conservation tools against the loss of biodiversity in Europe (Kati et al., 2015). Nonetheless, the biodiversity of sites included in the network is affected by several threats. Among them, the introduction of Invasive Alien Species (hereafter, IAS) is one of the most severe, preceded only by habitat loss and fragmentation (Foxcroft et al., 2013). IAS cause severe impacts on native communities and affect the functioning of ecosystems, with expected consequences on human health (Ricotta et al., 2010; Aerts et al., 2017; Hattab et al., 2017). Moreover, actions aimed at minimizing the impact of IAS on native communities imply high economic investments (Pimentel et al., 2002). In this context, the European Commission adopted a recent Regulation "on the prevention and management of the introduction and spread of invasive alien species" (EC Regulation 1143/2014) which came into force in 2015. According to the EU Regulation (hereafter, IAS Regulation), Member

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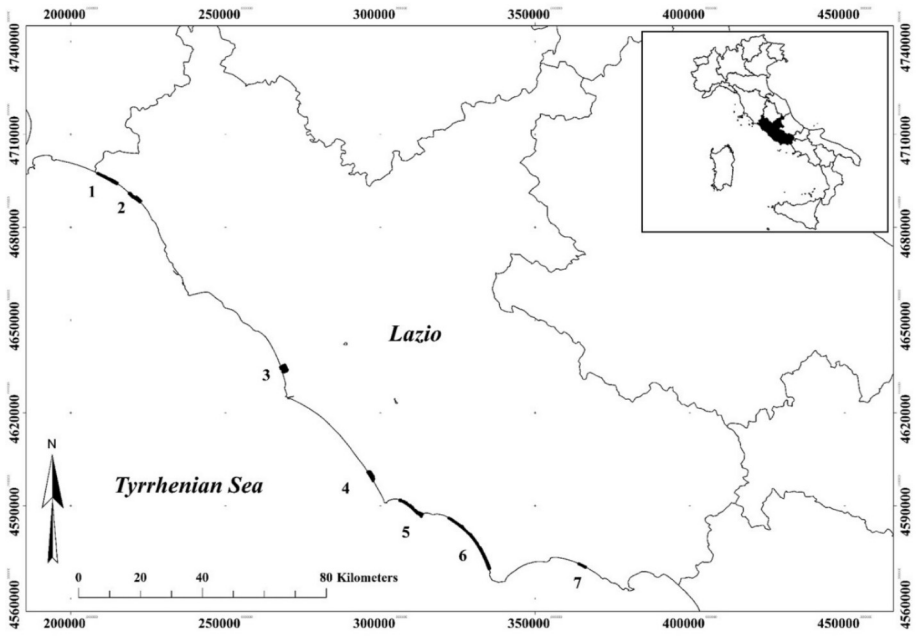

Fig. 1. Study area. Analyzed Sites of Community Importance (SCIs) are shown in black: (1) Litorale a Nord-Ovest delle Foci del Fiora (IT6010018), (2) Litorale tra Tarquinia e Montalto di Castro (IT6010027), (3) Macchia grande di Focene e Macchia dello Stagneto (IT6030023), (4) Lido dei Gigli (IT6030045), (5) Litorale di Torre Astura (IT6030048), (6) Dune del Circeo (IT6040018), (7) Duna di Capratica (IT6040021). Coordinates system: UTM(WGS 84).

States are committed to undertake specific actions related to challenging research, monitoring and surveillance aimed at early detection of invasive species and predict their spread into non-native regions.

Preventing the arrival of IAS is claimed as the most effective strategy to deal with biological invasions (Leung et al., 2002; Sitzia et al., 2016). To achieve this aim, invasive Species Distribution Models (iSDMs), based on the statistical relationship between invasive species (presence/absence or abundance data) and the invaded environment (environmental predictors), have been effectively applied to predict the distribution of IAS and to identify areas that are likely to be invaded (Muñoz and Real, 2006; Andrew and Ustin, 2009; Vicente et al., 2010; Gallardo et al., 2017). iSDMs have the potential to support conservation decision-makers in defining possible actions aimed at IAS monitoring and containment (Guisan et al., 2013). Nevertheless, although iSDMs are widely considered as powerful tools for managing IAS (Addison et al., 2013; Crall et al., 2013; Underwood et al., 2004), their implementation for mapping the risk posed by biological invasion remains sparse (Guisan et al., 2013). In fact, iSDMs are currently underused for conservation purposes, mainly due to the lack of resources (time and/or money) available to conservation managers (Addison et al., 2013; Guisan et al., 2013). In this regard, the recent evolution of remote sensing and the increasing availability of spatial data has provided modellers with new ecologically meaningful environmental variables suitable for modelling species distribution (Franklin, 2013; He et al., 2015). For this reason, the contribution of remote sensing could be crucial for overcoming the lack of resources to collect adequate (quality/quantity) data for implementing iSDMs, which is one of the main objections raised by conservation managers against the use of predictive models (Addison et al., 2013; Gil et al., 2013).

When implementing an iSDM, attention must be given to the theoretical background underlying the ecological processes that influence species distribution (Austin, 2007), as ill-informed models (e.g., based on inappropriate ecological assumptions) can lead to suboptimal conservation outcomes (Addison et al., 2013). Relying on an accurate theoretical framework, iSDMs should provide a sound tool for supporting decision-making and resource allocation in conservation (Catford et al., 2009). As biological invasions are complex processes whose success (or failure) is driven by multiple factors (Barney and Whitlow, 2008; Colautti et al., 2006; Pyšek and Richardson, 2006), integrative approaches should be adopted to effectively model the simultaneous influence of different invasion drivers in determining IAS occurrence and spread (Catford et al., 2009; Gurevitch et al., 2011; Malavasi et al., 2018; Theoharides and Dukes, 2007).

Although biological invasions represent a potential threat for the biodiversity in Europe and the IAS Regulation has explicitly highlighted the urgency of identifying management tools for reducing IAS impacts, few studies have attempted to propose model-based methodologies for preventing the expansion of invasive species in Natura 2000 sites (but see Dimitrakopoulos et al., 2017). Overall, an urgent need to bridge theory and practice in the application of iSDMs for conservation issues has been claimed (Guisan et al., 2013).

In response to the need for early warning tools claimed by the IAS Regulation, the present work aims at providing an iSDM-based methodology that accounts for the role of multiple drivers to assess the invasion risk posed by IAS on protected sites. In particular, the method aims at estimating the potential distribution of IAS for using model predictions of the invasive species occurrence to quantify site vulnerability to plant invasion (invasibility). The model framework presented here relies entirely on multi-source remotely sensed data, including high-resolution aerial orthophotos and Light Detection and Ranging (LiDAR) imagery. We test the proposed methodology for assessing the invasion risk posed by the non-native plant *Carpobrotus* sp. (*Aizoaceae*) in coastal Natura 2000 sites in central Italy. Currently, invasion by the South African *Carpobrotus* sp. constitutes one of the most severe threats to coastal plant communities of the Mediterranean basin (Vilà et al., 2006). *Carpobrotus* sp. is a succulent perennial *taxon* that has documented negative impacts on the diversity and functioning of Mediterranean coastal plant communities (Conser and Connor, 2009; Campoy et al., 2018).

The proposed approach could be extended to other invasion events to support conservation managers who aim to minimize the impact of invasive species on native communities in other conservation networks.

2. Material and methods

2.1. The selected Natura 2000 sites

The study was carried out on the Tyrrhenian coast of central Italy (Lazio administrative region) (Fig. 1). In this area, sandy dunes are relatively simple in structure and occupy a narrow strip (< 500 m) that extends parallel to the shoreline (Acosta et al., 2003). In this study, we considered seven SCIs hosting representative areas of coastal dunes that