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Ecology

Identifying areas of high invasion risk: a general model and an application to Mexico

Identificando áreas con riesgo elevado de invasión: un modelo general y una aplicación para México

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Abstract

Maps have become a key tool to guide priorities for biodiversity conservation, the maintenance of ecosystem services, but much less so for critical action against further service loss in critical areas. Biological invasions are important disruptors of ecosystem services given that they directly or indirectly affect human well being, as they are an important cause of biodiversity loss worldwide and interfere with the provision of many ecosystem services. Here, we propose a general model to identify regions where the probability of plant invasion is higher and can cause and/or aggravate negative effects upon ecosystems. We then apply the general model to Mexico. Our model of probability of invasion considers 4 main variables: propagule availability, vegetation type, anthropic disturbance and native plant species richness. We calculated an invasion risk index combining all factors. We produced 5 maps, one for each variable and another constructed with our model of combined risk, for a grid of 0.5º × 0.5º grid across the whole country. We validated our model with State level data on exotic plants per State and obtained a significant correlation ($r = 0.73$, $p < 0.001$) between our invasion risk index derived from the model and the observed density of exotic species. Areas with greater susceptibility to invasion are closer to large human settlements and to areas of intensive agriculture. Very high risk corridors and islands were detected in our maps, as well very high risk areas in high diversity regions such as Chiapas and the Puebla-Veracruz border where we suggest attention should be focused. Our model although simple, provides a useful tool for policy design to detect areas within a specific region or country where biotic invasions are likely to have a large effect. Locating these areas is important in order to maximize return on monetary and human resources and to minimize damaging effects of plant invasions.

Keywords: Exotic species; Invasion model; Ecosystem services; Biotic invasion

Resumen

El desarrollo de mapas se ha convertido en una herramienta clave para el mantenimiento de los servicios ecosistémicos; sin embargo, ha sido poco utilizada para prevenir la pérdida de estos. Las invasiones bióticas son consideradas como agentes de perturbación debido a que ocasionan importantes pérdidas en la biodiversidad e interfieren con la provisión de servicios. Este trabajo propone un modelo regional para detectar áreas con alta probabilidad de invasión por plantas. El modelo se parametriza y se valida para México considerando 4 variables: disponibilidad de propágulos, tipo de vegetación, disturbio antrópico y riqueza de plantas nativas. Obtuvimos 5 mapas para México, uno para cada factor y otro más con el resultado del modelo de probabilidad de invasión (cuadrícula 0.5º × 0.5º). Validamos nuestro modelo contra la densidad de exóticas por estado y obtuvimos una correlación significativa ($r = 0.73$, $p < 0.001$). Las regiones con mayor susceptibilidad de invasión estuvieron cercanas a grandes ciudades y grandes extensiones agrícolas, pero también a regiones con alta biodiversidad, como Chiapas y la frontera entre Puebla y Veracruz.

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Nuestro modelo, a pesar de ser simple, provee una herramienta útil para diseñar políticas públicas para detectar áreas con alta probabilidad de invasión y maximizar los recursos financieros y humanos.

Palabras clave: Especies exóticas; Modelo de invasión; Servicios ecosistémicos; Invasión biótica

Introduction

Mapping has become a key tool to guide priority action. Recent literature shows an increasing interest in mapping ecosystem services (Martínez-Harms & Balvanera, 2012). The identification of priority areas for maintaining the provision of ecosystem services and for exploring potential synergies or conflicts between biodiversity conservation and that of ecosystem services (Martínez-Harms & Balvanera, 2012; Turner et al., 2007) has relied on this approach. Also, recent emphasis has been put on how much ecosystems have been impacted by human enterprise (Ellis & Ramankutty, 2008; Halpern et al., 2008). Such maps are critical for identifying areas where restoration, for instance, is most urgently needed.

Maps to guide priority action in the prevention and management of invasive species are scarce (Chytry et al., 2009; Mgidi et al., 2007; Nel et al., 2004; Rouget et al., 2004). Invasive species are an increasing threat to human wellbeing and to ecosystems in general. Mapping invasibility, defined as the overall susceptibility of sites to invasion (Williamson, 1996), could become key tools to guide urgent preventive actions. Invasive species can cause severe shifts in ecosystems, leading to native species extinctions, to substantial economic loss, reductions in the ability to provide ecosystem services and threats human health (Mack & Erneberg, 2002; Pimentel, Zuniga, & Morrison, 2005). Today species invasions are considered as the second cause of biodiversity loss, just behind land use change (Leung et al., 2002; Vitousek, D´Antonio, Loope, & Westbrooks, 1996). Big shifts in native species composition have been documented in South Africa, Australia and the USA, where approximately 400 of the 958 species that are listed as threatened or endangered are considered to be at risk because of competition-with and predation by non indigenous species (Pimentel, Lach, Zuniga, & Morrison, 2000). Species invasions also cause substantial economic losses; Pimentel et al. (2005) have calculated that in the US alone over $120 billion are spent due to species invasions whereas Colautti, Bailey, van Overdijk, Amudsen, and MacIsaac (2006) estimated that Canada is losing $187 million Canadian per year. Other countries such as Mexico do not have sufficient information about the effects of non- indigenous species on the economy, but few plant and fish species cause severe losses (Aguirre-Muñoz et al., 2009; Espinosa-García & Vibrans, 2009; Espinosa-García, Villaseñor, & Vibrans, 2009).

Invasion research is ripe for the development of invasion risk maps to guide priority action. An increasing amount of empirical data available on invasive species, in many parts of the world (NLWRA, 2007; Rejmánek & Randall, 2004; Stohlgren, Barnet, & Kartesz, 2003; Villaseñor & Espinosa-García, 2004) and the drivers underpinning invasibility have been widely studied (Arriaga, Castellanos, Moreno, & Alarcón, 2004; Chytry et al., 2009; Chytry et al., 2012; Deutschewitz, Lausch, Künh, & Klotz, 2003; Pino, Font, Carbó, Jové, & Pallares, 2005; Stohlgren et al., 2006). On the other hand, niche-based predictions have been employed to project future distribution of individual invasive species (Arriaga et al., 2004; Zimmerman et al., 2011). Yet, this approach is extremely data intensive and action cannot wait until such information is gathered for all possible invasive species in most countries.

Invasion risk maps to guide priority action that can be produced with readily available information are urgent for most countries. This is particularly true for the case of Mexico for various reasons. First, it is a highly diverse country with little public and governmental awareness of the threats of the biological invasions (Espinosa-García, 2009), thus, information on areas where invasive species could have a significant negative effect on ecosystems and human societies are urgently needed (IMTA, TNC, Conabio, Aridamerica, & GECI, 2008). Second, there are well-known examples of how invasives are having a strong effect upon biodiversity, ecosystems and human-well being (Pejchar & Mooney, 1999), e. g. the exotic water hyacinth (*Eichhornia crassipes*) (Martínez-Jiménez & Gómez-Balandra, 2007; Pérez-Panduro, 1998) and the Itchgrass (*Rottboellia cochinchinensis*), considered to be one of the worst weeds in the world (Esqueda-Esquivel, 2005; Holm, Plucknett, Pancho, & Herberger, 1977; Medina-Pitalúa & Domínguez-Valenzuela, 2001). Third, ongoing research has already explored what are the most important factors associated with the presence of invasive species in Mexico as well as their relative importance at the country level (Espinosa-García, Villaseñor, & Vibrans, 2004; Villaseñor & Espinosa-García, 2004).

In this manuscript we developed a conceptual model and a simple analytical procedure based on readily available information for mapping invasibility. We apply the model to the case of the whole Mexican country, and use empirical data to validate our model. We then discuss how much was gained from this approach and what are its limitations. We also discuss how useful this map could be for other countries beyond Mexico.

Materials and methods

The conceptual model

Four main factors have been found to be among the most important for plant invasions into a spatially explicit model of