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Predictors, spatial distribution, and occurrence of woody invasive plants in subtropical urban ecosystems

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ABSTRACT

We examined the spatial distribution, occurrence, and socioecological predictors of woody invasive plants (WIP) in two subtropical, coastal urban ecosystems: San Juan, Puerto Rico and Miami-Dade, United States. These two cities have similar climates and ecosystems typical of subtropical regions but differ in socioeconomics, topography, and urbanization processes. Using permanent plot data, available forest inventory protocols and statistical analyses of geographic and socioeconomic spatial predictors, we found that landscape level distribution and occurrence of WIPs was not clustered. We also characterized WIP composition and occurrence using logistic models, and found they were strongly related to the proportional area of residential land uses. However, the magnitude and trend of increase depended on median household income and grass cover. In San Juan, WIP occurrence was higher in areas of high residential cover when incomes were low or grass cover was low, whereas the opposite was true in Miami-Dade. Although Miami-Dade had greater invasive shrub cover and numbers of WIP species, San Juan had far greater invasive tree density, basal area and crown cover. This study provides an approach for incorporating field and available census data in geospatial distribution models of WIPs in cities throughout the globe. Findings indicate that identifying spatial predictors of WIPs depends on site-specific factors and the ecological scale of the predictor. Thus, mapping protocols and policies to eradicate urban WIPs should target indicators of a relevant scale specific to the area of interest for their improved and proactive management.

1. Introduction

Urban areas are currently home to over 50% of the world's population and rates of urbanization will only increase through 2050 (Roberts, 2011). These urban areas are ecosystems offering habitats with novel disturbance regimes and new germination and colonization sites for the establishment of non-native species (Allen et al., 2013; Kowarik, 2011). Non-native or alien plant species now constitute an important and substantial part of the vegetation composition of urban ecosystems throughout the globe (Alston and Richardson, 2006; Kendal et al., 2014; Lima et al., 2013; Richardson and Rejmánek, 2011; Zhao et al., 2010a). However, alien vegetation has in many instances also become invasive, posing detrimental impacts to adjacent natural ecosystems (Bradley et al., 2012; Larson et al., 2011). Indeed, alien invasive plants have had major deleterious economic and ecological effects on urban and peri-urban landscapes throughout the globe because of their proximity to natural, agricultural and forest ecosystems. While much of the global research has been devoted to invasive plants in forested and agricultural landscapes, a little studied area is that of understanding and identifying the management relevant socio-ecological predictors of woody invasive plants (WIPs) in urban ecosystems where most invasive plants originate.

Plant invasions in urban areas affect ecosystem service provision (Escobedo et al., 2010; Kendal et al., 2014; Zhao et al., 2010b) and

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increase ecological homogenization (Groffman et al., 2014). In natural areas, invasive plants have been shown to reduce biodiversity and alter biogeochemical processes (Richardson and Rejmánek, 2011), change forest structure, and alter natural disturbance regimes (Vicente et al., 2013; Vitousek et al., 1995). Species such as *Schinus terebinthifolius* Raddi and *Melaleuca quinquenervia* (Cav.) S.F. Blake, for example, have displaced native plants in subtropical urban and natural areas, altering ecosystem function, and leading to reductions in some populations of associated native animal species (Larson et al., 2011; OTA, 1993).

Urban ecosystems and their inhabitants are primary sources of, and dispersal agents for, invasive plant species (Mack et al., 2000; Reichard and White, 2001). Invasive plants originate in urban ecosystems through horticultural plantings; 85% of all invasive woody species in North America were intentionally planted in urban areas (Martin et al., 2008). Invasive plants are able to spread as the boundaries between urban and peri-urban areas in many geographic locales are increasingly intermixed, and areas with natural vegetation become urbanized (Gavier-Pizarro et al., 2010). For example, the number of housing units in subtropical Florida has increased 23% over the last decade (US Census Bureau, 2012), and ~30% of its flora is non-native (Bradley et al., 2012). The introduction of *S. terebinthifolius* as an ornamental plant in urban and peri-urban areas which then escaped, has negatively affected expansive areas of the Florida Everglades, United States (US). The occurrence of invasive trees and shrubs is closely related to ecological processes and anthropogenic activities (Mack et al., 2000; Gavier-Pizarro et al., 2010; Richardson and Rejmánek, 2011), in particular land use change (Reichard and White, 2001; Vitousek et al., 1995). Therefore, identifying the socio-ecological factors, or spatial predictors influencing invasive trees and shrubs occurrence, in urban areas is necessary for their effective management and control (Alston and Richardson, 2006; Larson et al., 2011; Richardson and Rejmánek, 2011; Vicente et al., 2013).

Across the globe, urban WIP distributions have been associated with a variety of socio-ecological factors. In Phoenix, US and Santiago, Chile, plant diversity was shown to be driven by socioeconomic factors (de la Maza et al., 2002; Hope et al., 2003). Invasive plant richness and occurrence was also found to be strongly related to housing variables in the northern US, such as the boundary between low-density residential areas and peri-urban areas and the housing density (Gavier-Pizarro et al., 2010). Anthropogenic disturbance was found to influence alien plant richness in a subtropical South African peri-urban area, while alien stem density was not (Alston and Richardson, 2006). Allen et al. (2013) also found that regional patterns of urban development in the northern US were linked with woody plant invasions. Similarly, invasive trees and palms in Florida, US, were found primarily in residential land uses and natural areas as opposed to private and public non-residential land uses (Zhao et al., 2010a).

Studies have also shown how socio-ecological factors play a role in determining the spatial distribution of invasive species in urban forests. Urban and peri-urban chemical and physical soil properties and maintenance activities have been found to affect the composition, structure and function of urban vegetation in subtropical cities (Dobbs et al., 2011; Hagan et al., 2012). Climatic events, such as hurricanes have been reported to influence WIP occurrence, and spread (Zhao et al., 2010a). Vicente et al. (2013) for example used a multi-scale approach and 24 environmental predictors and geospatial data to develop a distribution model for prioritizing invasives management. Previous research on predicting urban WIPs has, however, been limited, as most studies have focused on temperate, herbaceous plants (Richardson and Rejmánek, 2011) in smaller sized study areas (Levine, 2008; Martin et al., 2008).

Overall, we found few landscape scale studies in the global literature that identified the socio-ecological predictors that could be used to predict subtropical, urban woody invasive tree and shrub occurrence. This is partially a result of the complexity of field data collection in urban areas, which is difficult and costly due to access, safety and logistical limitations. Given this gap in our understanding, the aim of our study was to analyze WIP distributions at the landscape scale and identify socio-ecological indicators that could spatially predict their occurrence. To better understand these management relevant factors, we chose two contrasting coastal urban ecosystems as our study sites: San Juan, Puerto Rico and Miami-Dade, Florida. These two study areas have similar climates and populations, are located between coastal and conservation areas, and encompass land uses and ecosystems typical of the Caribbean region and other subtropical areas in Asia, Australia, and elsewhere. However, they differ in socioeconomic patterns and topography, as Miami-Dade was relatively recently urbanized, whereas San Juan has a longer history of urbanization. We propose that these two cities could be used to develop an approach for use in other coastal cities in the subtropics, tropics, and elsewhere.

Specifically, our research objectives were to: (1) compare and contrast the spatial distribution, composition, and occurrence of WIPs in these two coastal cities, and (2) Identify regional commonalities and differences with respect to the socio-ecological predictors of urban WIP occurrence in similar climates, but with differing urban development histories. Landscape and regional scale knowledge about how the spatial distribution, abundance, and occurrence of WIPs in cities throughout the globe are related to site legacy, land use change, and site characteristics could be used to predict their occurrence, improve management and monitoring protocols, and better understand biodiversity dynamics in these novel ecosystems throughout the globe (Larson et al., 2011; Levine et al., 2003; Kendal et al., 2014; Kowarik, 2011; Richardson and Rejmánek, 2011).

2. Methods

2.1. Study areas

The Miami-Dade, Florida metropolitan area (MMA) covers 1273 km^2 and is located at 25° N and 80° W on the US mainland in southeast Florida, immediately adjacent to Everglades National Park (Fig. 1). Miami-Dade has humid subtropical and tropical climate with average maximum and minimum temperature of 28 °C and 20 °C, respectively. The mean annual precipitation is 1470 mm (Winsberg, 2003), with distinct wet and dry seasons. Miami-Dade, established in the late 1800s, is relatively recently urbanized, with most urbanization occurring after 1960. Substantial agriculture is common in the study area, where a variety of fruit and vegetable crops are grown. The MMA also has a wide range of ecological communities, including many wetland communities, though most of this area is classified as south Florida flatwoods, with interspersed hammock communities (USDA SCS, 1989). Soils are generally poorly-drained, shallow, non-hydric, upland soils with sandy marine sediments throughout the profile (USDA SCS, 1989).

The San Juan Metropolitan Area (SJMA) is located on the northeastern coast of the island of Puerto Rico at 18° N, 66° W (Fig. 1), and covers an area of 217 km^2. It has tropical marine climate with average minimum and maximum temperatures of 24 and 27 °C, and 1500–2300 mm of precipitation annually (Lugo et al., 2011), which is well-distributed throughout the year. Founded in 1521, SJMA is the second oldest European-established city in the western hemisphere. Its population peaked in the 1960's but has remained relatively constant since that time. Peri-urban areas encompass rangeland and agricultural areas, supporting a variety of