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Recommended Citation

Rogers, Cecilia, "Investigating the ecology of a rare species on St. John, Usvi: Reintroducing Solanum conocarpum in light of climate change" (2018). *Senior Honors Projects, 2010-current*. 571.
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Investigating the Ecology of a Rare Species on St. John, USVI: Reintroducing *Solanum conocarpum* in Light of Climate Change

An Honors College Project Presented to

the Faculty of the Undergraduate

College of Science and Mathematics

James Madison University

by Cecilia L Rogers

Accepted by the faculty of the Department of Biology, James Madison University, in partial fulfillment of the requirements for the Honors College.

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PUBLIC PRESENTATION

This work is accepted for presentation, in part or in full, at

Bioscience Biosymposium on 4/12/2018 .

The Ecology of a Rare Species, *Solanum conocarpum*, in St. John USVI

Cecilia L. Rogers

Approximately two thirds of St. John is National Park territory. However, the land has been threatened with tourism and development, greatly impacting island biodiversity. One species that may become extinct due to this degradation is *Solanum conocarpum. S. conocarpum* is a rare shrub, endemic to the dry tropical forests of St. John, USVI. This plant is a species of conservation concern and is one of very few native and endemic plants on this island. Very little is known about the ecology and reproduction of *S. conocarpum*. Most plants are found on the southern half of the island. Recent observations have indicated that the greatest threat may be lack of regeneration, possibly due to suboptimal habitat conditions. This study investigated the ecology of *S. conocarpum* in order to begin identifying optimal areas for reintroduction. Results showed that plant growth and reproduction differed significantly between five known populations. Some populations were more negatively affected by herbivory than other populations but this was not due to differences in secondary compounds (cyanogenic glycosides). The population closest to the shoreline (Nanny Point) had the greatest number of individuals and largest size (diameter) but also had the lowest survival due to the hurricanes in 2017. We conclude that sites further away from the shoreline and of western aspect (similar to Reef Bay) are optimal locations for *Solanum conocarpum* reintroduction.

Introduction

Our earth's ecosystems are currently in the midst of the 6th mass extinction; and this extinction is unique to others in that it has been catalyzed by human impact (Pouteau & Birnbaum, 2016). Urbanization, deforestation, and unsustainable resource usage have threatened the majority of species on earth, rapidly decreasing the earth's biodiversity. Biodiversity describes the vast number and variety of living organisms inhabiting a certain area, and has an important influence on the overall health of an ecosystem as well as the survival of species, which depend on one another's presence in order to survive (Pouteau & Birnbaum, 2016 and Ferriera et. al. 2015). Ecosystems with greater biodiversity are more resilient to disturbance.

Some of the most diverse ecosystems reside in island ecosystems. With approximately 52% of the world's species richness concentrated in around 7% of the earth's terrestrial surface, these areas are biodiversity hot spots (Kier et. al., 2008). Oceanic islands host many endemic species threatened with extinction due to human impact (Ferriera et. al. 2015). One third of global diversity hotspots reside on oceanic islands (Whittaker & Fernández-Palacios, 2007). Island species are less able to adapt to environmental degradation (Carlquist, 1974).

Isolation limits genetic heterogeneity in plants and animals, and for dispersal probability of flora (Harter et al., 2015). These ecosystems are therefore especially vulnerable to disturbance and invasive species, making them one of the most at-risk ecosystems on earth (Wisz et al., 2013). Island flora have evolved to have a particularly weak dispersal capacity, inhibiting plants from being able to disperse seeds across waters (Carlquist, 1974, Pouteau & Birnbaum, 2016). Since ecological features such as population size, genetic variability and resilience to disturbance are limited in the tropics, endemism is particularly high in oceanic islands (Ferriera et. al. 2015).

Endemism is a key feature of uniqueness to ecosystems that allows the great diversity seen across the planet. Endemic species are particularly sensitive and lack resilience to climate change, other natural disturbances, and human disturbance. (Harter et al., 2015). Isolation of areas of land due to these fluctuations in sea level are key indicators that endemism is affected by climate change, including but not limited to hurricane damage (Katovai et. al., 2015). The Caribbean Islands are one of the most exploited group of islands and hardest hit by the hurricane season of 2017.

Nearly 80% of favorable tropical land in the Caribbean has been converted from natural vegetation to human use, such as agriculture (Powers et al., 2011). Island forest cover in the Caribbean was replaced by sugar cane plantations in the 1700's. Sugar cane production fragmented the habitat, degraded the soil, and destroyed riparian forests (Martinelli & Filoso 2008). Water erosion became a serious agricultural and environmental problem as a result of deforestation. Under the best of conditions, islands tend to have structurally weak soil; however, when an additional disturbance such as deforestation is added, the effects can devastate portions of these fragile Caribbean ecosystems (Wuddivera, Stone, and Ekwue, 2013). When the sugar cane industry collapsed in the early 1900's, much of the land was allowed to regenerate back to forest (Oswalt et al. 2006).

St. John, USVI is a particularly mountainous island characterized by steep slopes and varying soil quality. Over 90% of the original vegetation (mostly dry tropical forest) on St. John has been destroyed or damaged by heavy tourism and domesticated and introduced animal species (Acevedo-Rodriguez et al. 1996). Much of the island (65%) is a protected national park but native species are still exposed to invasive animal and plant species (Oswalt et al. 2006; Weaver and Chinea-Rivera 1987; Ray and Brown 1995; Rogers and Reilly 1998). *Solanum* *conocarpum* is one of these species.

Commonly known as the marron (brown) bacoba, *Solanum conocarpum*, is characterized as an endemic and endangered species on St. John. *S. conocarpum* was thought to be extinct in the 1990s. In 1996, the plant was rediscovered in 1 population on the Europa Bay area, about one half of a mile from the current population at Reef Bay. Poor regeneration of *S. conocarpum* has been observed by others (Ray and Stanford, 2005). There is most likely a correlation between the slow growing nature of the plant, and survival in a suboptimal habitat, like the lands on St. John. Distribution and population size may be controlled by both biotic and abiotic factors.Overall, site will affect *S. conocarpum* growth (height and diameter), and greater growth would be present on sites at higher elevations due to the increased precipitation, protection from disturbance, and greater density of trees.

Methods

<u>Study Species</u>

There are only two species that are endemic to only St. John, which are *Eugenia earhartii* and *S. conocarpum* (Acevedo-Rodriguez et al. 1996). Both happen to be woody shrubs, residing in coastal scrubland dry noncalcareous forests. *S. conocarpum*, in the Solanaceae family, is characterized by large purple flowers and tall green stalks. *S. conocarpum* reaches anywhere from 5-9 feet in height in the wild, growing nearly twice as high in cultivated gardens. Plants are found in 4 populations along the southern shore of the island, with their two largest populations residing along Nanny Point in national park territory. Flowering and fruiting occurs during the wet season (May - July). Each of the 5 populations contains between one and two hundred individuals. *S. conocarpum* has also been determined to be sexually dioecious and selfincompatible (Ray and Stanford, 2005), making reproduction more difficult in scarce population numbers.

Study Site

Vegetation on St. John ranges from recently disturbed to late-secondary moist and dry tropical forest (Reilly, 1992). Some secondary forests regenerated almost immediately after sugarcane abandonment while others only recently regenerated after extensive pasture or agroforestry use (Oswalt, S., Brandeis, T., Dimick, B., 2006). Many plants have been introduced or intermixed with native species. A few woody plants are common on the island because of their ability to thrive in harsh environments and disperse better than others. This may be due to more abundant seed dispersers, or an overall heartier species. These species include *Leucaena leucocephala, Melicoccus bijugatus, Calotropis procera, and Cryptostegia grandiflora* (Acevedo-Rodriguez et al. 1996). St. John is classified as a subtropical dry forest consisting of mountainous topography with small valleys within the mountains and coastal plains (Acevedo-Rodriguez et al. 1996). The soil on the island is rocky, primarily volcanic, and well drained because of its location on the Puerto Rican bank. Climate of St. John is similar to many other Caribbean islands where precipitation is due to convection caused by physical obstruction of mountains to trade winds. The driest area on the island is the eastern extreme aspect that is regularly subject to trade winds along with low elevation. The average annual temperature falls at around 26.3 degrees Celsius, with the island receiving the most rain from May to November (600-1100 mm of precipitation) and a dry season from February to March (Oswalt and Brandeis, 2004).

St. John has two life zones classified as subtropical moist and subtropical dry. The forest cover in many areas is classified as dry noncalcareous forest, consisting of woody shrubs, semi-deciduous forest with cacti and mangroves. Most of the island is categorized as a forest canopy not exceeding 20 meters in height, with sparse deciduous trees, usually having leathery leaves.

The northern side of the island is categorized as moist tropical forest with 1100-2200 mm of precipitation per year. This may be in part because St. John has a tropical maritime climate and much of the rainfall is orographic. Rain falling as air masses are lifted over the mountains is often let out on the northern shores with mountain peaks, receiving the most intense precipitation and leaving the eastern ends more arid and with larger canopy gaps (Oswalt et al. 2006; Weaver and Chinea-Rivera 1987). The eastern and southern side of the island is categorized as dry tropical forest with 600-1100 mm of precipitation per year (Oswalt and Brandeis, 2004). Steep slopes facilitate rapid runoff, containing tree species characteristic of subtropical dry forest, such as *Bursera simaruba*, *Amyris elemifera* L., *Capparis cynophallophora* L., *Cordia rickseckeri* Millsp., *Lignum vitae*, and *Plumeria alba* L.

<u>Data Collection</u>

A total of four sites were located and surveyed for *S. conocarpum* populations. At each site, every individual was counted, mapped with its own GPS waypoint with an error of 3 meters (negligible error for this survey's purposes), and given a tag number if there was not already one present from previous research. Previously tagged individuals were noted and then given a new tag with the same number that was already on it. Plant height was measured to the nearest 0.001 meter using a height pole. Basal diameter was measured in millimeters taken at 10 centimeters above ground using a caliper and taken both at the wide and narrow sides of each stem. Diameter was measured this way due to the abnormal shape of the stem.

The presence of dieback was recorded using qualitative observation. It was noted that the plant either seemed to be healthy or have multiple branches with crumbling bark and dead stems. This is different from snags, which were completely dead. Flowering began after May 10th and continued until the surveys of all sites were complete. Flowers were observed in the months of May, July, and October. Fruit appeared in mid to late May and were counted on every individual. Fruit were found and counted from May until the beginning of August. Fruit were counted both on the plant and if they were lying on the ground around the plant. The presence of fruit and/or flowers was later used to determine whether or not an individual was reproductive.

Circular vegetation plots (20 meters in diameter) were established from a randomly selected *S. conocarpum* individual at each site. Plant species were put into 4 categories (woody, herbaceous, grasses, or vines). Each vegetation type was counted by number of independent stems connected to the forest floor to determine the ratios of each type of vegetation cover at each sub-population site. All species were added up to determine the number of plant species total in every plot, and then the number of each type was divided by the total to determine the percent of the plot each group of species comprised. Multiple stems on one individual were not counted as separate plants. One hundred grams of soil were collected at each of the four sites at 10cm depth. Nutrients, pH and texture were analyzed by UGA Ag and Soil Laboratory at the University of Georgia.

A second assessment was conducted eight months after Hurricane Irma hit St. John on the eastern aspect in September of 2017. During this assessment, damage to each population was quantified as percent survival. At this time, plants were tested for a class of anti-herbivory compounds, cyanogenic glycosides. Plant foliar tissue was mottled in a mortar and pestle and placed in a sealed test tube with a strip of sodium picrate and observed for a color change.

Data Analysis

Data were analyzed using SPSS Version 21.0. A one-way ANOVA test with a Tukey post-hoc was used to determine the effect of site on height and diameter. Chi square analysis was used to determine the effect of site on reproduction (presence of flowers and fruit) and post-hurricane survival. Any statistics done involving individual plant health, growth, or reproduction only included “wild” individuals in order to ensure the propagated ones that existed would not impact those results. This was due to a local expert replanting stem cuttings in an effort to repopulate years prior. All individuals including these were used in statistics for overall population size and survival, since there is a possibility they could contribute to the regeneration.

GIS Arc Map was used to map the GPS waypoints of the individuals at all four populations. Points were plotted on a USGS St. John land border layer and overlaid with land cover, aspect, and elevation. The overlay of these features allowed for the clipping of each layer to determine which areas of St. John are suitable for *S. conocarpum* reintroduction. Aspect was used in this habitat model to incorporate the impacts of climate change due to the direction that hurricanes hit the island. Irma, as well as others often hit the eastern facing aspects much harder and therefore non-eastern facing aspects were determined to be “safer” or more protected from storm damage in light of climate change and increasing frequency of large storms.

Results

The largest population was located at Nanny Point (Table 1), at the lowest elevation. Reef Bay, Brown Bay, and John’s Folly all had populations under N=20. Soil was similar at each site showing a range in pH from 6.3 to 6.6, texture from sandy loam to sandy clay loam, salinity from 0.43 ppm to 0.53 ppm, and nitrogen from 20.64 ppm to 36.51 ppm (Table 2). Reef Bay differed the most in having soil higher in clay and lower in salinity. In addition, no cyanogenic glycosides were detected in any of the four populations.

Basal diameter was significantly greater at Nanny Point, the site with the largest number of individuals, compared to all other species ($F = 3.439$; $p=0.019$) (Figure 1).

Site	N Wild	N Total	N After Irma	Survival
Nanny Point	104	161	57	0.35
John's Folly	13	19	9	0.47
Reef Bay	7	7	7	1.00
Brown Bay	11	15	8	0.53

Table 1. Population counts at all sites both prior (Summer 2017) and post hurricane Irma (Spring 2018) including wild and propagated individual counts.

Site	Soil Type	Sand%	Silt%	Clay%	NO3 (ppm)	NH4 (ppm)	pH	Salinity (ppm)	Ca (ppm)	K (ppm)	Fe (ppm)	Mg (ppm)
Johns Folly	Sandy Loam	64	20	16	26.04	0.39	6.3	0.51	10.05	5.07	1.49	9.55
Reef Bay	Sandy Clay Loam	54	18.1	27.9	21.72	0.66	6.3	0.47	45.29	7.51	1.56	7.72
Brown Bay	Sandy Loam	56	38	6	36.51	0.76	6.6	0.53	48.21	6.18	1.29	23.64
Nanny Point	Sandy Loam	70	16	14	20.64	1.55	6.4	0.43	12.02	8.48	1.28	11.11

Table 2. Soil analysis results showing soil type, pH, salinity, and several common compounds listed in units of ppm found in soil in the St. John region.

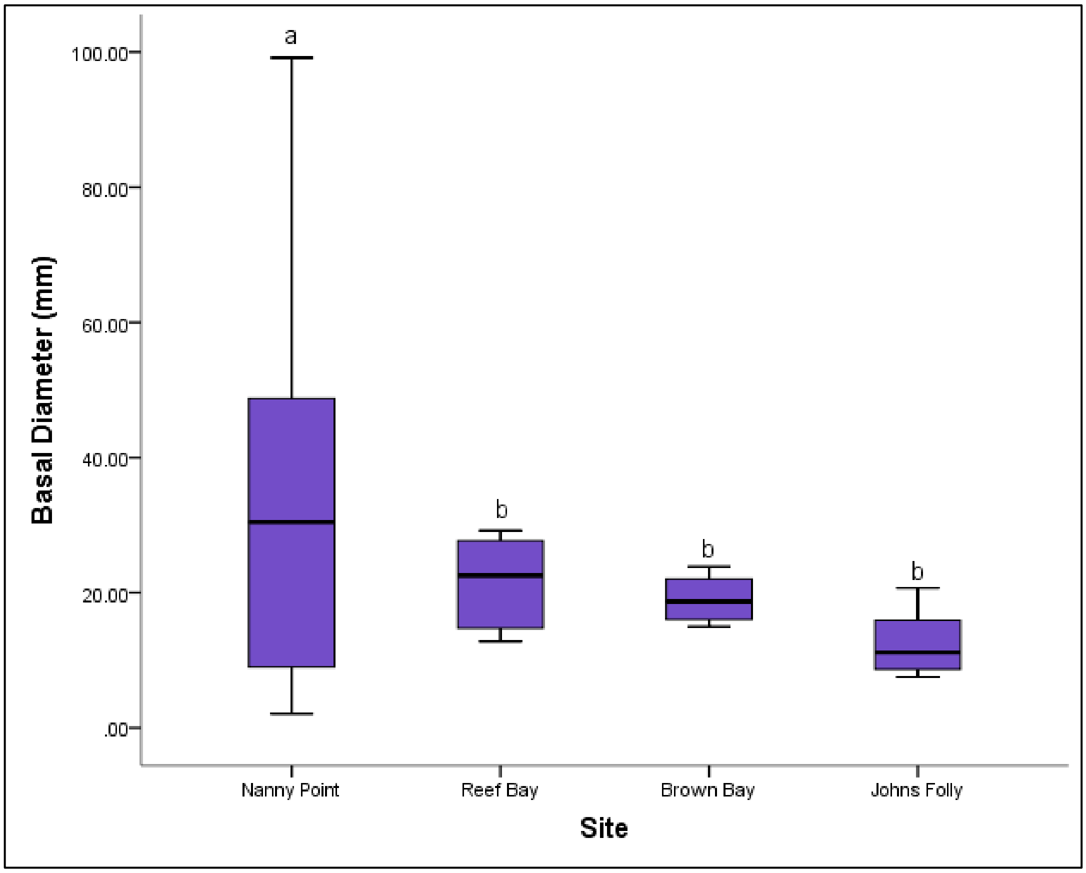

Figure 1. Boxplot of basal diameter taken at 10cm measured in mm. Average basal diameter from each site was compared using a one-way ANOVA. Basal diameter was significantly higher at Nanny Point compared to all other populations ($p=0.019$ $F=3.439$).

While the population at Nanny point was the greatest in number and showed the greatest basal diameter, reproduction (presence of flowers and/or fruit) was significantly higher at Reef Bay compared to other sites (Figure 2). Reef Bay had 100% of the individuals producing flowers and/or fruit, while the next highest level of reproduction was at Nanny Point at 65%. However, there were more likely young and/or smaller individuals at Nanny Point that were not yet able to reproduce.

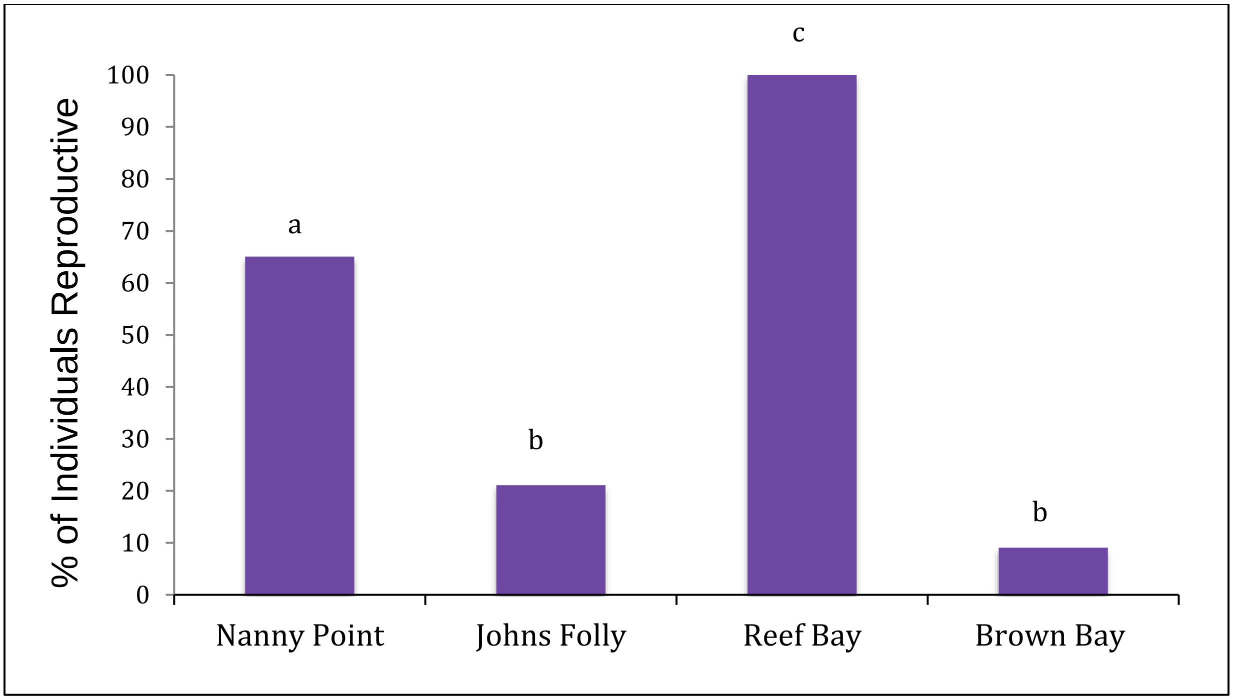

Figure 2. Quantified reproduction in all populations of S. conocarpum. Reproduction was classified as plants producing fruits, flowers, or both. Using chi square analysis, Reef Bay was determined to be significantly more successful in terms of plants that exhibit reproduction than all other sites (p=<0.0001).

After investigating percent land cover in terms of vegetation, it was determined that there was a significant difference between sites and the type of vegetation that dominated each site. More specifically, there was significantly more invasive vine coverage at Nanny Point rather than land structure attributes when compared to Reef Bay (Figure 3). Approximately 4% of the Reef Bay population area was vine coverage, while about 23% of the Nanny Point site was vine coverage. In addition, both sites had similar percentages of woody species (51% at Reef Bay and 47% at Nanny Point) and there were similar results for both snags and herbaceous species. Other sites had similar compositions, but overall Reef Bay had the least amount of invasive vines, and Nanny Point had the greatest amount.

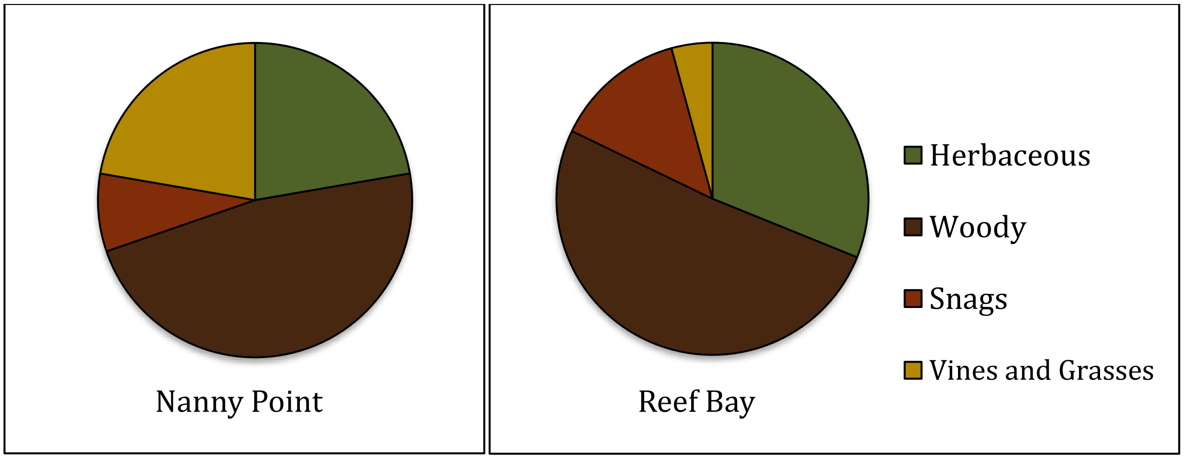

Figure 3. Double pie chart showing land cover in both Reef Bay and Nanny Point sites. Overall there was a significant difference between sites and the percent of invasive vine coverage ($p=0.001$). Nanny Point had significantly greater vine coverage ($p=<0.0001$) when compared to Reef Bay.

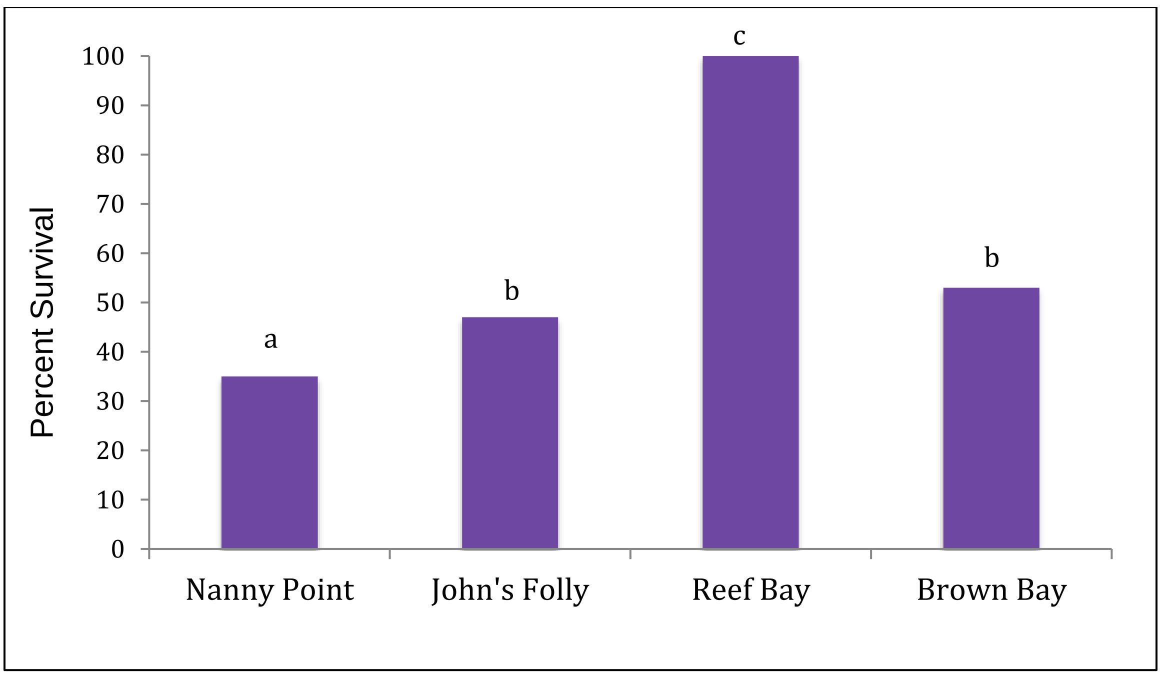

Figure 4. Quantified survival of *S. conocarpum* after Hurricane Irma. Survival is classified as the number of living individuals compared to the number of individuals counted in the preliminary assessment. Chi square analysis determined that survival was significantly greater at Reef Bay than all other populations ($p=<0.0001$).

S. conocarpum survival post Hurricane Irma was determined to be significantly greater at Reef Bay compared to the other sites (Figure 4). One hundred percent of the individuals survived, compared to the previously largest population at Nanny Point where only 35% of the individuals survived. Survival was determined to be the greatest on non-eastern facing aspects, due to the hurricane winds (185mph) coming in from the east. These winds decimated vegetation on more eastern-facing aspects compared to western-facing aspects.

Due to the obvious correlation between wind damage and aspect, it was determined not only from previous weather reports, but also aerial photography and this data that the storm hit eastern-facing mountains much harder than any other face. This allowed aspect to be used as a predictor of storm damage. Johns Folly and Nanny Point are on eastern-facing aspects (Figure 5) while Reef Bay is situated within a protected, western-facing aspect that lies within a cove of steeper slope mountain. Brown Bay is also on a western-facing aspect, but closer to the coast (lower elevation) compared to Reef Bay (Figure 4). The only population that was not completely exposed openly to the ocean on one side was the population at Reef Bay. This population had unique orientation due to its western facing aspect, but situated in a shoreline cove that offers protection from all directions. Aspect layers showed the protection around this site and how the population was situated deeper within a western facing hillside when compared to other populations.

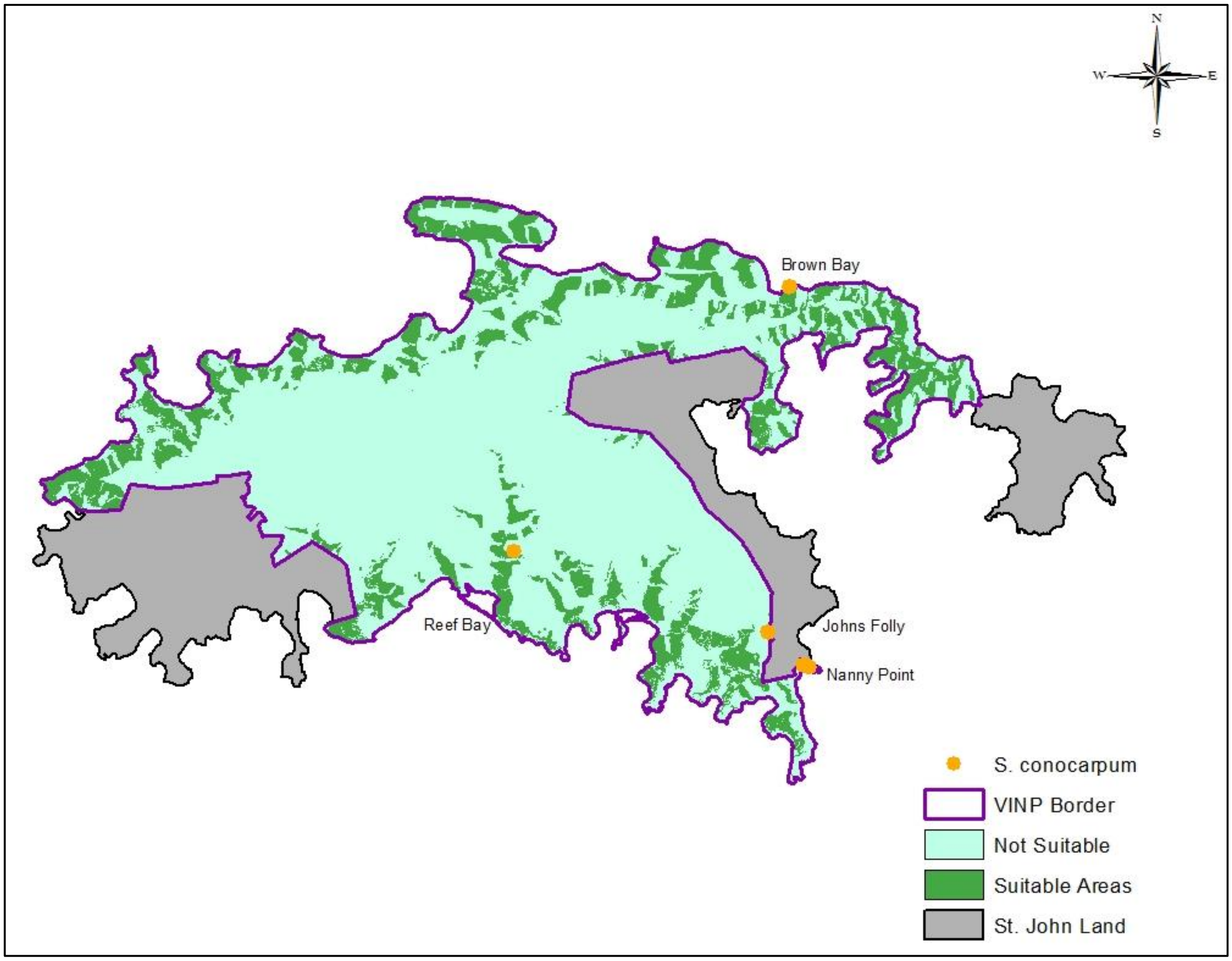

Figure 5. Updated habitat suitability model based on aspect, elevation, forest cover, and Virgin Islands National Park borders.

Discussion

Contradictory to what was predicted, Nanny Point, the site closest to the shoreline, had the greatest population numbers and largest individuals. Light exposure on populations has yet to be quantified, but the population count is most likely due to higher light levels assumed with a sparser canopy and initially less competition from native species in the suboptimal habitat. Although there are many invasive competing species and high vine coverage, the sparse canopy, as well as efforts made by those attempting to repopulate may account for the large size. Nanny Point also had significantly more invasive vines and grasses, which may be inhibiting seedling recruitment. Invasive plant species, such as *Megathyrsus maximus* (Guinea grass) and *Leucocephala leucaena* (Tan-Tan), are more likely to be successful in disturbed areas. Competition with the invasive species at Nanny Point may contribute to the hindrance of regeneration by possibly shading out new seedlings. Reef Bay, the most protected site from hurricanes, had the greatest percent of individuals flowering and fruiting, as well as significantly less vine and grass cover. This is thought to be due to the lower level of disturbance, and slightly more clay-rich texture soil than other sites.

Overall, it is concluded now that *S. conocarpum* is not successfully regenerating because it exists in its largest population at the most disturbed locations. *S. conocarpum* reproduction is limited due to not only disturbance, but disturbance-opportune species such as vines and grass that outcompete the seedlings. In addition, in order to successfully repopulate St. John with S. conocarpum, it is necessary to incorporate the more protected regions of the island into future propagation plans. Aspect should be considered as a crucial indicator of a suitable or non-suitable area for reintroduction, but other characteristics need to be considered including canopy density, soil type, and distance from shoreline.

Based on results from this study, propagation in the wild should be done on the western facing slopes of the Reef Bay and Lameshur Bay area where the environment is determined to be the most protected. Future experiments will allow greater knowledge on the mechanisms of survival and reproduction that *S. conocarpum* possesses and contribute to overall knowledge of habitat suitability for endangered species on this island and neighboring islands. If we assume that hurricane frequency and intensity will increase as global temperatures continue to rise, then we suggest reintroduction of *S. conocarpum* at more protected sites on western aspects at elevations near 150 meters at approximately 160 meters from the shoreline, similar to conditions of Reef Bay. We suggest experimental studies with seedlings at different locations that have been identified as optimal in the initial habitat model (Figure 5). The current habitat model should also include more extensive data on light exposure as elevation increases from coast to peak, possibly indicating a light threshold for *S. conocarpum* survival. In addition, insect and animal herbivory surveys may be taken in comparison with anti herbivory compound analysis to determine the plant's ability to defend itself chemically, since it possesses no noticeable physical defenses. Also, future experiments in a greenhouse with replanting individuals from seeds versus replanting from cuttings may be done to determine the best method for propagation in the wild.

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