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Landscape to site variations in species distribution models for endangered plants

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ABSTRACT

Present global plant extinction rates are 100–1000 times greater than pre-human levels and this is especially true on oceanic islands. There is a great need to model the distributions of endangered plants for reintroduction on oceanic islands, however, there are still questions concerning what is the most appropriate spatial scale and which environmental metrics should be included in order to guide restoration efforts. We examine the impact of spatial scale (1 km, 250 m, 10 m), environmental metrics (climate, topography, soils), and species overlap for 11 rare and endangered species in the dry forest of Oahu, Hawaii, which is one of the world's most endangered ecosystems, and contains some of the highest resolution data on species locations and environmental metrics for an oceanic island. At all spatial scales, the species distribution models reliably differentiated between occupied habitat and background for all 11 species (AUC $\geqslant$ 0.92). The relative importance of the environmental metrics did not vary across spatial scales with soil great group contributing most to the models followed by elevation, and mean precipitation of the driest quarter. The percent of the total island area with niche overlap for two or more species did not show any pattern with grain size, however, the 10 m model contained the largest areas of niche overlap for two or more species. There were 1292 10 m pixels on Oahu where models predict niche overlap for eight endangered species, however, only 1.2% of the total area is currently in protected areas. Results suggests that species distribution models are useful for predicting habitat suitability at all scales (1 km, 250 m, 10 m), environmental metrics do not change across scales but high resolution data on soils, topography, and precipitation are needed, and 10 m resolution data are the best for informing restoration decisions for the endangered species on Hawaii and other oceanic islands.

1. Introduction

Present global plant extinction rates are 100–1000 times greater than pre-human levels and could increase 10-fold by next century (Pimm et al., 1995; Ricketts et al., 2005). This is especially true for plants on oceanic islands that are extremely deforested and degraded and experiencing some of the highest extinction rates on the planet (Caujapé-Castells et al., 2010; Rolett and Diamond, 2004; Triantis et al., 2010). Native species reintroduction is one widely used method applied to conserving endangered species, which often face population growth challenges due to dispersal limitations and transient seed banks (Clark et al., 2007; Thompson, 1997). Despite its widespread use, reintroduction success rates are overall low due to the difficulty in identifying suitable habitat for restoration (Drayton and Primack, 2012; Godefroid et al., 2011; Questad et al., 2014). Thus, there is a need for methods that can identify suitable habitat for conducting endangered species reintroductions and evaluate the environmental factors influencing their distributions.

In Hawaii, almost half of all tropical dry forest tree and shrub species are listed as federally threatened or endangered (Pau et al., 2009). Historically, Hawaiian dry forest ecosystems contained high species richness and endemism (Rock, 1913), however, destruction of over 90% of the dry forest has resulted in widespread species loss (Bruegmann, 1996; Cabin et al., 2000; Sakai et al., 2002). Despite the pressing need for conservation of this ecosystem, management is greatly hindered by a lack of knowledge regarding the current distributions of Hawaiian dry forest species as well as potential sites for reintroduction (Pau et al., 2009). Although previous research has used GIS spatial analyses to map Hawaiian plant ranges (Price et al., 2012), none have used a

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predictive modeling approach to target sites for endangered species reintroduction.

In the past decade, species distribution modeling (SDM) for rare and endangered species has rapidly progressed and become an informative tool for identifying key areas for reintroduction and habitat conservation (Butler, 2009; Gallardo and Aldridge, 2013; Gogol-Prokurat, 2011; Guisan et al., 2006; Loiselle et al., 2003; Pearson et al., 2007; Thompson, 2004; Wilson et al., 2013). SDMs, also referred to as ecological niche models or habitat suitability models, are statistical models which predict the potential geographic distribution (or habitat suitability) of a species by measuring the relationship between a species' spatial distribution and select environmental variables (Franklin, 2009). In order to identify and prioritize conservation areas, maps identifying habitat suitability are essential for oceanic islands like Hawaii (Elith and Leathwick, 2009; Franklin, 2009).

Recently, there has been debate regarding the appropriate scale for SDMs, which are often constrained by coarse-resolution climate data (Austin and Van Niel, 2011; Franklin et al., 2013; Guisan et al., 2007; Niamir et al., 2011; Potter et al., 2013). In general, ecological modeling has been applied mainly for evaluating broad-scale species distributions, with few studies applying multi-scale techniques for an hierarchical assessment of potentially suitable habitat (Cabeza et al., 2010; Fernández et al., 2003; Razgour et al., 2011). On average, the pixel size used in SDMs for plants tend to be ca. 1000 times larger than the species being modeled, resulting in an inability for modeled distributions to capture the microenvironment in which a species lives (Potter et al., 2013). Accounting for microclimates is particularly important for oceanic islands with rugged terrain which often results in topographically controlled climate variation, only detected at 10–100 m scale (Caujapé-Castells et al., 2010; Franklin et al., 2013). Previous studies have successfully modeled potential distributions for rare plant species at fine-scale resolutions (25–250 m) (Engler et al., 2004; Gogol-Prokurat, 2011; Guisan et al., 2006; Marage et al., 2008; Williams et al., 2009); however, even scales of this resolution may not be fine enough. To be useful for local conservation planning, SDMs for rare and endangered species with low mobility and patchy distributions should identify suitable habitat at a similar scale to patch size (Trani, 2002). Thus, identifying the best spatial scale of SDM's for endangered species is of wide importance.

Variable choice has been another area of debate within the SDM community with some arguing that climate alone can be used in SDMs at coarse resolutions to broadly identify species distributions (Araújo and Peterson, 2012; Pearson and Dawson, 2003), whereas others suggest that SDMs based solely on coarse-scale climate data may not capture micro-environments determined by local topography (Ashcroft et al., 2009; Austin and Van Niel, 2011; Dobrowski, 2011; Franklin et al., 2013). While some studies have examined the contribution of variables to SDMs across spatial scales, few have compared variable contributions between even finer spatial resolutions. This is partly due to the lack of high-resolution spatial data for oceanic islands. Currently, globally comparative environmental metrics for oceanic islands are available at a1 km resolution for climate and up to 30 m resolution for elevation and topography. Furthermore, comparative geologic and soils data are limited. Despite the increased use of species distribution modeling for conservation planning, few studies have compared model predictions and variable importance for SDMs at different fine-scale resolutions: landscape (1 km), local (250 m), and site (10 m) levels for rare and endangered species on oceanic islands. This could identify the best environmental metrics and spatial resolution that should be used on other oceanic islands and other threatened ecosystems.

This research seeks to answer three primary questions relating to modeling rare and endangered species distributions on oceanic islands, such as Hawaii. First, does model accuracy significantly vary between a landscape, local, and site scale model? It is expected that coarser spatial scales will have lower model accuracies and higher predicted areas. Second, what combination of environmental metrics and spatial scale yields the best result for modeling rare and endangered plants on oceanic islands? In particular, we identify association among environmental metrics and identify if predictors of species distribution change across spatial scales. Third, does the total number of species with overlapping suitable habitat (niche overlap) vary between spatial scales?

2. Materials and methods

2.1. Study area

We created SDMs for rare and endangered plant species found in the seasonally dry forest on Oahu, Hawaii. Oahu is approximately 3.7 million years old and covers an area of 1546 km^2 with a maximum elevation of 1229 m (Macdonald et al., 1983). Two mountain ranges, the Wai'anae and Ko'olau, contribute to variation in temperature and precipitation across the island. Mean annual precipitation is highly variable (50–715 cm) with the rainy season occurring from November to March and the dry season persisting from April through October (Walker, 1990). Mean temperature ranges from 15.7 °C to 23.8 °C (Giambelluca et al., 2013). Historically, native tropical dry forests, scrublands, and grasslands occurred at low elevations and on the rainshadow or dry sides of the Wai'anae and Ko'olau mountain ranges (Cuddihy et al., 1989). On Oahu, there are 33 federally threatened and endangered dry forest plant species, many of which are on the brink of extinction (Pau et al., 2009).

2.2. Species and environmental data

Location data for 10 federally threatened and endangered plant species and one endemic dry forest plant species, that has experienced a recent decline in population size, were obtained from the Oahu Army Natural Resources Program (Gramling, 2005; Oahu Army Natural Resources Program, 2010), and are the only known living occurrences on Oahu (Table 1). These data are highly, spatially accurate due to precise GPS records of plants in the field, continuous monitoring, and searches conducted by botanists to find new individuals (Oahu Army Natural Resources Program, 2010). Only presence data were used for this study due to a lack of knowledge regarding the species historical distributions.

Climate, topography, and soil great group variables were used for creating SDMs at a landscape (1 km), local (250 m) and site (10 m) scale on Oahu, Hawaii. Mean monthly temperature and precipitation grids at a 250 m resolution were provided by

Table 1
Study species with occurrence numbers used for model testing over different spatial resolutions. Federal listings: E = Endangered, C = Critically Endangered, NL = Not Listed.

Scientific name	10 m	250 m	1 km	Federal
Abutilon sandwicense	72	43	19	E
Alectryon macrococcus micrococcus	204	101	39	E
Erythrina sandwicensis	21	12	7	NL
Eugenia koolauensis	53	19	13	E
Euphorbia celastroides kaenana	32	19	13	E
Euphorbia herbstii	15	9	5	E
Flueggea neowawraea	60	46	26	E
Hibiscus brackenridgei mokuleianas	49	20	12	E
Pleomele forbesii	38	37	26	C
Pritachardia kaalae	45	27	14	C
Pteralyxia macrocarpa	53	46	28	C