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Research Paper

Scale-dependence of environmental and socioeconomic drivers of albizia invasion in Hawaii

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ABSTRACT

To reduce the spread and impacts of invasive species in human-dominated landscapes, numerous and diverse residents often need to engage in individual as well as collective invasive species control efforts on their property and in their community. Combating invasion thus requires an understanding of what socioeconomic factors, in addition to ecological factors, may slow an invasive species or facilitate its spread. However, few studies have examined associations between invasive species and multi-scale socioeconomic and environmental factors, which may influence residents' decisions to control invaders. We combine spatially explicit social and environmental datasets, and we apply gradient boosting regression to examine the socioeconomic, land use, and environmental factors associated with the distribution of albizia (*Falcataria moluccana*), an invasive tree species, in Hawaii. We find that environmental factors are the dominant controls on albizia cover at the landscape scale, but socioeconomic variables lead to a modest improvement in the ability to predict albizia distribution at the housing subdivision scale. At the subdivision scale, albizia is more common on properties with absentee and/or less-wealthy landowners. Albizia is also more common on smaller properties and non-agricultural land. Our study provides policy recommendations for reducing the spread of invaders and outlines an approach using computation machine learning for examining multiple socioeconomic and environmental factors associated with biological invasion in complex social landscapes.

1. Introduction

Invasive species threaten native biodiversity, habitat and ecosystem functioning, the provisioning of ecosystem services, and human well-being (Asner et al., 2008; Funk, Matzek, Bernhardt, & Johnson, 2013; Pimentel, Lach, Zuniga, & Morrison, 2000; Vitousek, D'Antonio, Loope, Rejmanek, & Westbrooks, 1997). Scientists predict rates of invasion to increase with climate change, which will subsequently expand potential socioeconomic and ecological impacts (Hellmann, Byers, Bierwagen, & Dukes, 2008). Despite efforts by private organizations and government agencies to combat invasion, a lack of funding, political will, and cost-effective control techniques often limit the effectiveness of control efforts (Hershdorfer, Fernandez-gimenez, & Howery, 2007; Larson et al., 2011).

Researchers have identified the social complexity of the landscapes in which invasions occur as another key barrier to invasive-species control (Epanchin-Niell et al., 2010; Marshall, Coleman, Sindel, Reeve, & Berney, 2016). Complex social landscapes are defined as landscapes with numerous, diverse private and public landowners (Epanchin-Niell et al., 2010). Such landscapes increase the difficulty of invasive species control because the failure of one or several landowners to control on their property creates a reservoir of propagules, which can decrease the effectiveness of neighbors' efforts.

Despite the recognition that complex social landscapes are a critical barrier to effective invasive species control, much of the research on invasion has focused on the environmental and biological, rather than social, factors influencing invasive species distributions (Chytrý et al., 2008). Studies that have considered human influences on invasion typically examine how people facilitate the influx of invaders into a landscape or alter local environmental conditions and, therefore, change the "invasibility" of an area (Roura-Pascual et al., 2011; Vilà and Ibáñez, 2011). Studies have found connections between invader distributions, for example, and the distance to roads or other human infrastructure, the fragmentation of the landscape, current and past

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land use, and human population density (Decker et al., 2012; Manier, Aldridge, O'Donnell, & Schell, 2014; Vilà and Ibáñez, 2011). Decker et al. (2012) suggest that the relationship between invasive species and human population density could be explained by the density of roads, which can facilitate plant dispersal, or by greater landscaping in human-dominated landscapes, which can increase invasive plant dispersal through contaminated nursery stock or garden escapes. Vilà and Ibáñez (2011) suggest that humans can also facilitate invasion by increasing fragmentation and disturbance through land use, which creates the optimal habitat for many invaders to thrive.

Social science research suggests that humans influence the distribution of invasive species in a number of ways: by altering ecological conditions, introducing invaders, and taking action—individually and collectively—to manage invasive species on their property or community (Graham & Rogers, 2017; Niemiec, Ardoin, Wharton, & Asner, 2016). Niemiec et al. (2016), for example, found that residents in Hawaii took action to reduce the presence of the invasive albizia tree (*Falcataria moluccana*) by removing tree saplings and removing adult trees on their property, on others' property, and in public spaces. Many residents also took collective actions to combat albizia invasion. Those actions included contacting neighbors to convince them to take control measures and organizing community workdays to remove the invader trees. Residents have also taken collective actions to manage weeds in Montana, where residents organized volunteer weed brigades to assist their neighbors with weed control (Fiege, 2005), as well as serrated tussock in Australia, where residents shared information with their neighbors about weed control and coordinated control efforts with neighbors (Graham & Rogers, 2017).

Numerous social factors may influence the propensity of residents to engage in individual or collective action to combat invasive species. Those factors may operate at multiple scales: for example, property-level variables (e.g., property size), demographic characteristics (e.g., income), and characteristics of the communities in which the residents are embedded (e.g., community organizational capacity (Flint & Luloff, 2007)) may influence residents' decisions to engage in individual and collective invasive species control efforts (Cook, Hall, & Larson, 2012). Only a few studies, however, have sought to understand associations between a wide range of socioeconomic factors, in addition to environmental factors, and invader distributions (Gulezian & Nyberg, 2010; Staudhammer et al., 2015). Furthermore, research is lacking on how various social factors might interact to influence invader distributions across the landscape (Cook et al., 2012).

To address this gap, we examined social, economic, environmental, and land-use factors associated with the distribution of an invasive tree, albizia (*Falcataria moluccana*), across a human-dominated landscape. Specifically, we sought to answer three questions: (1) To what extent can variation in the spatial pattern of an invasive species be attributed to property- and community-level characteristics, rather than to environmental and land-use characteristics?; (2) Which environmental, land-use, land-owner, and community attributes are related to the distribution of an invasive species?; and (3) How might multiple socioeconomic drivers interact to influence the distribution of an invasive species?

2. Methods and materials

We combined remote sensing data on albizia distribution with spatially explicit property- and community-level social, economic, and environmental data across a landscape of ~100 800 hectares (ha) in the Puna District of Hawaii. We constructed a boosting regression model (Friedman, 2001) with those data, and we examined the model to identify the most important factors associated with the distribution of the invader at the scale of a district and a single subdivision (Fig. 1). In this section, we discuss our case study of albizia in Hawaii, followed by a review of the variables and datasets used in our analysis. Finally, we discuss how we use gradient boosting regression to examine the associations between environmental variables, socioeconomic variables, and albizia distributions.

Albizia (*Falcataria moluccana*) is a nitrogen-fixing tree native to the Moluccas, New Guinea, New Britain, and the Solomon Islands (Wagner, Herbst, & Sohmer, 1999). A botanist first brought albizia to Hawaii in the early 1900s. In the mid-1900s Territorial and State foresters planted albizia throughout the island of Hawaii as part of reforestation efforts (Hughes, Johnson, & Uowolo, 2011). The first large-scale plantings of albizia documented in the Puna District of Hawaii were in 1937 and 1940, when state foresters planted 318 and 183 albizia trees, respectively, in the Nanawale Forest Reserve (Fig. 1; Skolmen, 1963). Albizia forms a symbiotic association with *Rhizobium* bacteria, enabling the tree to fix nitrogen and colonize Hawaii's nitrogen-poor volcanic soils (Hughes & Denslow, 2005; Vitousek & Walker, 1989). Albizia facilitates invasion of other damaging exotic understory species and can overtop and remove native species, such as ʻōhiʻa lehua (*Metrosideros polymorpha*) (Hughes & Denslow, 2005). Due to the tall height and low wood density of albizia, its massive limbs can fall in high winds or with age, causing significant socioeconomic damage, particularly during tropical storms (Butler, 2014; Hughes et al., 2011).

In 2015, the Big Island Invasive Species Committee began outreach workshops in the Puna District to educate residents about how to control albizia on private property. A survey of landowners conducted in 2015 in the Puna District found that residents were generally aware of the socioeconomic and ecological threats posed by albizia (Niemiec et al., 2016); however, despite widespread awareness that albizia poses a problem, many residents had not taken action to control albizia in their community. A number of factors were suggested to influence resident engagement in efforts to combat albizia, including knowledge of effective control tactics, perceptions of social norms and reciprocity associated with albizia control (Niemiec et al., 2016), and emotional attachments to the tree (Niemiec, Ardoin, Wharton, & Brewer, 2017). However, socioeconomic factors, which may influence these perceptions and landowner decision-making more generally, have not yet been linked to albizia distributions across the landscape.

We examined factors associated with albizia distribution at the larger scale of the Puna District (~100 800 ha out the ~130 000 ha in the district) and the smaller scale of the Hawaiian Paradise Park housing subdivision (~4 000 ha) located within the district (Fig. 1). The Puna District includes a range of environmental and land-use conditions that vary over short distances (Armstrong, 1983; Asner et al., 2011), as well as a diversity of subdivision communities and demographics. Hawaiian Paradise Park (HPP) is the largest subdivision in the district, with a population of over 11 000 and 4 census block groups. Albizia is widespread throughout HPP (Fig. 1), possibly due to plantings of albizia in the area as well as widespread clearing of lots for development in the subdivision, which may have facilitated the spread and establishment of the tree.

We conducted our analysis at those two scales due to the possibility that various factors may show different relative importance at different scales (Crawley & Harral, 2001). Socioeconomic drivers may be less important at the district scale, compared to the subdivision scale, because the wide range of environmental filters within the district may supersede the influence of socioeconomic variables. In addition, at the larger district scale, government agencies or one of several major private landowners manage and own much of the land. These larger landowners may be less likely to take action to combat albizia because they may not live on their land and thus may not experience the socioeconomic impacts. Residents within subdivisions may therefore, as a whole, be more likely to manage albizia; this management could then impact albizia distributions.

2.1. Socioeconomic, land use, and environmental variables

We gathered spatially-explicit data on 56 variables that may influence the distribution of albizia across the Puna landscape. Table 1