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Cover Photograph: View of the coastal forest from the Bordeaux Mountains trail, Virgin Islands National Park. Coastal forests below 85 m elevation were identified as the most suitable habitat for the shrub Solanum conocarpum, endemic to St. John USVI. Photograph © Matthew D. Palumbo.

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A GIS Model of Habitat Suitability for *Solanum conocarpum* (Solanaceae) in St. John, US Virgin Islands

Matthew D. Palumbo[1,2], Jonathan P. Fleming[1,3], Omar A. Monsegur[4], and Francisco J. Vilella[5,*]

Abstract - *Solanum conocarpum* (Solanaceae) (Marron Bacora) is a rare, dry-forest shrub endemic to the island of St. John, US Virgin Islands, considered for listing under the Endangered Species Act. Given its status as a species of conservation concern, we incorporated environmental characteristics of 3 observed populations and 5 additional known locations into a geographic information system (GIS) analysis to create a habitat-suitability model for the species on the island of St. John. Our model identified 1929.87 ha of highly suitable and moderately suitable habitat. Of these, 1161.20 ha (60.2%) occurred within the boundaries of Virgin Islands National Park. Our model provides spatial information on potential locations for future surveys and restoration sites for this endemic species of the US Virgin Islands.

Introduction

The Caribbean islands are a priority global biodiversity hotspot given the high rate of habitat loss (Brooks et al. 2006). Within the Caribbean, Puerto Rico and the Virgin Islands represent a unique ecological province at the intersection of the Greater and Lesser Antilles (Santiago-Valentín and Olmstead 2004). The shrub *Solanum conocarpum* Dunal (Marron Bacora) is endemic to the island of St. John and is considered one of the rarest plants in the Virgin Islands. Approximately 198 individuals in 8 populations are known for the island of St. John. Of these populations, 6 occur within or on the periphery of Virgin Islands National Park (VINP). The largest known natural population is located at Nanny Point (about 144 adult individuals), a natural area in southeastern St. John recently donated to VINP (Acevedo-Rodriguez 1996, Ray and Stanford 2005, USFWS 2011).

Little is known regarding the natural history (i.e., pollinators and seed dispersal) and basic ecology of *S. conocarpum*, including effects of herbivory. Further, *S. conocarpum* is considered a functionally dioecious species, rendering its rarity even more critical given the need of multiple individuals to ensure cross pollination and fruit production (Anderson et al. 2015, Knapp 2009, Stanford et al. 2013, USFWS 2011). The flora of the Virgin Islands has been greatly altered due to

[1]Department of Wildlife, Fisheries and Aquaculture, Mississippi State University, Box 9690, Mississippi State, MS 39762, USA. [2]Current address - Biology Department Room 2025, University of Western Ontario, London, ON N6A 3K7, Canada. [3]Current address - Department of Geography, Box 5225, University of North Alabama, Florence AL 35632, USA. [4]US Fish and Wildlife Service, Caribbean Ecological Services Field Office, Box 491, Boquerón, PR 00622, USA. [5]US Geological Survey, Mississippi Cooperative Fish and Wildlife Research Unit, Box 9691, Mississippi State, MS 39762, USA. [*]Corresponding author - fvilella@usgs.gov.

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centuries of settlement, agricultural use and, more recently, urban development (Acevedo-Rodríguez 1996). However, the greatest present threat to *S. conocarpum* appears to be the lack of natural recruitment. Given that the species exhibits good germination rates under greenhouse conditions (Stanford et al. 2013), lack of germination and recruitment in natural populations may be a combination of fruit predation by native *Coenobita clypeatus* (Fabricius) (Caribbean Hermit Crab), the obligate outcrossing nature of *S. conocarpum*, and an apparent lack of seed dispersal. Similarly, *Goetzea elegans* Wydler (Solanaceae) (Mata Buey), endemic to Puerto Rico, is an endangered species that shows prominent flowering and fruit set, but also exhibits limited natural recruitment and low fruit set on isolated individuals (Caraballo-Ortiz et al. 2011).

Current populations of *S. conocarpum* occur on dry, poor soils, and these areas (i.e., coastal scrub) may not represent optimum habitat (Ray and Stanford 2005). Populations of *S. conocarpum* within VINP may be at further risk due to management practices such as trail and facility maintenance, as well as from feral mammalian browsers including *Capra aegagrus hircus* (L.) (Domestic Goat), *Equus africanus asinus* L. (Burro), and *Odocoileus virginianus clavium* Barbout & G.M. Allen (Key Deer) that may feed on the plants or trample small individuals. Moreover, individuals on private land are also at risk from residential and tourism development.

The application of habitat suitability index (HSI) models is a highly influential tool used by natural resource managers and decision makers (Brooks 1997). These models characterize landscapes with index values (e.g., range = 0–1), indicating habitat suitability based on measured features. Mapping products generated from HSI models are routinely used for making decisions on land management practices and guiding habitat conservation alternatives such as identifying reintroduction sites for endangered wildlife species (Lauver et al. 2002). Many remote-sensing and geographic information system (GIS) applications have been used to develop spatially explicit wildlife habitat models (Dale et al. 1998), but with few exceptions (Wu and Smeins 2000, Duarte et al. 2012), they have not been extended to plants. Herein, we present a spatial model of *S. conocarpum* habitat suitability to assess distribution, habitat quality, and potential locations for future field surveys and restoration sites on the island of St. John. We also present information on habitat structure and vegetation composition of 3 known *S. conocarpum* sites.

Methods

Study area

The US Virgin Islands, an unincorporated territory of the United States, includes the main islands of St. Croix, St. John, and St. Thomas, and numerous surrounding cays (Fig. 1). At approximately 53 km^2 in area, the island of St. John (18°20'33"N, 64°44'43"W) is the smallest of the US Virgin Islands. However, St. John has the greatest amount of forest cover (91.6%) and mature secondary forest (20%) in relation to total area compared to the other islands in the region (Brandeis and Oswald 2007). The vegetation of St. John is greatly influenced by humidity and mostly dominated by subtropical, dry, evergreen woodland (Acevedo-Rodríguez 1996).

Areas of moist forest are found at higher elevations where moisture carried by the trade winds provides increased humidity (Brandeis and Oswalt 2007).

Field surveys

Diagnostic characters of *Solanum conocarpum* include adult plants up to 4 m in height and coriaceous oblanceolate leaves measuring 3.5–7.0 cm by 1.6–3.0 cm with a conspicuous yellowish to orange midvein. Flowers are usually paired in nearly sessile lateral or terminal cymes with 5 separate 2-cm-wide, light-violet petals that are greenish at the base (Fig. 2). The fruit is a 2–3-cm-long ovoid-conical berry, which turns from green with white striations to golden yellow when ripe (Acevedo-Rodriguez 1996).

We conducted surveys on *S. conocarpum* in St. John during May 2010 and collected information on habitat structure and taxonomic composition of the surrounding vegetation at Nanny Point, Brown's Bay Trail, and John's Folly. Each

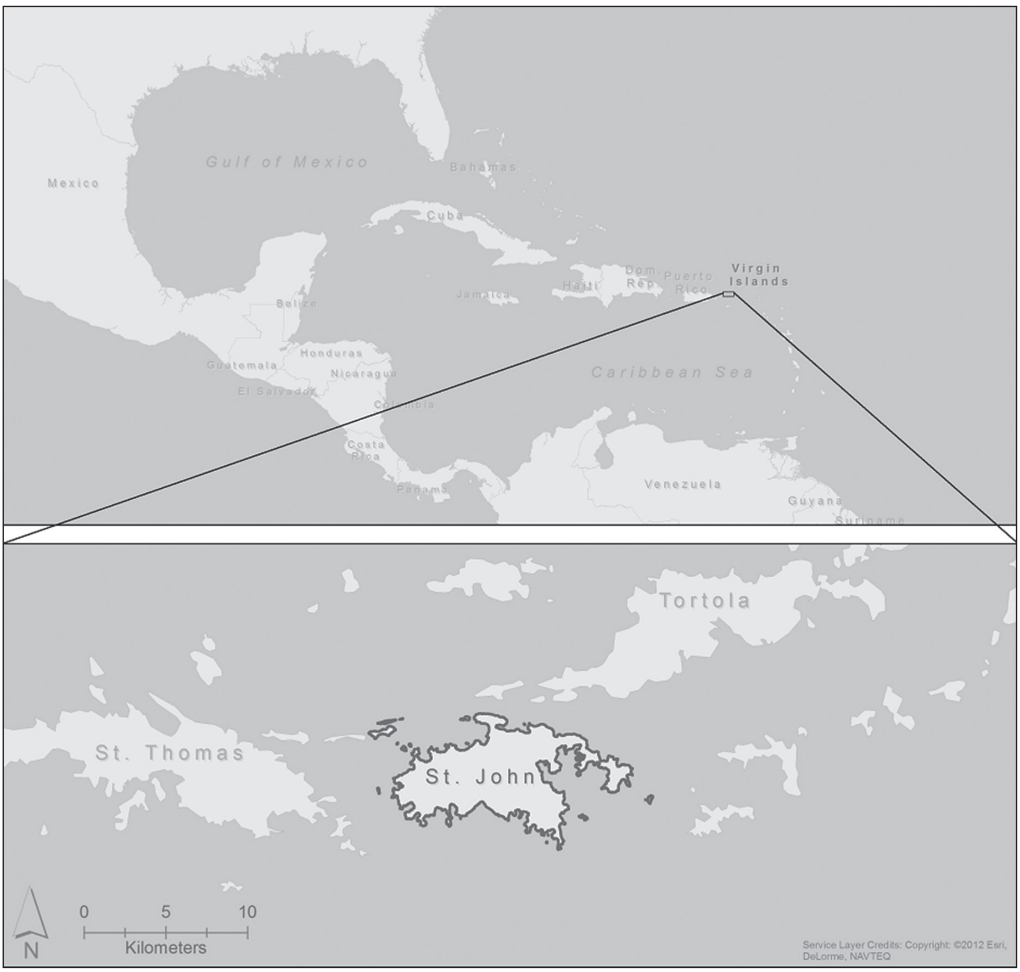

Figure 1. Map of the West Indies indicating location of the Virgin Islands (top) with St. John, USVI, and neighboring islands, St. Thomas, USVI, and Tortola, BVI (bottom).

location had at least one wild *S. conocarpum* individual and planted seedlings derived from the Nanny Point population. We recorded elevation (m) using a Thommen® altimeter, location coordinates with a Trimble® global positioning system (GPS), stem diameter (cm) with a Lufkin® diameter tape, and vegetation height (m) using a Suunto® clinometer. We report basal stem diameter and height as mean ± standard deviation.

Spatial analysis

We performed a geographic information system (GIS) analysis for the island of St. John using information collected at local sites where *S. conocarpum* occurs and obtained from available spatial databases. Databases included vegetation cover, soil associations, digital elevation models (DEM), and boundaries of VINP. Database sources included digital cover of soil associations obtained from the USDA (2008), DEM raster models (30-m resolution) developed by the Natural Resources Conservation Service (USDA-NRCS) National Geospatial Center of Excellence, and digital land-cover data on vegetation communities of St. John developed by the Conservation Data Center of the University of the Virgin Islands (UVI 2001).

We utilized these digital databases to generate a habitat suitability model for *S. conocarpum* in St. John using geographic locations of 3 surveyed populations and 5 other known populations made available following our field surveys, along

Figure 2. Flowering *Solanum conocarpum* individual at Brown's Bay trail, Virgin Islands National Park, St. John, USVI.

with the environmental characteristics of each location. Areas of distinct suitability represented a level of habitat quality based on the environmental parameters and topographic characteristics incorporated into the model. We used GPS locations recorded for the Nanny Point, John's Folly, and Brown's Bay Trail sites, and used our study GIS to derive approximate locations for the remaining 5 sites. For each location, we extracted values for elevation, slope, soil association, and vegetation. Suitable criteria were determined by taking the mean ± 2 standard deviations (elevation and slope) or encountered categories (soil and vegetation). Suitable criteria were: (1) elevation of 36.95 m ± (2*24.14 m); (2) slope of 16.65° ± (2*7.08°); (3) soil types of CgC (Cinnamon Bay gravelly loam), VsE and VsF (both Victory-Southgate complex with varying slope), and SrE, SrF, and SrG (all Southgate-Rock outcrop complex with varying slope); and; and (4) vegetation types of thicket scrub, pasture mixed scrub, drought deciduous forest, and semi-deciduous woodland.

Each layer of habitat suitability was converted to a binary raster format (30-m resolution) with a value of 1 assigned for suitable areas and a value of 0 for unsuitable areas. Binary raster layers were combined in ArcGIS using the weighted linear combination (WLC) method with the suitable area in each layer given an equal weight. The WLC model is one of the most widely used GIS-based decision rules for deriving composite maps. This linear modeling approach is often applied in analysis of land-use and suitability, site selection, and resource evaluation decisions (Herzfeld and Merriam 1995, Malczewski 2000). Each *S. conocarpum* location in St. John was assigned a value based on the resulting WLC solution. Areas where no suitable criteria were met received a value of 0 (unsuitable), while areas where all criteria were suitable received a value of 4 (highly suitable). Final WLC model outputs included a geographical representation of the spatial distribution of predicted *S. conocarpum* habitat and an estimate of area in hectares of each suitability category (unsuitable, poor, low, moderate, high).

Results

The results of our spatial habitat model for *S. conocarpum* in the island of St. John identified 694.94 ha of high-quality habitat, 1274.94 ha of moderate-quality habitat, 1568.53 ha of low-quality habitat, 1343.16 ha of poor-quality habitat, and 186.88 ha of unsuitable habitat (Fig. 3). Within the boundaries of VINP, the model identified 387.43 ha of high-quality habitat, 773.77 ha of moderate-quality habitat, 1096.91 ha low-quality habitat, 1106.30 ha of poor-quality habitat, and 181.22 ha of unsuitable habitat. When adding together the hectares of high- and moderate-quality habitat, approximately 32% of the land area of VINP may be suitable habitat for *S. conocarpum* (Fig. 3).

Our field surveys of *S. conocarpum* localities were in subtropical dry forest (Ewel and Whitmore 1973). At the Nanny Point site, a parcel recently donated to VINP, we sampled about 64 adult trees, some of which were flowering. Basal stem diameter averaged 5.1 cm ± 2.95 cm, and height of individual plants averaged 2.46 m ± 0.57 m. The site was dominated by species in the families Cactaceae, Capparaceae, and Euphorbiaceae. The population of *S. conocarpum* at Nanny Point was dominated by adult individuals, with limited evidence of wild seedlings in the area, suggesting a lack of natural recruitment. Fruit collected from this population was previously used as a seed source and germinated under greenhouse conditions (Stanford et al. 2013). Further, *S. conocarpum* individuals near the edges were overgrown by vines and exotic grasses (i.e., *Megathysus maximus* (Jacq.) B.K.Simon & S.W.L.Jacobs [Guinea Grass]). Private lands surrounding the *S. conocarpum* population at Nanny Point were subject to housing development. However, these adjacent lots were under a conservation easement whereby clearing of natural vegetation was restricted to 25% of the area, providing further protection to the population and its habitat.

The second *S. conocarpum* population surveyed was located at John's Folly Bay at the boundary with VINP. The site was located upslope in a gully about 20 m from a paved road and in the same drainage as the Nanny Point population. All 11 adult plants located were naturally occurring, with several surviving saplings transplanted from the Nanny Point population. Plants were flowering, but no fruiting was observed and no natural recruitment was apparent. The *S. conocarpum* population was composed of older, mature individuals. Basal stem diameter at John's Folly Bay averaged 3.14 cm ± 1.85 cm, and height of individual plants averaged 1.76 m ± 0.41 m. A total of 22 plant species were found in the vicinity dominated by species in the Cactaceae, Capparaceae, and Rhamnaceae families.

The third *S. conocarpum* site assessed was located along the Brown's Bay trail within VINP, an area of mature dry forest located on the northeastern shore of St. John. The site was located on a slope approximately 60 m from shore and included a single wild adult specimen with several saplings propagated from the Nanny Point population. The mature plant was located directly on the edge of the Brown's

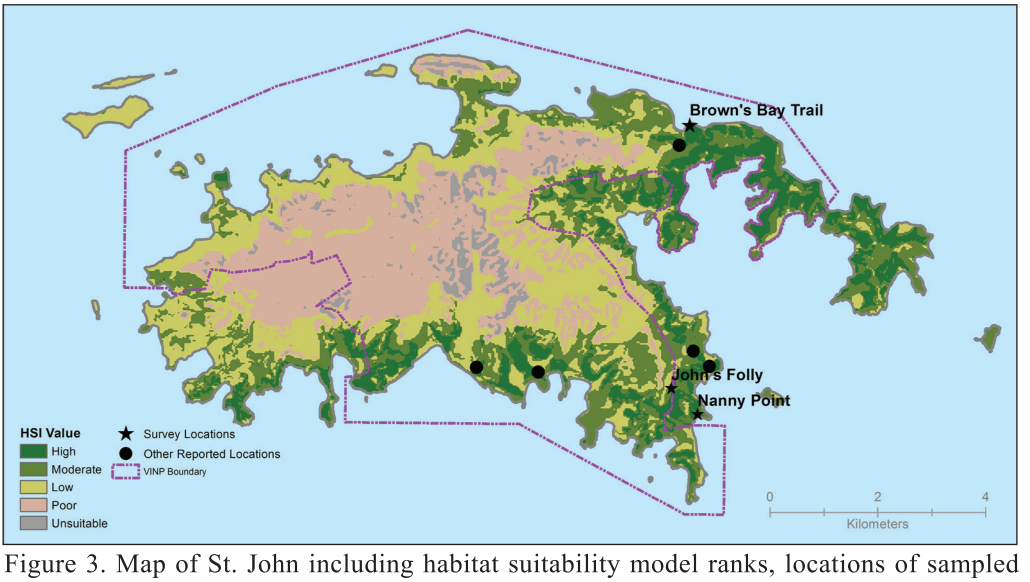

Figure 3. Map of St. John including habitat suitability model ranks, locations of sampled populations of *Solanum conocarpum*, other known populations, and boundaries of Virgin Islands National Park.

Bay hiking trail and showed signs of direct impacts from trail maintenance activity (i.e., clearing of vegetation). Similar to the other sites visited, there was no direct evidence of natural recruitment. The adult plant had a stem diameter of 5.8 cm and a height of 4 m, and was flowering, but no fruit production was observed. We documented 30 plant species at the site; dominant families included Cactaceae, Celastraceae, and Rubiaceae.

Discussion

The results of the habitat model indicate *S. conocarpum* habitat was restricted to lower elevation (<85 m) coastal scrub forest (Fig. 4), with much of it found on private lands. As the history of the Nanny Point population demonstrates, additional *S. conocarpum* populations may be found on private lands in other parts of St. John, e.g., coastal scrub and dry forests on the eastern shores of St. John (e.g., East End peninsula and Coral Bay) that are virtually all privately owned. Furthermore, coastal scrub habitats of St. John are prone to fires that decrease their stature and allow persistent shrublands dominated by introduced woody species and grasses (Brandeis and Oswalt 2007). Therefore, the areas identified by our model as highly suitable for *S. conocarpum* within VINP and privately owned lands may assist in focusing future surveys and habitat protection efforts (Fig. 3).

Ecological data can sometimes reflect a "convenience sampling" approach (Anderson 2001). This occurs when data are collected either at sites located by chance or readily accessible along roads or trails, and are not representative of

Figure 4. Coastal scrub community typical of *Solanum conocarpum* habitat at Nanny Point, St. John, USVI.

the population of interest. Consequently, this may limit the inductive inference concerning the population parameters of interest (i.e., *S. conocarpum* geographic distribution and abundance). For instance, the Nanny Point population was only identified as a result of the landowner's concern for the potential presence of species of conservation importance on his property. Furthermore, both the John's Folly and Brown's Bay sites are located along existing trails and easily accessible by road. Forest lands cover approximately 91.6% of the surface of St. John, due in large part to the fact that 53% of the island lies within VINP. However, there has been increasingly rapid development of vacation homes and tourist-related businesses on private lands. A statistically based sampling approach (e.g., stratified random sampling) on portions of St. John identified by our model may result in more reliable knowledge of *S. conocarpum* geographic distribution and abundance.

Plants face unique conservation challenges, including seed dormancy, diverse mating systems (i.e., self-fertilization to complete outcrossing), and reliance on animals for dissemination of pollen and seeds (Schemske et al. 1994). Pollination and herbivory may be particularly important in small populations and may be disrupted as a result of habitat fragmentation (Kolb 2008). Therefore, other ecological factors besides a fragmented geographic distribution and low abundance may be negatively impacting *S. conocarpum*. Whether the lack of natural recruitment is due to poor microhabitat conditions or browsing by hermit crabs or exotic mammals is unknown. Despite these potential limiting factors, *S. conocarpum* exhibits adequate levels of heterozygosity (Stanford et al. 2013), and propagation using seeds or cuttings can be successful, highlighting the recovery potential for the species.

Validating the predictions of the habitat model would benefit the conservation of *S. conocarpum*, as model improvements are possible. Developing habitat models for rare and endangered plants is not frequently pursued, due in part to the absence of suitable locational data necessary for robust ecological modeling (Duarte et al. 2012). Yet from a conservation perspective, predicting geographic distribution is particularly useful (Engler et al. 2004). The use of spatial information technologies to generate solutions on geographic distribution and habitat relationships of *S. conocarpum* and other rare plants of the Virgin Islands (i.e., *Zanthoxylum thomasianum* (Krug & Urb) P. Wilson [St. Thomas Prickly Ash], *Calyptranthes thomasiana* O. Berg [Thomas' Lidflower], and *Eugenia earhartii* Acev.-Rodr. [Earhart's Stopper]) would improve the capabilities to define areas for protection or targeted management, and to identify suitable sites for successful reintroductions. These efforts would benefit the conservation of rare endemic plants in the US Virgin Islands.

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