Virgin Islands Tree Boa

(Chilabothrus granti)

Species Status Assessment

Version 1.0

Photo by Dustin Smith, NC Zoo

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U.S. Fish and Wildlife Service

Region 4

Atlanta, GA

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EXECUTIVE SUMMARY

The Virgin Islands tree boa (VI boa, *Chilabothrus granti*) is endemic to Puerto Rico and the Virgin Islands (US and British), and has been listed as an endangered species since 1970, originally as a subspecies of the Puerto Rican boa. It is now considered to be a separate species. The VI boa is a medium-length, slender, nonvenomous, and nocturnal snake with dark blotches on lighter background coloration. In captivity, their life spans can exceed 30 years, and they are still reproductive beyond 20 years of age. The VI boa is found primarily in subtropical dry forest and subtropical moist forest, and require high tree density and connectivity (forest structure is more important than species composition), refugia for resting, and adequate prey (primarily *Anolis cristatellus*, the Puerto Rican crested anole).

We considered VI boas within each island they occur on to be single populations. There are presently 6 confirmed populations (6 occupied islands) of VI boa in Puerto Rico and the US Virgin Islands (USVI): Cayo Diablo, Cayo Ratones, Culebra, Río Grande, St. Thomas, and USVI Cay. The species is also known to occur on Tortola of the British Virgin Islands, but no data on this population are available, so the following assessment is limited to the Puerto Rico and USVI populations. It is possible that populations exist on other islands, but VI boas are notoriously difficult to find, and no other populations are confirmed to be in existence currently.

Threats to the VI boa mainly include habitat loss and fragmentation from human development (and lack of regulation/enforcement around development), exotic mammals (namely cats, *Felis catus*; and rats, *Rattus rattus*), and climate change, particularly increasing sea levels and frequency of major hurricanes. Conservation actions that have benefited the VI boa include captive breeding and subsequent reintroductions, and rat eradication efforts. Other influential factors include public attitudes towards snakes, education and outreach, genetics, and the financial resources and political will to carry out conservation.

We determined population resilience by assessing 3 habitat metrics (habitat protection, exotic mammals, and storm surge risk) and 1 population metric (best available information on population size/trend). Of the 6 assessed populations, only the Cayo Diablo population currently has moderately high resilience. This is an offshore island that is protected for conservation and is free of exotic mammals. Recent surveys revealed a seemingly healthy boa population, although again, these snakes are very difficult to survey for, and survey methods and population estimation techniques have not been consistent over time. The USVI Cay population was determined to have moderate resilience. This is also a protected offshore island with no exotic mammals, but recent surveys have revealed a potential decline in abundance, and the loss of two prey species. The other 4 assessed populations currently have moderately low or low resilience. Three of these (Culebra, Río Grande, and St. Thomas) occur on islands with human development, and are threatened by habitat loss and degradation from development, as well as the exotic cat and rat populations that accompany human populations. The last population with low resilience, Cayo Ratones, is an offshore island that hosts a reintroduced boa population that had grown substantially over the 10 years post release. However, at some point between 2004 and the most recent survey in April 2018, the island was recolonized by rats, and no boas were found in 2018. Again, VI boas are difficult to find, and there may still be a population on the island, but the robust rat population lowers the value of the habitat for population resilience.

We assessed the future condition of the VI boa under 3 scenarios 30 years into the future. Under the Status Quo scenario, development continues to threaten the populations currently on developed islands, no new habitat is protected, and one new reintroduction takes place. Two moderately high or high resilience populations are predicted to remain after 30 years (Cayo Diablo and a new reintroduced population), while USVI Cay remains moderately resilient, and the remainng 4 populations are predicted to have low resilience or potentially be extirpated. Under the Conservation scenario, some habitat on the 3 developed islands is protected for conservation/restoration, reintroductions occur at a rate of 1 per decade, and exotic mammals are controlled (though likely not eradicated) via eradication efforts and public outreach. Six highly resilient populations are predicted to exist after 30 years. Under this scenario, 3 populations are expected to have moderately low or low resilience, but are protected from complete extirpation by active conservation measures. Under the Pessimistic scenario, development continues to threaten populations on developed islands, no reintroductions occur, and rats colonize/recolonize the islands where they are not currently present. No highly resilient populations are predicted to remain after 30 years, and all 6 current populations run the risk of extirpation.

We also assessed the risk from sea level rise and hurricanes at 30 years into the future, and ~80 years into the future, in alignment with the 2100 prediction horizon of most sea level rise projections. In 30 years, sea level rise alone is unlikely to significantly impact VI boa populations. Habitat on low-lying cays (Cayo Diablo, Cayo Ratones, and USVI cay) has proven to be highly resilient to hurricanes in the past, and likely will remain so with 0.30 meters of sea level rise expected over the next 30 years, although the exact impacts of any particular future storm are impossible to predict. By 2100, sea level rise alone (0.61 to 0.91 meters) is still not likely to inundate large portions of VI boa habitat on low-lying cays, perhaps with the exception of USVI Cay where the middle of the island is already a low-lying depression filled with ocean ground water, but these populations will be at much higher risk from hurricane storm surges on top of sea level rise. Cayo Diablo and USVI Cay are most at risk, while there is a moderate risk of sea level rise and storm surge impacts to VI boas and habitat on Cayo Ratones, and low risk at Culebra, Río Grande, and St. Thomas.

1 INTRODUCTION

The Virgin Islands tree boa (VI boa, *Chilabothrus granti*) is endemic to Puerto Rico and the Virgin Islands (US and British). It was first listed as endangered under the Endangered Species Act of 1973 (the Act), as amended, in 1970 (35 FR 16047), and again under a different taxonomic classification in 1979 (44 FR 70677) due to its restricted and fragmented habitat, habitat disturbance, and the influence of exotic predators. Challenges associated with this species' habitat and behavior have made it extremely difficult to monitor and estimate the sizes of all known populations. Since the writing of the recovery plan (Service 1986), two new populations have been reintroduced (Cayo Ratones and USVI cay), and two previously unknown populations have been discovered (Culebra and Río Grande). The most recent 5-year review (Service 2009) recommended downlisting to threatened, but the current status of most populations is unknown.

The Species Status Assessment (SSA) framework (Service 2016) is intended to support an in-depth review of the species' biology and threats, an evaluation of its biological status, and an assessment of the resources and conditions needed to maintain long-term viability. The intent is for the SSA to be easily updated as new information becomes available and to support all functions of the Endangered Species Program from Candidate Assessment to Listing to Consultations to Recovery. This SSA for the VI boa is intended to provide the biological support for the decision on whether or not to reclassify the species and for potential future actions under the Act. Importantly, the SSA does not result in a decision by the Service on whether this species should be proposed for reclassification under the Act. Rather, this SSA provides a review of the available information strictly related to the biological status of the VI boa. The reclassification decision will be made by the Service after reviewing this document and all relevant laws, regulations, and policies, and the results of a proposed decision will be announced in the Federal Register, with appropriate opportunities for public input. For the purpose of this assessment, we generally define viability as the ability of the VI boa to sustain populations in its range over time. Using the SSA framework (Figure 1), we consider what the species needs to maintain viability by characterizing the status of the species in terms of its resiliency, redundancy, and representation (Wolf et al. 2015).

- **Resiliency** describes the ability of populations to withstand stochastic events (arising from random factors). We can measure resiliency based on metrics of population health; for example, birth versus death rates and population size. Highly resilient populations are better able to withstand disturbances such as random fluctuations in birth rates (demographic stochasticity), variations in rainfall (environmental stochasticity), or the effects of anthropogenic activities.

- **Redundancy** describes the ability of a species to withstand catastrophic events. Measured by the number of populations, their resiliency, and their distribution and connectivity, redundancy gauges the probability that the species has a margin of safety to withstand or return from catastrophic events (such as a rare destructive natural event or episode involving many populations).

- **Representation** describes the ability of a species to adapt to changing environmental conditions. Representation can be measured by the breadth of genetic or environmental diversity within and among populations and gauges the probability that a species is capable of adapting to environmental changes. The more representation, or diversity, a species has, the more it is capable of adapting to changes (natural or human caused) in its environment. In the absence of species-specific genetic and ecological diversity information, we evaluate representation based on the extent and variability of habitat characteristics across the geographical range.

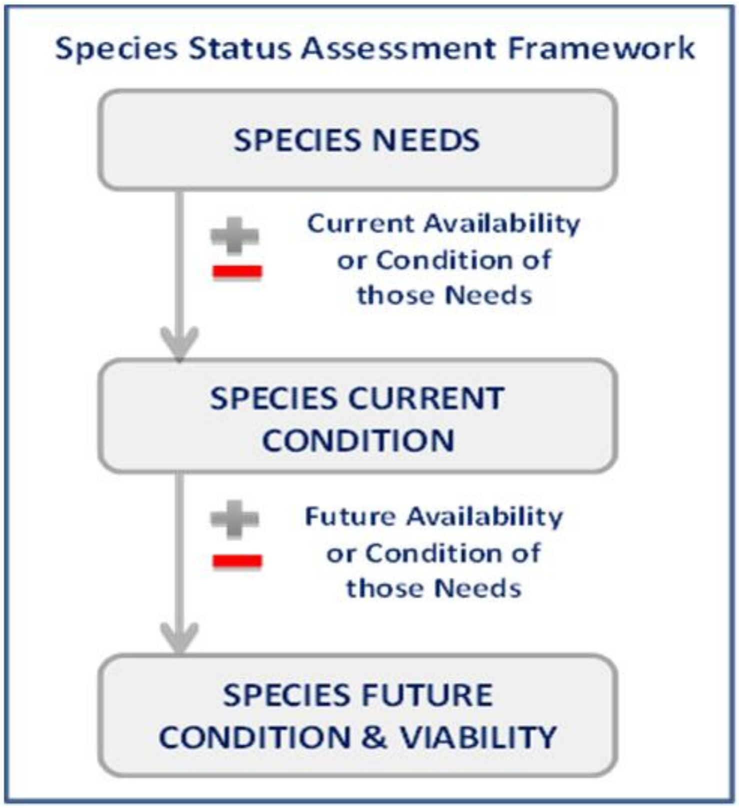

Figure 1. Species Status Assessment Framework

To evaluate the biological status of the VI boa both currently and into the future, we assessed a range of conditions to allow us to consider the species' resiliency, redundancy, and representation (together, the 3Rs). This SSA Report provides a thorough assessment of biology and natural history and assesses risks, stressors, and limiting factors in the context of determining the viability of the species.

The format for this SSA includes: (1) species biology, influences on viability, and needs (Chapters 2 - 4), (2) current conditions (Chapter 5), and (3) future conditions (Chapter 6). This document is a compilation of the best available scientific and commercial information and a description of past, present, and likely future risk factors to the VI boa.

1.1 Species Federal Status

The VI boa was originally listed as an endangered species as a subspecies of the Puerto Rican boa (*Epicrates inornatus* at time of listing, now *Chilabothrus inortatus*) on October 13, 1970 (35

FR 16047). The VI boa was again listed as an endangered species in 1979 (44 FR 70677) due to its restricted and fragmented distribution, habitat disturbance, and predation by nonnative mammals, but as a subspecies of the Mona Island boa (*Epicrates monensis granti* at the time of listing, now *Chilabothrus monensis granti*), reflecting a new taxonomic distinction (Sheplan and Schwartz 1974). The most recent 5-year review (Service 2009) listed the species as stable based on rapid assessments at two populations (Cayo Diablo and Cayo Ratones) in 2007 and surveys of a reintroduced population (USVI Cay) in 2004. A recovery priority number of 9c was assigned to the species, representing a moderate degree of threat and high recovery potential. No critical habitat has been designated.

In addition to federal protection, the VI boa is protected in the US Virgin Islands (USVI) under the Virgin Islands Endangered and Indigenous Species Act (VI Code Title 12 Chapter 2), which protects all native species from killing, injury, possession, trade, and transport. In Puerto Rico, the VI boa (and its habitat) is protected as 'critically endangered' under Article 2.06 of the Reglamento para Regir el Manejo de las Especies Vulnerables y en Peligro de Extinción en el Estado Libre Asociado de Puerto Rico (Regulation to regulate the management of threatened and endangered species in the Commonwealth of Puerto Rico). Although the species is officially protected under these regulations in USVI and Puerto Rico, enforcement is lacking (J. Yrigoyen, pers. communication). The species is also classified as endangered by the International Union for Conservation of Nature Red List (IUCN 2017).

2 SPECIES BIOLOGY

2.1 Species Description and Taxonomy

The holotype of the VI boa was collected on Tortola (British Virgin Islands) in 1932 by C. Grant and described by G. Stull (1933). The VI boa is a medium length, slender, nonvenomous snake. The largest snout-vent lengths (SVL) recorded for the species were 1066 mm for females and 1112 mm for males (total lengths 1203 mm and 1349 mm, respectively; Tolson 2005), although most specimens range between 600 and 800 mm SVL, with an average mass of 165 g (USVI Division of Wildlife, unpublished data). Adults are gray-brown with dark brown blotches that are partially edged with black, and feature a blue-purple iridescence on their dorsal surface; the ventral surface is creamy white or yellowish white. Neonates on the other hand have an almost greyish-white body color with black blotches. The head is arrow-shaped, with a blunt nose and silvery eyes (Figure 2).

Figure 2. Virgin Islands tree boa. Clockwise from top: adult head, juvenile coloration, adult coloration. Photos by R. Platenberg.

Originally, the VI boa was considered a subspecies of the Puerto Rican boa (*Epicrates inornatus*; Stull 1933). Sheplan and Schwartz (1974) later found that the VI boa was more closely related to the Mona Island boa, and altered their nomenclature to result in two subspecies, *Epicrates monensis monensis* (Mona Island boa) and *E. m. granti* (VI boa). In 1979, the VI boa was again listed as an endangered species reflecting this new taxonomic distinction. Phenotypic, behavioral, and genetic differences occur between the Mona Island and VI boa. Genetic analyses by Rodríguez-Robles et al. (2015) and Reynolds et al. (2015) estimated that the two species have been on separate evolutionary trajectories for 3.3 or 2.1 million years, respectively. Additional molecular phylogeny work has indicated that the genus *Epicrates* is paraphyletic, and the West Indian clade (as opposed to the mainland clade) was designated as *Chilabothrus* (Reynolds et al. 2013). As a result of these studies, the VI boa is now considered its own species *Chilabothrus granti*.

The currently accepted taxonomic ranking for the VI boa is described below:

Kingdom	Animalia
Subkingdom	Bilateria
Infrakingdom	Deuterostomia
Phylum	Chordata
Subphylum	Vertebrata
Infraphylum	Gnathostomata
Superclass	Tetrapoda
Class	Reptilia
Order	Squamata
Suborder	Serpentes
Infraorder	Alethinophidia
Family	Boidae
Genus	*Chilabothrus*
Species	*Chilabothrus granti*

*Retrieved 1/29/2018 from the Integrated Taxonomic Information System on-line database, http://www.itis.gov

2.2 Life History and Demography

Much of what is known about VI boa life history comes from studies in captivity. Life spans in captivity often exceed 20 years, and sometimes exceed 30 years (7% of captive VI boas exceeded 30 years of age, D. Smith, pers. communication), but typical life spans in the wild are not known. Sexual maturity is reached at 2-3 years of age (Tolson 1989, Tolson and Piñero 1985), and boas are still reproductive at > 20 years of age (P. Tolson, pers. communication). Females breed biennially, but studies have suggested that annual breeding may occur in some conditions (Tolson and Piñero 1985). Courtship behaviors and copulation occur from February through May, and interaction with conspecifics of the opposite sex appears to be necessary for reproductive cycling (Tolson 1989). The gestation period, observed from a single known copulation between two individuals, is about 132 days (Tolson 1989). VI boas give birth to live young from late August-October to litters of 2-10 young, and litter size increases with female body size (Tolson 1992, pers. communication). Neonates weigh 2.0-7.2g with SVLs of 200-350 mm (Tolson 1992, pers. communication). Neonates shed on the day of or following birth, and begin feeding on average 11 days after birth (Tolson 1989).

2.3 Habitat

The VI boa occurs in subtropical dry forest and subtropical moist forest (Service 2009). Subtropical dry forest covers approximately 14% (128,420 ha) of Puerto Rico and USVI and typically receives less than 750 mm of annual rainfall (Ewel and Whitmore 1973). It is characterized by small (<5m) deciduous trees with small, coriaceous or succulent leaves and thorns, spines, and secondary defensive compounds, with high densities of inter-digitating branches and vines greater than 1 cm in diameter connecting adjacent tree canopies (Ewel and Whitmore 1973). The subtropical moist forest covers approximately 58% (538,130 ha) of Puerto Rico and USVI, typically receives >1,100 mm of annual rainfall, and experiences low variability in temperature. It is dominated by semi-evergreen and evergreen deciduous trees up to 20 m tall with rounded crowns. The VI boa has also been reported to occur in mangrove forest, thicket/scrub, disturbed lower vegetation, and artificial structures (Harvey and Platenberg 2009, Tolson 2003). Where habitat is available but the species is not present (most of the small islands in the eastern Puerto Rico bank and USVI), it is believed that absences are due to local extirpation resulting from habitat degradation and colonization of exotic species (Service 2009).

Habitat needs for VI boa can be divided into those for foraging, and those for resting. Factors contributing to foraging habitat quality are tree density and connectivity, presence of arboreal and ground-level refugia, prey density, and rat presence/density (Tolson 1988). Tree density is more important than tree species or diversity; VI boas do not appear to prefer particular tree species after accounting for availability and structure (R. Platenberg, pers. communication). Connectivity is achieved in the canopy via interlocking horizontal branches between trees, which allow boas to move from tree to tree without having to descend to the ground. The highest densities of VI boas are found where there are few or no exotic predators, and high densities of *Anolis* prey (Tolson 1988, 1996*b*). Resting habitat includes refugia for inactive boas to use during the day. Refugia can be the axils (angles between trunk and branches) of *Cocos* or *Sabal* species, tree holes, termite nests, or under rocks and debris (Tolson 1988).

Harvey and Platenberg (2009), updated by Harvey (2010), built a habitat model using 168 opportunistic VI boa observations collected over 27 years to predict boa habitat on St. Thomas, USVI. The authors used a multi-scale approach to address challenges related to the spatial resolution of the observations and bias (i.e., more boas encountered where there are more people to encounter them). On St. Thomas, VI boas were associated with low elevation (<150 m), non-stony soils, gentle slopes (<60 degrees) and certain land cover/land use types (e.g. mangrove, drought deciduous forest, low-intensity development). The association with low elevation and soil type could be indicative of a preference for the warmer and drier climate that is also associated with low elevation and non-stony soils on St. Thomas. The association with gentle slopes is suspected to reflect either more consistent sun exposure, or is an artefact of the tendency of flat areas to be developed. Vegetation near boa observations consisted of woody plants (5-10 m, tall shrubs or short trees) with a high degree of continuity. The model predicted that VI boas could occur in approximately 801 ha on St. Thomas, almost 75% of which has been developed to some degree.

2.4 Activity

The VI boa is considered to be nocturnal, but some are active during the day. Tolson (1986*a*) found a large non-gravid female and one large male eating an anole during daylight hours. In the same survey, boas were found in the afternoon in refugia that were unoccupied the same morning, indicating that they had moved there during the day. The species is primarily arboreal and forages in the trees every night, but will use terrestrial refugia and disperse along the ground. Little is known about VI boa movement, the study of which is challenging because of the rarity and secrecy of the species and difficulty accessing its habitat.

2.5 Interspecific Interactions

The VI boa forages at night by gliding slowly along small branches in search of sleeping lizards (Service 1986). The primary prey for the VI boa is the Puerto Rican crested anole (*Anolis cristatellus)*, and the greatest concentrations of VI boa are found where *Anolis* densities exceed 60 individuals/100m^2 (Tolson 1988). Other prey species include ground lizard (*Ameiva exsul*), house mouse (*Mus musculus*), small birds, iguana (*Iguana iguana*) hatchlings, and likely other small animals encountered (Maclean 1982, Tolson 1989, Tolson 2005, R. Platenberg pers. communication). The VI boa may also compete for prey and other niche components with the Puerto Rican racer (*Borikenophis portoricensis*), a native snake found on Puerto Rico, the US and British Virgin Islands, and surrounding cays.

Tolson (1988) observed that 17% of VI boas captured had obvious wounds, scars, or partially amputated tails, suggesting that predation does occur. Natural predators might include the yellow-crowned night heron (*Nyctanassa violacea*) and American kestrels (*Falco sparverius*). Introduced feral cats (*Felis catus*) are known to prey on VI boa; in 1988, two boas were rescued from cats and subsequently incorporated into a captive breeding program, and many dead boas brought to the USVI Division of Fish and Wildlife show signs of cat predation (Tolson 1988, R. Platenberg pers. communication). Cats hunt at night, when the VI boa is active, and can access snakes in trees. Feral cat populations are often subsidized by human-provided feeding stations, with detrimental effects to native wildlife that cats prey on.

The interactions between VI boas and introduced rats (*Rattus rattus*) and mongooses (*Herpestes javanicus*) are not well understood. Rats are known to negatively influence VI boa presence, but perhaps not via direct predation. It has been suggested that rats impact VI boas indirectly via competition for *Anolis* prey, or by changing *Anolis* perching and resting behavior so that they are less accessible to VI boas (Tolson 1988). Introduced mongooses are diurnal and terrestrial, so while they may pose a significant risk to other snake species, they are likely not a significant threat to the nocturnal and arboreal VI boa (Tolson 1988).

2.6 Distribution and Abundance

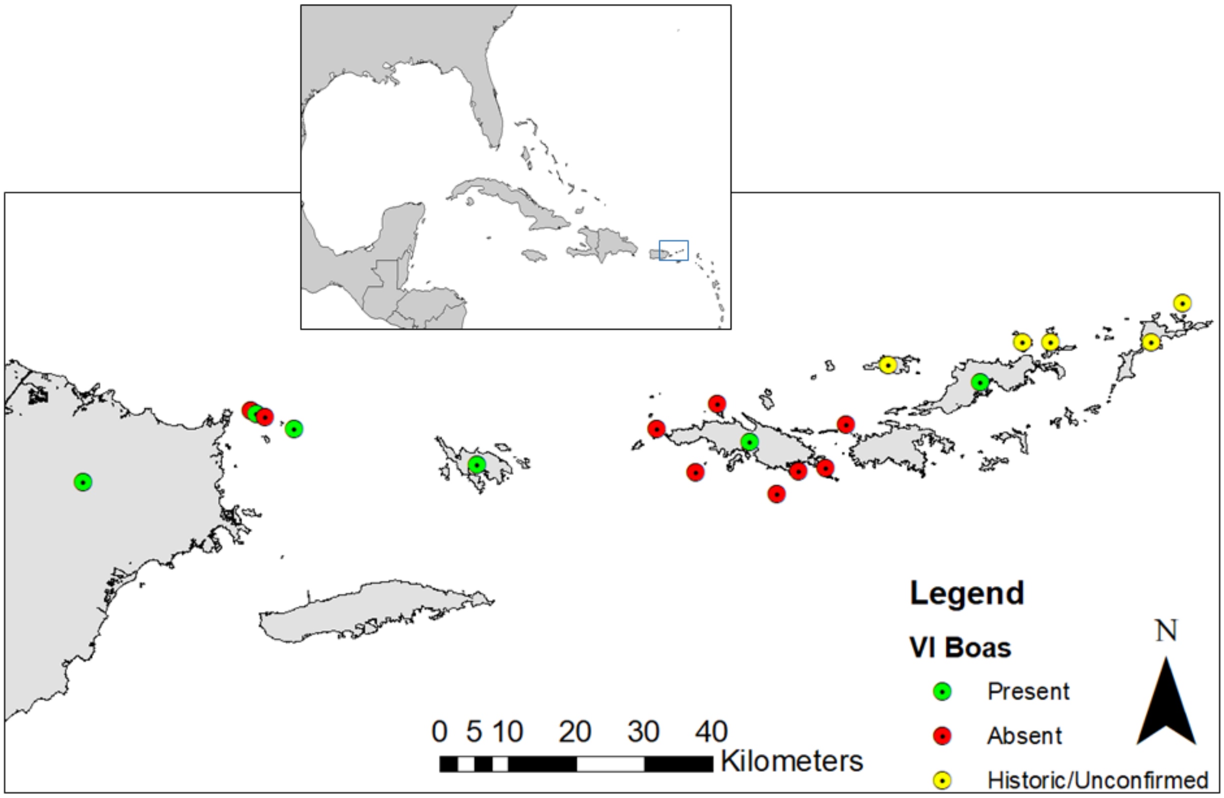

Figure 3. Range of the VI boa. Indicated are islands where VI boa presence is confirmed (green), islands where they were surveyed for but not found (presumed absent; red), and islands where there are historic records of presence, but no confirmed contemporary observations (yellow). The occupied USVI cay is not shown on this figure to protect the sensitive location of the population.

The VI boa is endemic to Puerto Rico and the Virgin Islands (US and British). When the recovery plan (Service 1986) was written, the VI boa was only known to exist in 2 populations, Cayo Diablo (Puerto Rico) and St. Thomas (USVI), with a total of 71 known specimens. Other populations did exist at that time, but were not yet known. Presently, the species is known to occur on 6 islands in Puerto Rico and USVI (Figure 3): the eastern Puerto Rican islands of Cayo Diablo, Culebra, and Cayo Ratones (introduced); Río Grande on the Puerto Rican mainland; and St. Thomas and an offshore cay in USVI (introduced). An estimated 1,300-1,500 VI boas were thought to occur on these islands as of the most recent 5-year review (Service 2009), although many population sizes used for this estimate are highly speculative. Buck Island, Cas Cay, Salt Cay, Congo Cay, Cayo Icacos, Cayo Lobos, Great St. James Cay, Saba Cay, Outer Brass Island, and Savana Island were surveyed (Figure 3; Tolson 1986*b*, 1991*b*); all were overrun with rats and no VI boas were encountered. The species is also known or thought to occur, either presently or historically, on Tortola Island (confirmed as recently as 2018, C. McGowan, pers. communication), Jost Van Dyke, Guana Island, Necker Cay, Great Camanoe, and Virgin Gorda of the British Virgin Islands (Mayer and Lazell 1988), but data and confirmed observations are severely limited, and for the SSA we will focus on populations in Puerto Rico and USVI.

Despite the current disjunct distribution of VI boa, they were likely historically distributed more widely across the small islands within their range. The leading hypothesis for widespread extinctions of arid-adapted vertebrates (like the VI boa) in the West Indies is climate shifts and sea level rise since the Pleistocene, resulting in a less-arid climate and isolation of islands that were once interconnected with each other (Pregill and Olson 1981). More recent extirpations are likely due to habitat loss and degradation from development, and the introduction of exotic predators (Service 2009).

2.7 Genetics

The isolation of VI boa populations and relatively small litter sizes make them vulnerable to inbreeding and genetic drift, but no genetic abnormalities or evidence of inbreeding depression have been observed at this time (Tolson 1996*b*). When populations are reintroduced, either from captive breeding programs or translocations from other wild populations, there is a risk of lowered fitness in the introduced individuals if they lack local adaptations to their new environment. To decrease this risk, VI boa populations in captivity from 2 distinct source populations (St. Thomas and Cayo Diablo, which exhibited differences in mtDNA restriction enzyme cleavage sites; M. Gach, M. García, and P. Tolson, unpublished data) were not interbred. Each reintroduction site then received captive-bred individuals only from the source population geographically nearest to the reintroduction site (Tolson 1996*b;* more information about captive breeding and reintroductions in the Influences on Viability section).

Later studies provided further insights into the genetic structuring of VI boa populations. Rodríguez-Robles et al. (2015) found that each island sampled (Puerto Rico, Cayo Diablo, Culebra, St. Thomas, Tortola), and each locality on islands where more than one site was sampled (Culebra, Tortola), contained private (not occurring at other sites) mtDNA haplotypes, indicating that gene flow between populations is minimal or nonexistent when habitat is not continuous. Despite these differences and evidence of genetic structure, the authors report overall low levels of genetic diversity in the species. There was no mtDNA diversity within any sampling location, and 5 of 7 examined nuclear DNA genes exhibited no variation. However, the nuclear genes tested were highly conserved, and would not necessarily be expected to vary within the species (G. Reynolds, pers. communication). Based on these results, Rodríguez-Robles et al. (2015) suggest that managing the species as a single genetic population, with interbreeding, can serve to counteract genetic drift and inbreeding and improve fitness. Reynolds et al. (2015) developed primers for 9 polymorphic microsatellite loci, the first VI boa species-specific markers, and used them to analyze specimens from 3 islands. Using empirical data to parameterize simulations, they found that the St. Thomas boa population has most likely undergone a significant genetic bottleneck. Sample sizes were very small, but further studies using these markers with more samples across more populations can reveal more about the genetic diversity and structuring of this species within and between islands, as well as a more nuanced description of historical connectivity and gene flow.

3 INFLUENCES ON VIABILITY

Influences on VI boa viability vary from location to location, but threats include habitat loss and degradation from development, exotic predators, sea level rise and a changing climate, and poor enforcement of existing regulatory mechanisms. There is also some evidence that the species has been illegally collected to keep as pets. Positive influences on VI boa viability have been habitat protection, captive breeding and reintroduction, and predator control.

3.1 Development and Habitat Protection

Virgin Islands tree boas occur on both private and publicly owned land. Where VI boas coexist with urban development, development threatens populations. This is the case on St. Thomas, Río Grande (Puerto Rico mainland), and Culebra Island. Interestingly, in Puerto Rico, human populations are decreasing, but residential development continues to increase around protected areas and island-wide (Castro-Prieto et al. 2017). Consequences of human development on boa habitat include habitat loss as land is deforested for urban and tourism development, and fragmentation as areas of suitable habitat are increasingly isolated from each other. Direct impacts on boas include mortality from vehicular strikes, predation by feral cat colonies associated with human populations (humans who may provide supplemental food in 'cat cafes'), predation by or competition with other exotic species, and/or other persecution by residents or poachers (Platenberg and Harvey 2009, Service 2009, Tolson 1988). The division of land into small privately-owned parcels also makes it difficult to conduct surveys and conservation measures (R. Platenberg, pers. communication).

Where regulations are in place to conduct environmental assessments and mitigate damage of development, they are difficult to enforce and do not cover all actions in all VI boa habitat. For example, in St. Thomas, major permit applications submitted for projects in the coastal zone require an Environmental Impact Assessment that addresses endangered species and protected habitat, but these do not apply to smaller projects and/or those outside of the coastal zone. A protocol has been developed and applied to delineate habitat on protected sites and identify mitigation strategies (Platenberg and Harvey 2010), but the absence of a legal mechanism to enforce mitigation has led to varying success. Platenberg and Harvey (2009, and R. Platenberg pers. communication) observed that VI boas can and do live in developed areas around residences, suggesting that if no cats are around, VI boas can do well if habitat patches are available within developed areas.

Fortunately, most offshore cays are formally protected as conservation lands. On Culebra Island, although some VI boa habitat is privately owned, > 1000 acres of boa habitat occur on Culebra National Wildlife Refuge (Service 2009). Cayo Ratones and Cayo Diablo are included in La Cordillera Natural Reserve managed by the Puerto Rico Department of Natural and Environmental Resources (DNER), and the offshore cay in USVI is managed and protected by the USVI Department of Planning and Natural Resources (VIDPNR). Even on protected lands, lack of enforcement means that VI boas and their habitat are at risk from illegal activities of campers, fishermen, and other visitors, who cut trees for firewood and might directly persecute boas (Tolson 1986*a*, 1991*b*, 1996*a*).

3.2 Exotic Predators

One of the primary threats to VI boa populations is the presence of exotic mammalian predators, namely cats and rats, but possibly mongoose to a lesser degree. Feral cats are known to prey upon boas (Tolson 1996*b*), and cat populations around human development are further bolstered by 'cat cafes', feeding stations set up by well-meaning residents. Rats were likely introduced to the West Indies shortly after Spanish colonization (Atkinson 1985). There has not been direct evidence of rats preying upon VI boas, but VI boas are not present on islands with high densities of rats (Tolson 1986*b*, 1988). Rather than direct predation, the negative influence of rats on VI boas might be from competition for prey, or by inducing behavioral changes in *Anolis* prey that make them less likely to be encountered by boas (Tolson 1988). Complete predator removal on large developed islands would be challenging, but is feasible on smaller cays. Rats were successfully eliminated from Cayo Ratones and the USVI cay prior to reintroductions using anticoagulant poison (Tolson 1996*b*), although Cayo Ratones has been recolonized by rats since 2004, highlighting the importance of ongoing monitoring for rat presence after a removal project. There are no VI boas present on islands with rats and no rat predators; where cats and rats both exist, cat predation on rats may lessen the threat from rats, allowing VI boa populations to persist, as they presently do on 3 islands (P. Tolson, pers. communication). Mongoose are likely not a major predator of VI boa because mongoose are terrestrial and active during the day, while VI boas are arboreal and active primarily at night, although not exclusively. In addition to the exotic mammals known to impact VI boa populations and habitat, other exotic species (including but not limited to other snakes, plants, invertebrates, and pathogens), could influence boa populations and habitat in the future.

3.3 Captive Breeding and Reintroduction

Two populations of VI boa were reintroduced to protected cays after predators had been removed, one on Cayo Ratones (Puerto Rico) in 1993, and another on a cay off of USVI (henceforth referred to as 'USVI cay') in 2002. Founders for these reintroductions came largely from a cooperative captive breeding program initiated in 1985 between the Service, DNER, VIDPNR, and the Toledo Zoological Garden. Husbandry, breeding, and raising VI boas in captivity did not prove difficult (Tolson 1989). Two separate managed demes were maintained in captivity to avoid mixing genetic material of the two source populations (Cayo Diablo and St. Thomas), which display unique genetic and phenotypic traits (Tolson 1996*b*). Cayo Diablo provided the founding individuals for the captive population that was reintroduced to Cayo Ratones (6 km away from Cayo Diablo), and St. Thomas provided the founding individuals for the captive population that was reintroduced to the USVI cay. Released adults were quarantined for 30 days prior to reintroduction, screened for disease and parasites, and were tested on their ability to hunt live prey (Tolson 1996*b*). Neonates were released within a week of birth, and had not yet been fed (Tolson 1996*b*). It was also the policy of the USVI Division of Fish and Wildlife until 2005 to release VI boas found on St. Thomas to the USVI cay, rather than where they were originally found (R. Platenberg, pers. communication).

The Cayo Ratones reintroduction was initiated with the release of 28 captive-born boas from 7 different zoos (Buffalo, Denver, Ft. Worth, Milwaukee, San Antonio, Virginia, and Toledo; Service 2009), and was supplemented later with 13 additional boas for a total of 41 individuals. Released snakes were the offspring of adults captured from Cayo Diablo. Post-release survival was high; 82.6% of individuals survived at least 1 year, and 89% of neonates survived a year (Tolson 1996*a*). By 2004, the population had grown to an estimated 500 boas (Tolson et al. 2008). Unfortunately, since 2004, Cayo Ratones has been recolonized by rats, and no boas were found during a 3-night transect survey in 2018. Because VI boas are difficult to find, intensive follow-up surveys are needed to confirm whether a population still persists, but it is clear that the population has suffered a severe decline.

The USVI cay reintroduction was initiated with the release of 42 VI boas in 2002 and 2003, 11 from captivity, and 31 from St. Thomas. Follow-up surveys in 2003-2004 provided an estimate of 168 boas (202 boas/ha), which Tolson (2005) suspected was near carrying capacity for the island. More recent surveys in 2018 detected 20 boas over 2 nights, resulting in an estimate of 26 - 33 boas across the island (Island Conservation 2018). Differences in survey and analysis methodology complicate direct comparisons of population size between these time points.

Factors for consideration for future reintroduction sites include the presence and amount of suitable habitat (appropriate forest structure, adequate prey base, refugia available), protection status or threat of development, the presence/absence/eradication of exotic predators like rats, and geomorphology that provides protection from sea level rise and hurricane storm surges that are likely to threaten the persistence of low-lying habitat. Potential sites for new reintroductions identified by the team of species experts contributing to this SSA include Salt Cay, Savanna Island, West Cay, new sites on the Puerto Rico mainland, and others, provided that predator removal happens before boas are moved.

3.4 Climate Change

The present disjointed distribution of VI boa and other West Indian vertebrates is a result of cyclic climate change and sea level rise (SLR) dating to the Pleistocene epoch (Pregill and Olson 1981). Climate change will continue to influence VI boa persistence into the future. The Intergovernmental Panel on Climate Change (IPCC) concluded that warming of the climate system is unequivocal (Pachauri et al. 2014). Species that are dependent on specialized habitat types, limited in distribution (e.g. VI boa), or at the extreme periphery of their range are most susceptible to the impacts of climate change (Byers and Norris 2011).

The climate in the southeastern United States and Caribbean has warmed about 2 degrees Fahrenheit from a cool period in the 1960s and 1970s, and is expected to continue to rise (Carter et al. 2014). Projections for future precipitation trends are less certain than those for temperature, but suggest that overall annual precipitation will decrease, and that tropical storms will occur less frequently, but with more force (more category 4 and 5 hurricanes) than historic averages (Carter et al. 2014, Knutson et al. 2010). With increasing temperatures and decreasing precipitation, drought could negatively influence VI boa populations. After a severe drought in Eastern Puerto Rico, *Anolis* populations crashed on Cayo Diablo and body condition indices of the boas plummeted (P. Tolson, pers. communication).

Sea levels are expected to rise globally, potentially exceeding 1 m of SLR by 2100 (Reynolds et al. 2012; Figure 4). Local SLR impacts depend not only on how much the ocean level itself rises, but also on land subsidence and/or changes in offshore currents (Carter et al. 2014); impacts on terrestrial ecosystems can occur via submergence of habitat during storm surges or permanently, salt water intrusion into the water table and inundation of habitat, and erosion. Sea level rise and hurricane storm surges in the Caribbean will inundate low-lying islands and parts of larger islands (Bellard et al. 2014). The low-lying islands of Cayo Diablo, Cayo Ratones, and the USVI cay, all of which support VI boa populations, are all vulnerable to SLR and storm surges. During Hurricane Hugo in 1989, about 2000 m^2 of coastal forest on Cayo Diablo was eroded into the sea or otherwise deforested (Tolson 1991*b*, pers. communication). Past and current observations suggests that the species can survive major hurricane events, although lasting impacts to habitat, particularly die-off of vegetation inundated by storm surges, have been observed (R. Platenberg pers. communication, Smith 2018, Tolson 1991*b*, J. Yrigoyen pers. communication).

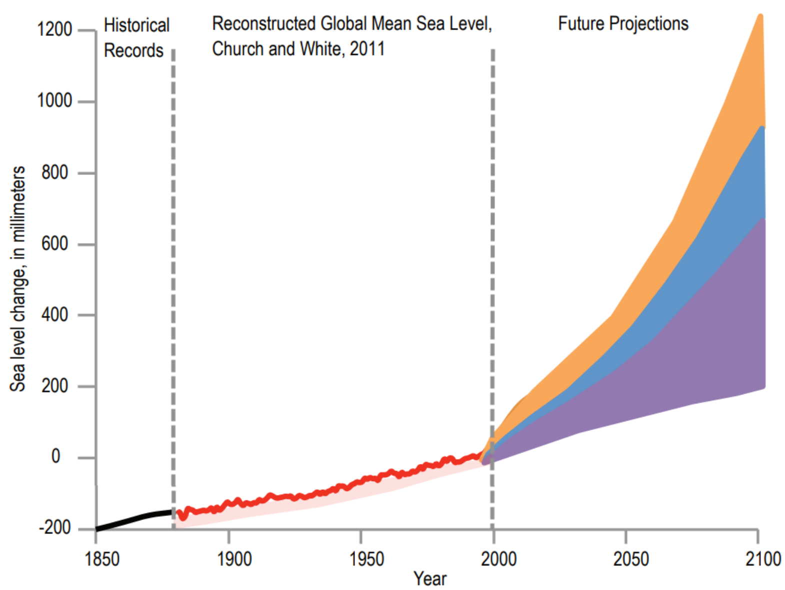

Figure 4. From Reynolds et al. 2012; global mean sea level and future projections (with uncertainty) based on three climate models from the Intergovernmental Panel on Climate Change (IPCC 2007). The purple projection represents a scenario without scaled-up ice sheet discharge, blue represents a scenario with scaled-up ice sheet discharge, and orange is based on a different semi-empirical projection approach (Rahmstorf 2007).

3.5 Other

Other influences on VI boa viability in Puerto Rico and USVI include:

- Negative public attitudes towards snakes, with strong cultural and religious underpinnings.

- Public confusion between invasive boa constrictors (*Boa constrictor*) on St. Croix, where the message is that boas are bad and should be eradicated, and the VI boa, which is endemic and in need of conservation.
- Education and public outreach in schools and the community
- Governmental financial resources and political will to direct towards conservation of the VI boa in a climate of debt, other priorities, and an electorate with negative prejudices towards snakes
- Genetic effects of reproductive isolation, which have not yet been seen, but can be staved off in the future by translocating boas between populations periodically to infuse new alleles into populations.

4 SPECIES NEEDS FOR VIABILITY

4.1 Individual Level

At the individual level, the VI boa requires suitable foraging and resting habitat to flourish during each life stage from birth to adulthood, and to successfully reproduce. Suitable habitat contains dense and interconnected trees and/or tall shrubs to facilitate arboreal foraging, prey densities to support survival, growth, and reproduction, and terrestrial and arboreal refugia to provide safety when resting, particularly for gravid females. Individual boas are susceptible to mortality from known and suspected predators including yellow-crowned night herons, feral cats, and rats (not confirmed), and are frequently found as roadkill in developed areas.

4.2 Population Level

For resilient populations to persist, the needs of individuals (foraging and resting habitat, adequate prey base) must be met at a larger scale. Connectivity must be adequate not only for an individual's foraging needs, but to connect individual boas to a larger interbreeding population. While VI boa populations can persist in co-occurrence with exotic predators like cats or rats, the most resilient populations occur where these predators are few or absent.

4.3 Species Level

For the species to be viable, there must be adequate redundancy (suitable number, distribution, and connectivity to allow the species to withstand catastrophic events) and representation (genetic and environmental diversity to allow the species to adapt to changing environmental conditions). Redundancy improves with increasing numbers of populations (natural or reintroduced) distributed across the species range, and connectivity (either natural or human-facilitated) allows connected populations to "rescue" each other after catastrophes. Representation improves with increased genetic and/or ecological diversity within and among populations. Long-term viability will require resilient populations in locations that are protected from the long-term catastrophic but permanent effects of climate change (e.g. sea level rise and catastrophic hurricanes claiming low-lying habitat). See Figure 5 for a summary of how the discussed biological needs and external influences impact VI boa viability.

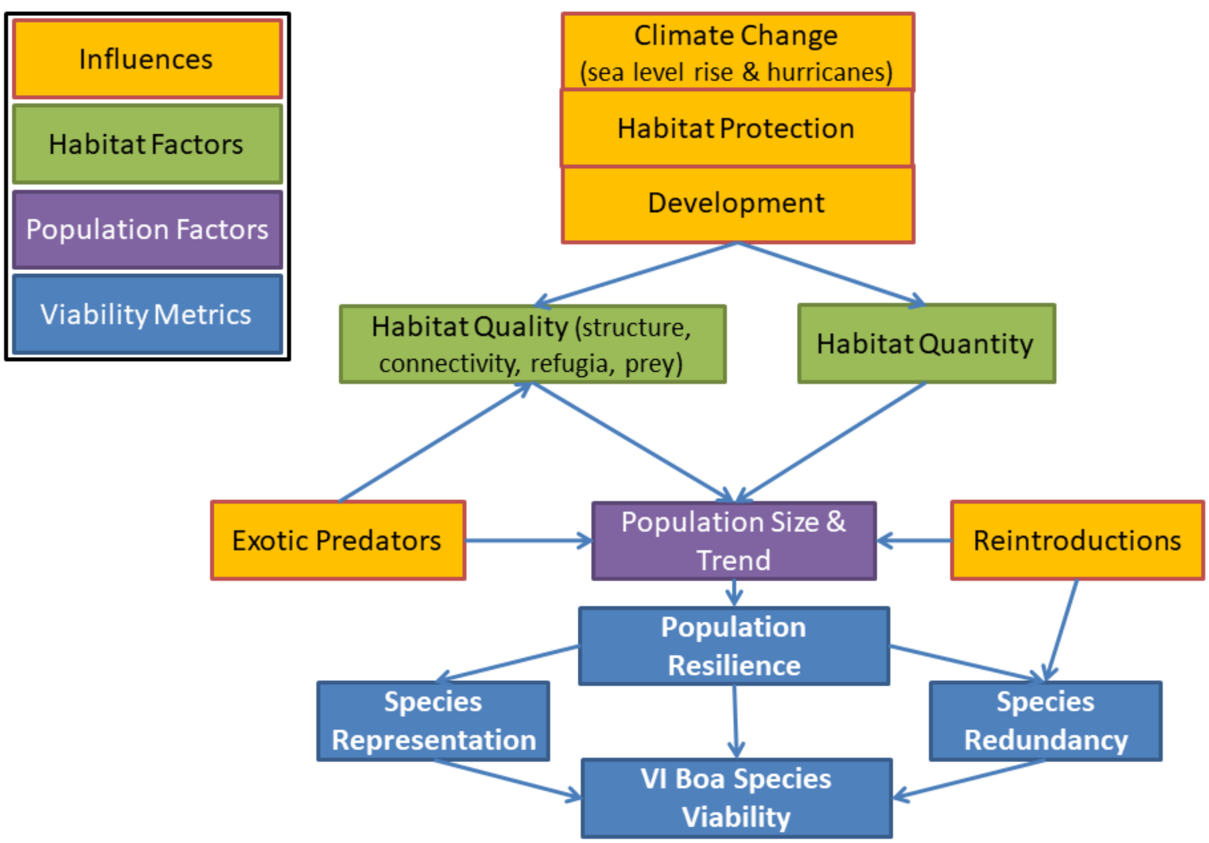

Figure 5. Summary of key habitat factors, population factors, and influences on viability used to assess resilience, redundancy, and representation for the Virgin Islands tree boa.

5 CURRENT CONDITION

5.1 Delineating Populations

In the SSA framework, resilience is assessed at the population level, which is then scaled up to species redundancy and representation. Because resilience applies to populations, defining a population is a crucial, and often challenging, first step to assess the viability of the species. Available scientific evidence lends support to different delineation strategies. Rodríguez-Robles et al. (2015) recommend managing the entire species as a single population because of low levels of genetic diversity within the entire species. If a population is thought of as an interbreeding group however, then defining the entire species as a single population is too broad, as VI boas do not disperse from island to island to interbreed. Rodríguez-Robles et al. (2015) also found that there is reproductive isolation, resulting in unique genetic signatures, among different locations within islands, which supports a strategy of delineating multiple reproductively isolated populations within each island occupied by VI boas. However, we lack genetic and occurrence data at an appropriate scale to delineate populations in this way.

For this SSA, we took an intermediate approach and considered all boas within each island to be single populations. Peter Tolson (pers. communication) observed phenotypic differences from island to island. The geographically isolated groups on each island do not interact with each other, and the influences on and threats to VI boas tend to occur to entire islands (e.g. rats are present on the island or they are not). What we define as a population, on small offshore cays, might consist of a single interbreeding deme of VI boas. On larger islands, what we define as population functions more as a metapopulation, with multiple interbreeding groups in isolated habitat patches that may interact weakly via dispersal and recolonization of extirpated patches. Alternately, multiple occupied patches on large islands may be completely isolated from one another.

We consider 6 populations for this SSA: In Puerto Rico the populations are Cayo Diablo, Cayo Ratones, Culebra, and Río Grande; in USVI there is a population on St. Thomas and a reintroduced population on a USVI cay. One or more populations exist in the British Virgin

Islands, but are only briefly described here because data are severely limited, although they could be considered as potential source populations for future reintroductions. Other populations may occur on islands in Puerto Rico and USVI, but VI boa habitat and activity patterns make them difficult to find, and no other populations are confirmed to be extant at this time despite extensive searching (Tolson 1986*b*, 1991*b*).

5.2 Current Resilience

Resilience scores were generated by combining scores for 3 habitat metrics (Protection/Development Risk, Exotic Mammals, and Storm Surge Risk) and one population metric (Population Size and/or Trend, dependent on availability). The best available information for each population was gathered from the literature and species experts. Each metric was weighted equally, with the overall effect that habitat (3 metrics) was weighted 3 times higher than population size/trend (1 metric). The VI boa recovery plan (Service 1986) called for periodic monitoring to estimate population sizes and trends, but surveys since then have been few and far between. Survey methodology and reporting has varied from population to population, with survey results given as estimated abundances, estimated densities, or encounter rates per man-hour of searching. Even with the same methodology and reporting, survey success can differ based on external factors like weather conditions, surveyor experience, or phase of the moon during surveys. All of the above-described factors in combination contribute to high levels of uncertainty in what current and past population sizes truly are/were, and how they have changed over time. This is why resilience classifications relied more heavily on habitat conditions than population size and trend estimates. For each metric, populations were assigned a score of -1, 0, or 1, as described below in Table 1.

Table 1. Description of how habitat and population factors were scored to determine VI boa population resilience.

	Habitat Metrics			Population Metric
Score	Habitat Protection/ Development Risk	Exotic Mammals	Storm Surge Risk	Population Size/Trend
-1	Habitat not protected, at risk of being developed	Exotic mammals present	Topography and elevation leaves population vulnerable to storm surges	Relatively low population size and/or declining trend
0	Some habitat protected, some at risk of being developed	NA	NA	Relatively moderate population size and stable trend, OR High degree of uncertainty in population size/trends
1	Habitat protected	Exotic mammals absent	Protected by topography and elevation	Relatively high population size and/or growth

The scores for each population across all metrics were summed, and final population resilience categories were assigned as follows:

Low Resilience:	-4 to -2
Moderately Low Resilience:	-1
Moderate Resilience:	0
Moderately High Resilience:	1
High Resilience:	2 to 4

Below, we describe each population and the conditions contributing to their resilience classifications.

Cayo Diablo

Cayo Diablo is a 6.8 hectare low-lying (14 m maximum, 3 m mean elevation) island off the eastern coast of Puerto Rico that supports a natural (not reintroduced) population of VI boas. In 1985-1986, 104 VI boas were captured and marked, and the population appeared to be stable (Tolson 1986*a*). Tolson (1996*b*) specifies that survey efforts in Cayo Diablo had marked and released over 250 individuals. As a comparison to other populations where populations are only summarized in terms of boas per man-hour of searching, 3.1 boas per man-hour were found on Cayo Diablo in 1992 (P. Tolson, unpublished data). Prior to 2018, the most recent surveys resulted in a population estimate of about 500 boas in 1993, or ca. 100 boas/hectare (P. Tolson unpublished data). In 2018, Cayo Diablo was surveyed across 8 transects over 3 nights, and 10 boas were found (0.25 boas per-man hour; Island Conservation 2018). Abundance within the transect area (4.15 ha) was estimated to be 12 (95% confidence interval 8-24) using a model that incorporated an effect of anole abundance on VI boa abundance, and an effect of sand and canopy cover on detection rates. Extrapolating the density within the transect area (2.9 boas/ha) to the entire island, the model provides an estimate of 20 boas on the island (95% confidence interval 13-39). This is much lower than the unpublished survey results from 1993, but the survey and analytical methodologies for this earlier survey are not available for comparison. Survey and analytical methodologies in 2018 also differed from those used in 1985-1986, and comparisons should be made with caution.

Some habitat damage from Hurricanes Irma and Maria was evident in 2018, but the habitat seemed to be recovering well (Island Conservation 2018), although canopy heights were lower (average 2.1 m) than previously reported by Tolson and Piñero (5 m in some areas; 1985). Cayo Diablo is free of exotic rats (Island Conservation 2018, Tolson 1988), and is protected by DNER for conservation as part of La Cordillera Natural Reserve, so the cay is not at risk from development. It is at risk from extreme weather events. While sea level rise is a long term process that will not severely impact Cayo Diablo within the immediate future, the low elevation of the island does currently render it vulnerable to storm surges, as evidenced by Hurricane Hugo in 1989 when about 2000 m^2 of coastal forest eroded into the sea or deforested; every mature tree in this area was either uprooted or snapped off at the base (Tolson 1991*b*, pers. communication). However, Tolson (1996*b*) encountered 34 snakes in 3 nights of searching after Hurricane Hugo and describes capture rates comparable to those obtained before the storm for Cayo Diablo. Based on the available information, the VI boa population has demonstrated its resilience to severe hurricane impacts.

Based on the protected status of Cayo Diablo (+1), absence of exotic mammalian predators (+1), vulnerability to storm surges (-1), and an unclear population trend indication potential declines (0), the Cayo Diablo population is considered to have **moderately high resilience (+1)**.

Cayo Ratones

In 1993, VI boas were reintroduced from captivity to Cayo Ratones, a 4 hectare low-lying (13 m maximum, 4 m mean elevation) offshore cay off the eastern coast of Puerto Rico. Like Cayo Diablo, Cayo Ratones is also protected for conservation as part of La Cordillera Natural Reserve, so is not as risk of being developed. Rats were formerly present on Cayo Ratones, but were eliminated prior to VI boa reintroduction (Tolson 1996*b*). The Cayo Ratones VI boa population originated from 41 boas (offspring of Cayo Diablo boas in captivity) released during 1993-1995. One-year post-release survival was high (82.6%) and released individuals bred in the wild. A 10-year post-release evaluation in 2004 resulted in a Schnable mark-recapture population estimate of 483 boas with a favorable age structure indicating stability (Tolson 2005). Cayo Ratones was not surveyed again until April 2018, when 6 transects were surveyed for 3 nights, and no boas or boa sign (e.g., shed skin) were found (Island Conservation 2018). Rather, a robust rat population was found; rats were detected using chewing sticks, tracking tunnels, and cameras, and were observed frequently during boa survey transects (Island Conservation 2018). While no boas were found during this survey, VI boas are notoriously hard to find, and there is not yet enough evidence to conclude that the population has been extirpated. It is clear that it has suffered a severe decline. The habitat was in good condition following the 2017 hurricane season (Island Conservation 2018). Further monitoring is imminently needed to determine the status and needs of this population. Like Cayo Diablo, Cayo Ratones is vulnerable to storm surges from tropical storms and hurricanes.

Despite the protected status of Cayo Ratones (+1), the presence and abundance of rats on the island (-1), vulnerability to hurricane storm surges (-1), and the detection of no boas or boa sign during the latest survey (-1), the Cayo Ratones population is considered to have **low resilience (-2)**.

Culebra

On Culebra in Puerto Rico, surveys have resulted in 0.72 boas found per man-hour of searching in 1992 (García 1992), 0.01 boas per man-hour in 2001 (Puente-Rolón 2001; 2 boas found during a year with 3 site visits every 2 months), and 0.22 boas per man-hour in 2012 (P. Tolson, unpublished data). In 1990, no boas were found. Three locations on Culebra were surveyed in May 2018 for 3 nights, and no boas were found (Island Conservation 2018), although one site on Culebra (Monte Resaca) was estimated by a statistical model to still contain boas that were undetected because of environmental conditions (canopy cover and sand). Because VI boas are difficult to find, Culebra is a large island, and previous surveys have failed to find boas when they indeed persisted, more surveys will be needed to determine whether a population currently persists. The failure to find boas during 3 nights of searching transects is not enough evidence to conclude that the population has been extirpated. About 160 hectares of boa habitat on Culebra are protected as part of Culebra National Wildlife Refuge, which are not at risk of being developed, but other parts of the island are developed. Along with this intensive human activity, both cats and rats are common on the island, and eradication is likely not feasible, although cats do also prey upon rats and could be regulating their population (P Tolson, pers. communication). Due to the elevation and topography of Culebra (198 m maximum and 62 m mean elevation of potential VI boa habitat on Culebra, habitat identified by DNER, unpublished data), the population is not highly vulnerable to storm surges from tropical storms and hurricanes. Some damage to habitat from the 2017 hurricane season was evident, but overall the habitat was considered suitable for VI boas (Island Conservation).

Based on the protected status of some but not all habitat (0), presence of exotic mammals (-1), low vulnerability to hurricane storm surges (+1), and historical rarity of VI boas combined with the lack of any detections in 2018 (-1), the Culebra population is considered to currently have **moderately low resilience (-1)**.

Río Grande

The Río Grande population on mainland Puerto Rico is localized to approximately 130 hectares (precise area unknown) and is not protected for conservation. Recent survey efforts in May 2018 of 4 transects, surveyed for 3 nights, found 3 boas (0.125 boas per man-hour; Island Conservation 2018). Abundance within the transect areas was estimated to be 3 (95% confidence interval 3-7) using a model that incorporated an effect of anole abundance on VI boa abundance, and an effect of sand and canopy cover on detection rates. Surveys in 2012 resulted in 0.14 boas per man-hour of searching (P. Tolson, unpublished data). Prior to that, site visits conducted 3 times per month for a year, found only 2 boas, or 0.05 boas per man-hour of (Puente-Rolón 2001). A decade earlier, García (1992) found 0.27 boas per man-hour. Reynolds et al. (2015) similarly report low encounter rates with VI boas when collecting samples for genetic analysis during 2011-2012, including many surveys where no boas were found. There is some protected habitat in this location, but it is surrounded by urban development, which continues to expand, and both rats and cats are present (Island Conservation 2018, Puente-Rolón 2001, Reynolds et al. 2015). Eradication of rats and cats here is not likely due to the large area and large human population on the Puerto Rican mainland. Due to the elevation and topography of the region (128 m maximum and 52 m mean elevation of potential VI boa habitat in the area, habitat identified by DNER, unpublished data), the population is not highly vulnerable to storm surges from tropical storms and hurricanes. In 2018, noticeable habitat degradation was apparent from human clean-up activities after Hurricanes Irma and Maria, particularly the appearance of dumps in boa habitat (Island Conservation 2018). Of note, this is the only VI boa population that presently exists with a congener, the Puerto Rican boa (*Chilabothrus inornatus*), with which it might compete for food (G. Reynolds, pers. communication).

Based on threats from urban development (-1), exotic mammals (-1), low vulnerability to hurricane storm surges (+1), and relative low population sizes (-1), the Río Grande population is considered to currently have **low resilience (-2)**.

St. Thomas

The island of St. Thomas in USVI is 8,300 hectares, but VI boas are restricted to the extreme eastern end where the climate is drier and hotter than other regions of the island. Habitat models predict that boas can occur on 801 hectares on St. Thomas (Harvey and Platenberg 2009, Harvey 2010). Almost 75% of this area is developed, and the authors report a 27% increase in development from 2000 to 2007. Tolson (1991) provided a speculative estimate of 300-400 boas in rapidly dwindling habitat, after finding 0.025 boas per man-hour in 1988 (P. Tolson, unpublished data). There have been no recent systematic surveys for VI boa on St. Thomas; much of eastern St. Thomas is inaccessible due to private ownership and/or impenetrable habitat, but opportunistic observations (used to inform the above habitat models) have averaged about 10 observations per year since 2000. VI boa observations have increased over time, although likely due to increased encounter rates as development expands into boa habitat rather than an increase in population size and increased awareness of the species. Reynolds et al. (2015) found evidence for a severe genetic bottleneck on St. Thomas, and estimated that fewer than 100 VI boas exist on St. Thomas, based on an estimate of effective population size using genetic data and an effective population size to census population size ratio of 0.15. Exotic predator elimination is not feasible on the large and human-occupied island of St. Thomas, and VI boas are impacted by both rats and feral cats; boas wounded by cats have on many occasions been brought to the USVI Division of Wildlife. Boas on St. Thomas are also vulnerable to vehicular strikes; half of the new observations used to update the habitat model (Harvey 2010) were dead by human-related means like car strikes. There are no areas within the range of the VI boa on St. Thomas that are protected and managed for conservation, and where there are regulations to mitigate habitat destruction due to development, they are often ignored and unenforced (R. Platenberg, pers. communication). Due to the elevation and topography of the area (242 m maximum and 46 m mean elevation of potential VI boa habitat on St. Thomas identified by Harvey and Platenberg 2009 and Harvey 2010), the population is not highly vulnerable to storm surges from tropical storms and hurricanes.

Based on the abundant threats facing the St. Thomas population from development (-1), exotic mammals (-1), low vulnerability to hurricane storm surges (+1), and an uncertain but presumed to be declining population (-1), the St. Thomas population is considered to currently have **low resilience (-2)**.

USVI Cay

In 2002, VI boas were reintroduced from captivity to a small (2.2 hectares) low-lying (9 m maximum, 2 m mean elevation) offshore cay in USVI that is protected for conservation by VIDPNR, and thus not at risk of being developed. While it is protected, the cay is regularly visited by tourists (D. Smith, pers. communication). Rats and cats are not present on this cay; rats were eradicated in 1985. However, the cay is within 1 km of a large island that does have exotic predators. The population on this cay originated from 42 boas (11 offspring of St. Thomas boas in captivity and 31 from St. Thomas) reintroduced during 2002-2003. Follow-up surveys resulted in estimates of 98 boas in 2003 and 168 boas (202 boas/ha) in 2004, which Tolson (2005) suspected was near carrying capacity for the island. This population was surveyed again in March 2018. After Hurricane Maria in 2017, damage to trees was evident (foliage stripped from trees, trees damaged or destroyed, vegetation browning or possibly dying in areas inundated by salt water; D. Nellis and J. Yrigoyen, pers. communication), but during the 2018 survey, the habitat seemed to be recovering well and was able to provide suitable boa habitat (Smith 2018). Over 2 nights, 20 boas were found (13 the first night, 7 the second night, 0.57 boas per man-hour; Smith 2018). Although present during previous surveys, iguanas and ground lizards (VI boa prey species) were not observed during this most recent survey, but *Anolis cristatellus* was still abundant. This loss of prey species could be influencing boa population dynamics and carrying capacity, but this is speculative as *A. cristatellus* was still abundant. However, Tolson (2005) specifies the importance of hatchling iguanas in the diet of the VI boa population on this cay. The resulting VI boa population estimate was 26 - 33 boas, estimated from extrapolating the estimate within the surveyed area (20 - 26 boas) to the entire island (Island Conservation 2018), but this estimate is not directly comparable to the 2003-2004 estimates; survey methodology, length of surveys (2 days vs. multiple weeks), and statistical analyses all differed between the 2018 survey and the 2003-2004 surveys.

Additionally, all captured snakes in 2018 were subadults or juveniles; no adult snakes were captured. However, this may not be a true representation of the current population structure; adults may be more elusive during the breeding season, which coincided with the 2018 survey (P. Tolson, pers. communication). During both 2003 and 2004, the population was surveyed for 1-2 weeks during the breeding season (surveys in Feb and March), and visited again for 1-2 weeks in August after the breeding season was over (Tolson 2005). The presence of < 1-year-old boas in the 2018 survey sample is evidence that there are reproductive adults present on the cay. Given the lack of comparability between population estimates, evidence of reproductive adults, and 2018 nightly capture rates comparable to the 2003-2004 surveys, the lower population estimate in 2018 is not immediately alarming. If there was indeed a decrease in population size, possible causes include density dependent effects from rapid growth after reintroduction, hurricane impacts, or the observed shift in prey species (J. Yrigoyen, pers. communication).

Based on the protected status of this cay (+1), absence of exotic mammalian predators (+1), vulnerability to hurricane storm surges (-1), and an uncertain but potentially declining population size (and potentially declining body size) and loss of 2 major prey species (-1), the population on this USVI cay is considered to have **moderate resilience (0)**.

British Virgin Islands

In the British Virgin Islands, VI boas are known to occur on Tortola and possibly other islands. The holotype VI boa was collected from Tortola (Stull 1933), and specimens from Tortola were included in the genetic analysis of Rodríguez-Robles et al. (2015). The island-by-island list of reptiles and amphibians updated by Mayer (2012) lists VI boas as occurring on Tortola (5400 hectares), Jost van Dyke (840 hectares), Great Camanoe (340 hectares), and possibly Guana Island (300 hectares). However, no data are available in the literature or from British Virgin Islands officials about the size or status of these populations, and we do not attempt to classify their resilience. The status of the species on Tortola, though we lack data, is presumed to be similar to the St. Thomas population (low resilience), facing threats from development and exotic mammals (M. Garcia-Bermudez, pers. communication).

5.2.1 Current Resilience Summary

Table 2. Summary table of the 6 assessed VI boa populations and factors that contributed to their resilience classification. Values reflecting good conditions for boas are shaded green, while values reflecting unfavorable conditions are shaded red (darker red for worse conditions), and moderate values are shaded yellow.

	Habitat Metrics			**Population Metric**	
Population	**Habitat**	**Exotic Mammals**	**Storm Surge Risk**	**Population Size/Trend**	**Resilience**
Categories	Protected or Development Risk	Present or Absent	Low or High	Description	Category
Cayo Diablo	Protected (+1)	Absent (+1)	High (-1)	Potentially Declining (0)	Moderately High (+1)
Cayo Ratones	Protected (+1)	Present (-1)	High (-1)	Declining, no boas detected 2018 (-1)	Low (-2)
Culebra	Both (0)	Present (-1)	Low (+1)	Rare, trend unknown, no boas detected 2018 (-1)	Moderately Low (-1)
Río Grande	Development Risk (-1)	Present (-1)	Low (+1)	Rare, trend unknown (-1)	Low (-2)
St. Thomas	Development Risk (-1)	Present (-1)	Low (+1)	Trend unknown but presumed declining (-1)	Low (-2)
USVI Cay	Protected (+1)	Absent (+1)	High (-1)	Potentially Declining, loss of 2 prey species, possible decline of body size (-1)	Moderate (0)

In Puerto Rico and USVI (excluding British Virgin Islands populations for which we have n o data), there are 6 known populations of VI boa, 1 we classified as having moderately high resilience, 1 with moderate resilience, 1 with moderately low resilience, and 3 with low resilience (Table 2). Our classifications of resilience rely heavily on habitat characteristics in the absence of highly certain population size or trend estimates; more regular monitoring and improved survey and abundance estimation methods would improve our understanding of the resilience of these populations. The population classified as moderately highly resilient (Cayo

Diablo) occurs on a small offshore island that is free of exotic rats and cats and is protected for conservation. Primarily because of the protected and exotic-mammal-free state of the habitat, this population is considered to be fairly resilient to demographic and environmental stochastic events and disturbances (e.g. fluctuations in demographic rates, variation in climatic conditions, illegal human activities). The USVI Cay population was determined to have moderate resilience. This is also a protected offshore island with no exotic mammals, but recent surveys have revealed a potential decline in abundance, and the loss of two prey species, possibly as a result of density dependence as the population approached carrying capacity after reintroduction. Three of the populations with low or moderately low resilience (Río Grande, Culebra, and St. Thomas) occur on larger and higher-elevation islands, which provide more protection from storm surges, but come with growing human populations and increasing human-boa interactions, habitat loss and fragmentation from development, and exotic cats and rats. In the face of these threats, these 3 populations are not expected to well withstand stochastic demographic and environmental events and disturbances. The remaining low-resilience population is classified as such as a result of the recolonization of rats on the island and resulting crash of the boa population.

5.3 Current Redundancy

Redundancy for the VI boa, a narrow ranging endemic, is inherently low. With 6 populations in Puerto Rico and USVI (and one or more populations in the British Virgin Islands of unknown status), and only 1 of those considered currently moderately highly resilient, the species is not well buffered against the effects of catastrophic events. Catastrophic events that could affect single or multiple VI boa populations include but are not limited to hurricanes (multiple populations), colonization or recolonization of exotic mammals to cays where they are not currently present (generally single populations, but rats could use cays as stepping stones, increasing the risk of colonization for nearby cays), disease outbreaks, and fires (single populations).

The lack of redundancy in the face of hurricane threats is well illustrated by the path of Hurricane Maria in 2017 (Figure 6). The entire range of the VI boa in Puerto Rico and USVI were subjected to hurricane force winds (> 64 knots) as the hurricane passed over, first as a

Category 5 hurricane, weakening to a Category 4 hurricane over the Puerto Rico mainland. Hurricane Hugo in 1989 followed a similar path and caused extensive habitat damage, striking the range of the VI boa first as a Category 4 hurricane and weakening to a Category 3 hurricane (Tolson 1991*b*).

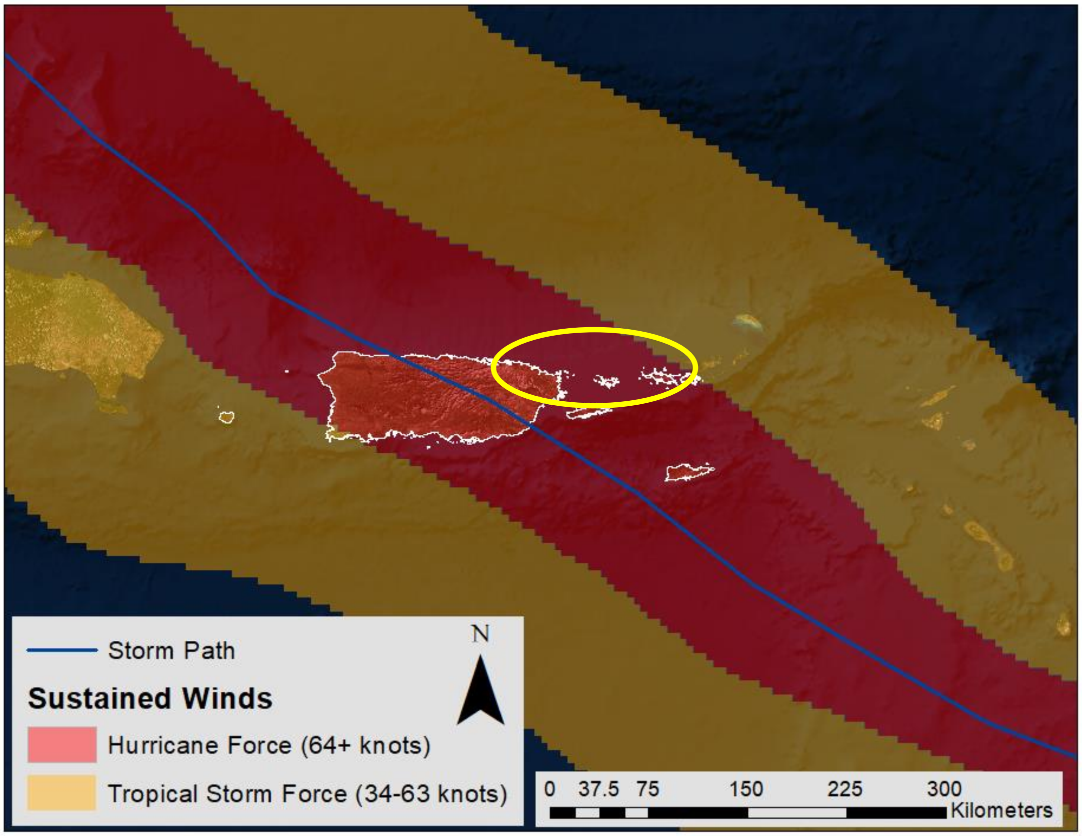

Figure 6. Path and wind speed of Hurricane Maria in September 2017. Puerto Rico and the US Virgin Islands are outlined in white, and the approximate range of the VI boa is circled in yellow. (Data accessed from National Hurricane Center, National Oceanic and Atmospheric Administration, https://www.nhc.noaa.gov, March 27 2018)

The exact historic distribution (redundancy) of the VI boa is unknown, but their present disjoint distribution suggests that they were once more widely distributed across small islands within their range, which have been subject to local extirpations from habitat degradation, invasive species, and historic climate and sea level changes.

5.4 Current Representation

Given the information available, there is not a clear and readily apparent strategy for considering representation for this species. Input from the literature and species experts ranged from considering all populations a single representative unit, to considering each population a representative unit, to refraining from calling any grouping a representative unit. Here, we capture the uncertainty and discussion around this topic and discuss representation under one idea, but acknowledge that there are other ways to think about it and more research is needed to better understand the adaptive potential and differences between VI boa populations.

A range-wide genetic analysis of VI boa showed that there was little genetic variation within the species (Rodríguez-Robles et al. 2015), supporting the idea that there is only one representative unit of VI boa. The authors recommended managing the entire species as a single genetic population, and promoting interbreeding across populations to maintain genetic diversity. The same study, however, found that each sampled island, and each sampled locality within the same island, have private mtDNA haplotypes, indicating a lack of gene flow between islands/populations. These results suggest that each population has a different genetic signature, perhaps as a result of genetic adaptations to their local environment, or genetic drift with increasing isolation of small populations. The reintroduction program took this view, and managed captive populations sourced from Cayo Diablo and St. Thomas separately (Tolson 1996*b*). To minimize the chances of introducing individuals poorly suited to their new environment, the captive Cayo Diablo population was used to found the reintroduced population on nearby Cayo Ratones, and the captive St. Thomas population was used to found the reintroduced population on the nearby USVI cay (Tolson 1996*b*). In addition to genetic differences, these populations also have noticeable phenotypic differences from each other. Phenotypic differences are not just limited to differences between USVI and Puerto Rican populations (different coloration; Tolson 1996*b*) ; Cayo Diablo reportedly has phenotypic differences even from the Río Grande and Culebra populations (lighter coloration on Cayo Diablo; P. Tolson, pers. communication). The Río Grande population also occurs in a different habitat type (subtropical moist forest) than the others (subtropical dry or littoral forest; Tolson 1996*b*).

In light of this information, we here consider each of the 4 natural populations (not introduced and excluding the British Virgin Islands populations that we did not assess) a representative unit (Table 3). The Cayo Diablo population is considered moderately highly resilient, and was the source for the low-resilience Cayo Ratones population. Therefore, there are 2 populations representing the Cayo Diablo genetic signature, 1 each with moderately high and low resilience. Similarly, the USVI cay population was sourced from St. Thomas, so there are 2 populations with St. Thomas representation, with none considered to be highly resilient at this time. The other 2 natural populations, Culebra and Río Grande, both characterized as having moderately low or low resilience, have not been used for captive breeding and reintroduction, so have no additional populations on other islands with the same genetic characteristics. Overall, only 1 of 4 representative units has at least 1 moderately high resilience population. Because of how representative units were defined here, any redundancy within representative units is the result of sourcing reintroductions from existing natural populations; low redundancy within representative units is a natural consequence of the species occurring in isolated island populations. While currently we could consider the reintroduced populations (currently with moderate and low resilience) to be redundant populations sharing the same genetic signature and adaptive potential as their source populations, all of the islands occupied by VI boa are isolated from each other. Without human-mediated movement of boas between islands, the reintroduced populations are expected to diverge genetically from their source populations over time, and may at some point in the future (decades to centuries; Reynolds et al. 2015) be different enough to be considered their own unique representative unit.

Table 3. Number of VI boa populations of each resilience class in each representative unit, corresponding to natural (not introduced) populations, which themselves correspond to unique genetic signatures.

Natural Population (Genetic Signature)	High or Moderately High Resilience Populations	Moderate Resilience Populations	Low or Moderately Low Resilience Populations
Cayo Diablo	1	0	1
Culebra	0	0	1
Río Grande	0	0	1
St. Thomas	0	1	1
British Virgin Islands			Not assessed, presumed low

6 FUTURE CONDITION

6.1 Future Considerations

To assess the future resilience, redundancy, and representation for VI boa, we considered impacts of human development, habitat protection and restoration, reintroductions, public outreach and education, and sea level rise. We predicted resilience at 2 future time points, 30 years and ~80 years in the future (2048 and 2100). We considered all of the above influences for the 30-year prediction. This time frame was chosen, with input from species experts, based on: encompassing multiple generations of VI boa (which can live past 20 years, and reproduce at 2-3 years of age; Tolson 1989, Tolson and Piñero 1985), the time required to plan and execute a reintroduction (about 10 years, P. Tolson, pers. communication), and time required for habitat restoration (10 years or less, R. Platenberg, pers. communication). Given the uncertainty in future conditions (environmental and fiscal; both Puerto Rico and USVI local governments are in the midst of financial crises), the only factor considered at the ~80-year time period is sea level rise. Our projection for sea level rise was tied to the year 2100 because of the availability of sea level rise projections from the IPCC (Church et al. 2013).

Potential future impacts that we do not consider explicitly include genetics and climate change impacts (other than sea level rise and hurricane storm surges) directly on the boas or their habitat. Species that are dependent on specialized habitat types and limited in distribution and/or migration ability(e.g. VI boa) are susceptible to the impacts of climate change (Byers and Norris 2011), but the direction, magnitude, and time frame of these impacts on VI boas are uncertain. There is no natural migration of boas between islands, making these isolated populations vulnerable to inbreeding and genetic drift. No genetic abnormalities of evidence of inbreeding depression have yet been observed (Tolson 1996*b*), but periodic genetic monitoring should be done to assess whether deleterious genetic material is building up in isolated populations and translocation of snakes between islands might be necessary to increase genetic diversity.

For the impacts that we considered to assess future resilience of VI populations, we first describe how we approached each factor with regards to future resilience, then introduce 3 potential future scenarios and what each impact looks like under each scenario. We then describe the predicted resilience of VI boa populations under these scenarios.

6.1.1 Development

While 3 VI boa populations occur on cays protected for conservation, the other 3 populations (Culebra, Río Grande, and St. Thomas) in Puerto Rico and USVI share islands with human development. Development threatens VI boas in multiple ways, including the direct loss and fragmentation of habitat, exotic cats and rats that accompany human populations, vehicular strikes, and persecution from residents or poachers. Although not a result of human development on the cays themselves, human activities (e.g. boat travel) around and to boa-occupied cays heighten the risk of colonization or recolonization of rats to offshore cays, putting boa populations even on protected and undeveloped islands at risk.

Development is expected to continue around these 3 populations. Of 801 hectares of high quality habitat modeled by Harvey and Platenberg (2009) on St. Thomas, 73% had some degree of development in 2007, resulting from a 27% increase in development within the species range from 2000 to 2007. On St. Thomas, VI boas can co-occur with development if habitat is preserved or restored (R. Platenberg, pers. communication). However, where new development projects occur on St. Thomas, existing regulations to conduct environmental assessments and mitigate habitat damage are difficult to enforce and do not cover all development projects in all potential VI boa habitat (R. Platenberg, pers. communication). For each of these 3 human-inhabited islands, land not specifically protected for conservation is at risk from development. In all considered future scenarios, development is expected to continue along present trajectories, negatively influencing the resilience of the Culebra, Río Grande, and St. Thomas populations.

6.1.2 Habitat Protection and Restoration

As stated above, land not specifically protected for conservation is at risk of being developed. Three populations currently exist on protected islands (Cayo Diablo, Cayo Ratones, and the USVI cay). Resilience of the other populations on human-inhabited islands can be increased by permanently protecting habitat, and habitat protection will be an important component of future reintroductions, whether by reintroducing boas to already protected islands or acquiring new lands for conservation. Restoration of habitat, including the establishment of movement corridors between habitat patches, can also increase VI boa resilience.

6.1.3 Exotic Predators

The presence of exotic predators on islands with VI boa populations is in most cases closely tied to the presence of human populations and development. On the 3 human-populated islands, Culebra, Río Grande, and St. Thomas, VI boas co-occur with cats and rats. On these large islands, it is not feasible that cats and rats can be completely eradicated within our 30-year future time period, but the impacts on VI boa populations might be lessened with outreach, education, and conservation measures. Aided my human movements, rats can colonize smaller offshore cays that do not have permanent human developments; this has happened to many cays of USVI and Puerto Rico. Cayo Ratones, where rats were eradicated prior to reintroducing VI boas in 1993, has been recolonized by rats since the last rat-free surveys in 2004. On smaller islands like this, island-wide eradication is feasible within our future time period. However, the colonization or recolonization of rats to currently rat-free cays (Cayo Diablo and USVI cay) is also a possibility that must be considered.

6.1.4 Reintroductions

Reintroduction has proven to be an important and successful conservation strategy for the VI boa. Future reintroductions will be necessary to increase the redundancy of resilient populations across the species range, especially when considering the potential loss of currently resilient populations to sea level rise. Important factors to consider for future reintroduction sites include availability of habitat and prey, habitat protection status, presence/abundance of exotic mammals at the site, and safety from imminent effects of sea level rise (elevation and topographic features). Potential future reintroduction sites to be considered include Salt Cay, Savanna Island, West Cay, new sites on the Puerto Rico mainland, and others. One new reintroduction is already in the initial stages; during the March 2018 survey for VI boas on the USVI cay, boas were collected to reinvigorate captive breeding efforts for future reintroductions. In addition to reintroductions to new sites, augmentation of existing populations may prove beneficial and/or necessary for the persistence of existing populations, particularly on developed islands.

6.1.5 Public Outreach and Education

Where VI boas and humans co-occur, public outreach and education in schools and the community can have positive outcomes for both direct (intentional persecution of VI boas as a result of fear, ignorance, or deep-seated prejudices) and indirect (supplemental feeding of feral cats) threats from humans to VI boas (R. Platenberg, pers. communication).

6.1.6 Sea Level Rise and Storm Surges

6.1.6.1 Background

As global temperatures warm, sea levels are expected to rise as a result of thermal expansion of ocean water and melting of ice sheets and glaciers, and already have risen about 0.19 m between 1901 and 2010, an average of 1.7 mm per year (Church et al. 2013). The rate of sea level rise (SLR) more recently (1993-2010) is about 3 mm per year, and it is very likely that the rate of increase will continue to rise (Church et al. 2013). Median estimates of global SLR by 2100 (relative to 1986-2005 sea levels) under 4 different CO_2 emissions scenarios (RCP2.6, RCP4.5, RCP6.0, and RCP8.5; Church et al. 2013) using a process-based model range from 0.44 to 0.74 meters, with likely ranges around those central estimates between 0.28 and 0.98 meters. Sea level rise projections for 2046-2065 (aligned with our 30-year VI boa projection time frame) range from 0.24 to 0.30 meters across the 4 scenarios, with likely ranges around those estimates of 0.17 to 0.38 meters. Based on these SLR projections, we examined the effects of 0.30, 0.61, and 0.91 meters (1, 2, and 3 feet) of SLR on islands occupied by VI boas. It is important to note that other SLR projection models constructed using a different modeling method (semi-empirical models, as opposed to the process-based models described above) predict even higher amounts of SLR, but there is not yet a consensus within the scientific community about the reliability of these types of models (Church et al. 2013). Sea levels are also expected to continue to rise past 2100, but the IPCC cautions that currently available projections of SLR beyond 2100 (1-3 m per degree Celsius of warming) have much lower confidence associated with the estimates (Church et al. 2013).

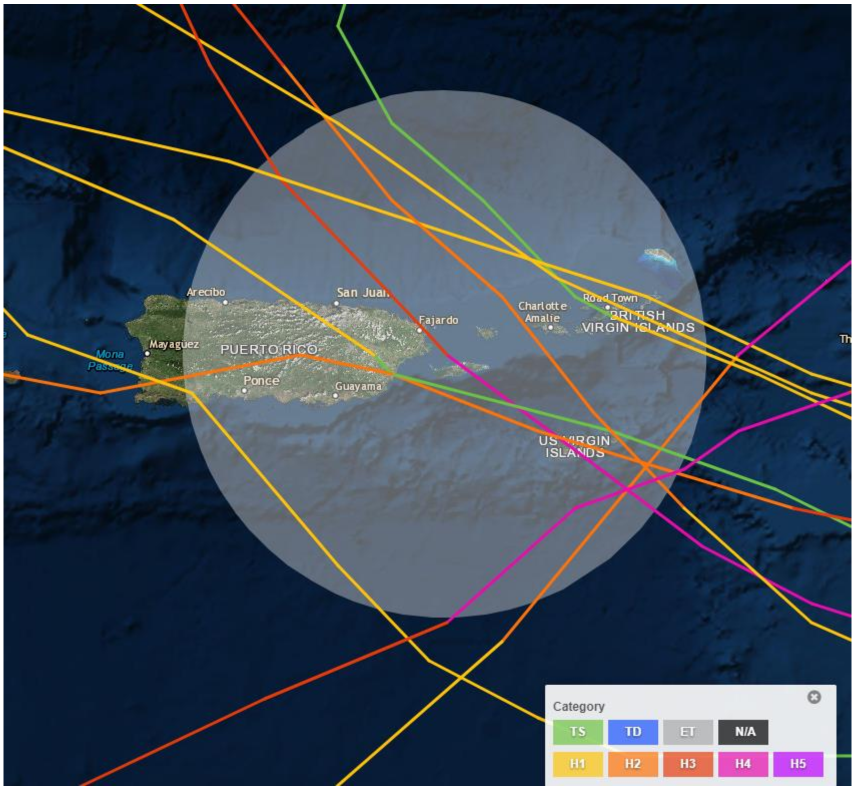

Figure 7. Paths of hurricanes (not including tropical depressions and tropical storms) that struck the VI boa range in Puerto Rico and USVI between 1988 and 2016. Paths for Hurricanes Irma and Maria in 2017 were not yet available in the data set and are not shown. The color coded legend refers to storm categories: tropical storm (TS), tropical depression (TD), extratropical storm (ET), and category 1-5 hurricanes (H1-5). Data were retrieved and viewed from https://coast.noaa.gov/hurricanes/ on 4/12/2018.

Habitat for VI boa will not just be impacted by SLR alone. Tropical storms and hurricanes bring storm surges that impact habitat in combination with SLR. The combination of SLR and storm surges can be additive (i.e., X meters sea level rise + Y meters storm surge = X + Y meters total height of surge), but in shallow areas, the resulting surge can be higher than the sum of SLR and the storm surge alone (Smith et al. 2010). Hurricanes are not uncommon in the VI boa species range. Over the last 30 years (since 1988), 12 named storms struck VI boa habitat as a Category 1 hurricane or stronger (Figure 7). Of these, 4 were major hurricanes (Category 3 or stronger), 2 of which occurred in the last year (Hurricanes Irma and Maria in 2017). To count hurricanes striking VI boa habitat, we used the National Hurricane Center definition of a hurricane strike, which is based on the typical extent of hurricane force winds, 75 nautical miles to the right of a storm's center, and 50 nautical miles to the left of a storm's center, looking in the direction of the storm's forward motion.

With SLR, the frequency of flooding events of any given height, whether associated with hurricanes or not, is expected to increase. Using predictions of region-specific SLR under a moderate CO_2 emissions scenario, frequencies of floods of any given height are expected in increase by about 3 orders of magnitude (~ 1000 times) in the Caribbean by 2081-2100 (Figure 8; Hunter 2012, Church et al. 2013).

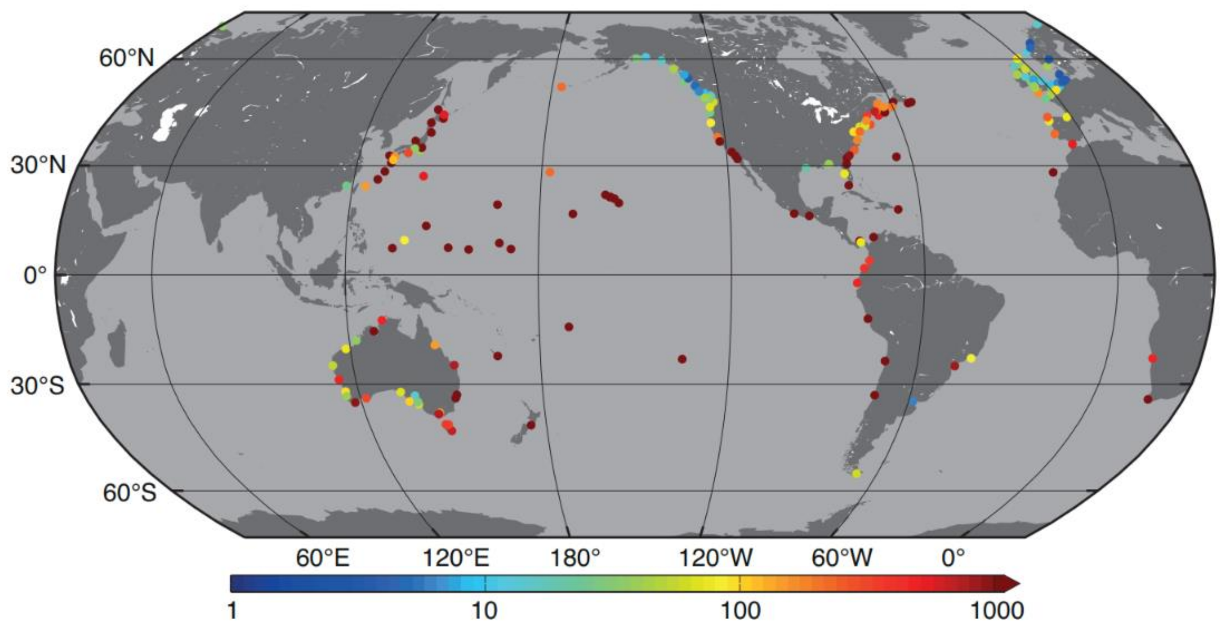

Figure 8. The estimated multiplication factor (shown at tide gauge locations by colored dots), by which the frequency of flooding events of a given height increase using regional projections of mean sea level rise by 2081-2100 for a moderate CO_2 emissions scenario (RCP4.5). Figure from IPCC Fifth Assessment Report (Church et al. 2013).

Within the context of resilience, redundancy, and representation, catastrophic impacts of hurricanes on populations could be considered only while assessing redundancy. There should be redundant populations across a species range to buffer against catastrophes that are outside of the range of normal stochastic variation. However, given the frequency of hurricanes, especially major hurricanes, that impact the VI boa range, predictions that the strength of hurricanes will increase as the global climate warms (Carter et al. 2014, Knutson et al. 2010), and additive effects of SLR and storm surges, we assert that hurricanes are within the range of normal stochastic events in this species' range, and need to be considered in assessing population resilience. It is a given that hurricanes will happen multiple times in our future projection time periods, the uncertainty is in exactly when, where, how often, and with what force they will strike.

6.1.6.2 Methods

For all scenarios, we predicted the impact of SLR and storm surges on VI boa populations. The populations on mainland Puerto Rico, Culebra, and St. Thomas were considered not at risk from SLR due to their existence on large islands, with a large portion, if not all, of their range on these islands at elevations well out of reach of rising sea levels and storm surges over the next century. Cayo Diablo, Cayo Ratones, and the USVI cay are small low-lying islands, and the risk of SLR and storm surge impacts on VI boa populations on these islands was assessed using GIS. We used 3-m resolution elevation data for the USVI cay derived from 2016 LiDar data (available at https://coast.noaa.gov/slr/, accessed 10 April 2018), and 1-m elevation data for Cayo Diablo and Cayo Ratones derived from 2016 LiDAR data (available at https://coast.noaa.gov/htdata/raster2/elevation/NGS_PR_DEM_2016_8462/, accessed 23 April 2018). As described above, we considered SLR of 0.30, 0.61, and 0.91 meters, with the 0.30 meter rise corresponding to our 2048 projections, and a range of 0.61-0.91 meters of SLR by 2100. In addition to SLR alone, we considered the impact of hurricane storm surges. Storm surge heights were estimated using the sea, lake, and overland surges from hurricanes (SLOSH) model used by the National Weather Service (Jelesnianski et al. 1992). To capture a range of heights for different storms, we simulated Category 1 hurricanes at mean tide level, Category 3 hurricanes and mean and at high tide, and Category 5 hurricanes at high tide. All simulated hurricanes had a forward speed of 15 miles per hour (the closest simulation option to the average hurricane speed of 10.8 miles per hour at 15-20 degrees north latitude; NOAA 2014) in a northwesterly direction, the primary direction of hurricane movement in the VI boa range. The SLOSH model predicts average storm surge heights for multiple trajectories of a hurricane of the same strength, speed, direction, and tide to account for uncertainty in the path of any one storm. Storm surge heights were added onto SLR, giving a conservative estimate of storm surge height, since in some local conditions, resulting storm surge height can exceed the sum of SLR and storm surge alone (Smith et al. 2010).

For each SLR amount and simulated hurricane storm surge, we calculated the percent of each VI boa-occupied cay that lies below that elevation, and would thus be inundated (or potentially flooded in cases where lower elevation areas are inland and surrounded by higher elevation areas).

6.1.6.3 Results

From SLR alone, the three VI boa-occupied cays are predicted to lose 4-5% of their area to a 0.30 meter (1 ft) SLR, 8-12% of their area to a 0.61 meter (2 ft) SLR, and 10-23% of their area to a 0.91 meter (3 ft) SLR (Table 4). These estimates are based solely on rising water levels, and do not incorporate other processes like erosion, or land subsidence, and should thus be considered conservative. Similarly, the percent of dry land area inundated by hurricane storm surges also does not include other processes like salt-water intrusion that are known to impact habitat. Aside from the permanent loss of habitat, VI boa habitat appears to be surprisingly resilient to hurricane strikes; during surveys in 2018 after Hurricane Maria on each of these 3 low-lying cays, there was evidence of hurricane damage (e.g., downed and damaged trees), but overall the habitat was in relatively good shape and suitable for VI boas. Below, we discuss the risk of SLR and storm surges on each cay individually.

Table 4. Predicted sea level rise (SLR) plus storm surges from different hurricanes (Category 1, 3, 5 at either mean or high tide, moving NW at 15mph). Shown are the amounts of SLR in meters, and the percent of currently dry ground predicted to be inundated.

	Year 2048 0.3 m SLR (1 ft)						**Year 2100 0.61-0.91 m SLR (2-3 ft)**				
Cay	**Only SLR**	**Cat 1 mean tide**	**Cat 3 mean tide**	**Cat 3 high tide**	**Cat 5 high tide**		**Only SLR**	**Cat 1 mean tide**	**Cat 3 mean tide**	**Cat 3 high tide**	**Cat 5 high tide**
Cayo Diablo **Area** 6.8 ha **Max elev.** 14.0 m **Mean elev.** 2.7 m	0.3m **4%**	0.96m **11%**	1.36m **14%**	1.63m **20%**	1.98m **36%**	0.61m	0.61m **8%**	1.27m **13%**	1.67m **21%**	1.94m **33%**	2.29m **59%**
						0.91m	0.91m **10%**	1.57m **18%**	1.97m **35%**	2.24m **56%**	2.59m **75%**
Cayo Ratones **Area** 4.0 ha **Max elev.** 13.2 m **Mean elev.** 3.7 m	0.3m **4%**	0.93m **11%**	1.31m **16%**	1.60m **21%**	1.95m **27%**	0.61m	0.61m **8%**	1.24m **15%**	1.62m **21%**	1.91m **26%**	2.26m **33%**
						0.91m	0.91m **11%**	1.54m **20%**	1.92m **27%**	2.21m **32%**	2.56m **39%**
USVI Cay **Area** 2.2 ha **Max elev.** 9.4 m **Mean elev.** 1.6 m	0.3m **5%**	0.5m **9%**	0.87m **11%**	1.17m **21%**	1.54m **54%**	0.61m	0.61m **12%**	0.81m **18%**	1.18m **36%**	1.48m **51%**	1.85m **70%**
						0.91m	0.91m **23%**	1.11m **34%**	1.48m **51%**	1.78m **67%**	2.15m **83%**

Cayo Diablo

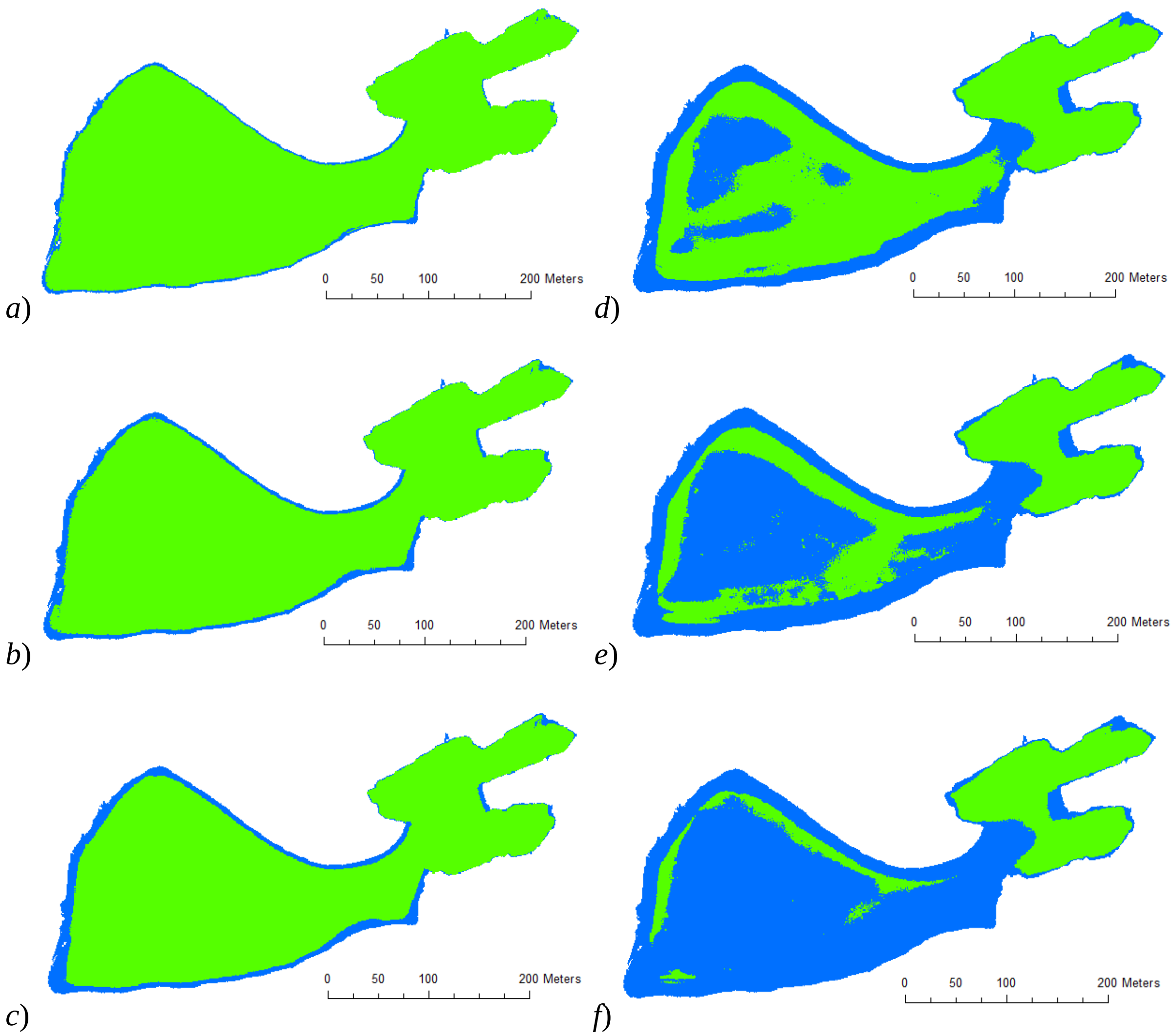

Figure 9. Cayo Diablo dry land (green) and potential inundation (blue) at *a*) 0.30 m (1 ft) of SLR, *b*) 0.61 m (2 ft) of SLR, *c*) 0.91 m (3 ft) of SLR, *d*) 2.0 m (6.4 ft) of SLR and storm surge, associated with a Category 5 hurricane at high tide with 0.31 m of SLR, a Category 3 hurricane at high tide with 0.61 m of SLR, or a Category 3 hurricane at mean tide with 0.91 m of SLR, *e*) 2.3 m (7.5 ft) of SLR and storm surge, associated with a Category 5 hurricane at high tide with 0.61 m of SLR or a Category 3 hurricane at high tide with 0.91 m of SLR, and *f*) 2.59 m (8.5 ft) of SLR and foot storm surge from a Category 5 hurricane striking at high tide with 0.91 m of SLR, the most extreme hurricane scenario assessed.

From SLR alone, little VI boa habitat on Cayo Diablo is predicted to be lost with a 0.30-0.91 meter increase in water level (Figure 9, panels *a-c*). However, storm surges from hurricanes on top of SLR do have the potential to flood large portions of VI boa habitat in the western portion of the cay with on top of 0.61-0.91 meters of SLR (Figure 9, panels *d*-*f*). This western portion of the cay is where VI boas are primarily found.

Cayo Ratones

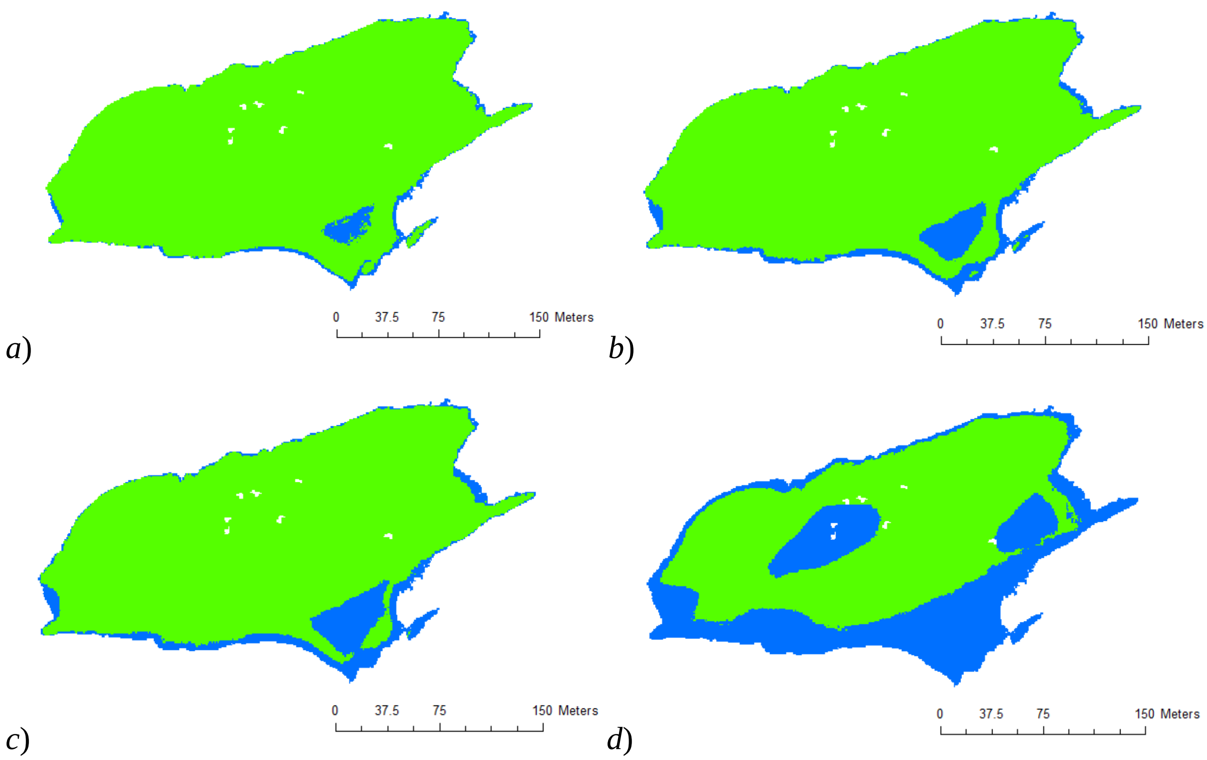

Figure 10. Cayo Ratones dry land (green) and potential inundation (blue) at *a*) 0.30 m (1 ft) of SLR, *b*) 0.61 m (2 ft) of SLR, *c*) 0.91 m (3 ft) of SLR, and *d*) 2.6 m (8.4 ft) of SLR and storm surge from a Category 5 hurricane striking at high tide with 0.91 m of SLR, the most extreme hurricane scenario assessed. White patches indicate no elevation data.

From SLR alone, little habitat on Cayo Ratones is predicted be lost with 0.30-0.61 meters of SLR. A large portion of the land below the high water mark at these levels of SLR is in an inland depression of lower elevation along the southern part of island (Figure 10, panels *a* and *b*), and may or may not actually become flooded with SLR depending on how the area is hydrologically connected. With 0.91 meters of SLR, this area is predicted with more certainty to become permanently inundated (Figure 10, panel *c*). When SLR and storm surge combined reach about 1.5-1.6 meters, two more low-lying inland areas become vulnerable to flooding, one of which (on the eastern part of the southern edge of the island, Figure 10, panel *d*) loses its high-elevation barrier from the sea only for a Category 5 hurricane striking at high tide on top of 0.91 meters of SLR (the most extreme of the assessed hurricane scenarios).

USVI Cay

From SLR alone, little habitat on the coast of the USVI cay is expected to be lost with 0.30-0.91 meters of SLR (Figures not shown so as not to disclose the sensitive location of the cay). However, the center of the cay is a low-lying wetland, inundated with ocean ground water, and would flood more with rising sea levels and storm impacts. When hurricane storm surges are added on top of SLR, the higher-elevation barrier around the central low-lying region becomes tenuous, and eventually disappears with increasing storm strength.

Summary

For all three cays, inundation from SLR alone by 2100 is not expected to significantly impact VI boa population resilience. While some habitat may be permanently inundated, large intact portions of habitat are predicted to remain. However, SLR rise will not occur alone, and will interact with hurricane storm surges, coastal erosion, salt water intrusion/inundation and other processes. Major hurricanes are normal occurrences in the Caribbean, and as the global climate warms, hurricanes are predicted to occur less frequently, but are predicted to be stronger on average when they do occur. The habitat and boa populations on these cays have proven to be resilient against hurricanes at current sea levels, but as conditions change and the ocean rises, hurricane impacts might become more catastrophic, leaving lasting damage. While we cannot precisely predict whether once-resilient habitat and populations will or will not remain resilient in the face of storms of different strengths and oceans of different heights, we can provide a relative ranking of risk based on the above GIS assessment. In order of higher risk to moderate risk (none of these are at low risk), the ranking of these three cays is 1) USVI cay, 2) Cayo Diablo, and 3) Cayo Ratones.

6.2 Future Scenarios

Below we present 3 hypothetical future scenarios for the VI boa over the next 30 years (to 2048), Status Quo, Conservation, and Pessimistic. Impacts of climate change and SLR are treated the same across all three scenarios, as the trajectory of climate change will proceed regardless of different levels of local conservation for VI boa. The factors that change across different scenarios are those local factors that can be easily manipulated (at least more easily than the global climate). As mentioned previously, predictions farther into the future, to 2100, are based only on sea level rise of 0.61-0.91 meters (2-3 feet) and hurricane storm surges, as predictions about other factors (e.g., habitat protection, risk of exotic mammal invasion, VI boa population dynamics) would be far too uncertain to be meaningful.

6.2.1 Status Quo

Under the Status Quo scenario, conditions continue along their current trajectory. Development continues at the current pace, and populations that are currently threatened by development and associated exotic mammals remain negatively impacted by these threats. Population sizes in these areas decline, as they are suspected to be in decline presently by species experts (but hard data are lacking to confirm trends). No new habitat is protected. One new reintroduction takes place under this scenario, because one has already been initiated with the 2018 capture of snakes to reinvigorate captive breeding. Sea level rise occurs at a rate of 0.30 meters by 2048, and 0.61-0.91meters by 2100. Multiple major hurricanes are expected to strike within the VI boa range.

6.2.2 Conservation

Under the Conservation scenario, while development continues on human-occupied islands, some VI boa habitat is protected on the Puerto Rico mainland, Culebra (where some habitat is already protected), and St. Thomas to preserve and/or restore habitat and habitat connectivity. Because of the size of the islands and human populations there, exotic cats and rats remain problematic, but risk might be lessened by conservation efforts and effective community outreach and education about the effect of free-roaming cats on native wildlife. Regulations and enforcement improve on protected lands. Rats are again eradicated from Cayo Ratones, and if necessary, more boas are translocated there. Reintroductions occur at a rate of 1 per decade, including the reintroduction already planned, and struggling populations on developed islands are augmented. Sea level rise occurs at a rate of 0.30 meters by 2048, and 0.61-0.91meters by 2100. Multiple major hurricanes are expected to strike within the VI boa range.

6.2.3 Pessimistic

Under the Pessimistic scenario, no reintroductions occur, presumably due to reduced funds or changes in governmental or conservation priorities. No additional habitat is protected and development continues to impact populations on human-inhabited islands. Exotic mammals remain a threat where already present. Rats colonize Cayo Diablo and recolonize the USVI Cay from which they were previously eradicated; the recent recolonization of Cayo Ratones demonstrates that this is a real risk to populations. Sea level rise occurs at a rate of 0.30 meters by 2048, and 0.61-0.91meters by 2100. Multiple major hurricanes are expected to strike within the VI boa range.

6.2.3 Likelihood of Scenarios

Given current resources, priorities, and conservation momentum, the Status Quo scenario is the most likely scenario for the future. The Status Quo scenario includes the implementation of a new reintroduction, which is contingent on continued funding (not yet secured) and long term commitment to manage and propagate a captive population, select a suitable site (which may involve rat eradication), reintroduce boas, and conduct post-release monitoring. After Status Quo, the likelihoods of the Conservation and Pessimistic scenario are contingent upon the decisions, resources, and priorities of management and conservation organizations, which is difficult to predict. The Pessimistic scenario is likely if funds and effort are not directed to captive breeding and reintroduction, community outreach and education, habitat protection and restoration, and ongoing monitoring of VI boas, their habitat, and exotic species. The Conservation scenario is likely if abundant funds and effort are directed towards these initiatives.

6.3 Future Resilience

As mentioned previously, predicted resilience in year 2048 is influenced by all considered factors (e.g., reintroductions, development, SLR, etc.). For 2048 projections, we predict the resilience of populations in the same way as in the current condition, by summing together scores for each habitat or population metric, with one exception. When population trends under a scenario suggest that extirpation is somewhat likely, though uncertain, resilience for the population is forced to Low/Extirpated, with a corresponding numerical score of -4 to demonstrate that although extirpation is not predicted with 100% certainty, the condition of the population is expected to be worse than others receiving a low resilience score (no other scores drop below -2). Due to high degrees of uncertainty about all of the considered factors farther into the future, the only factor considered for 2100 resilience is habitat loss due to SLR and hurricane impacts. For 2100 projections, we do not assign a resilience category, but instead describe the risk from SLR and hurricane impacts.

Cayo Diablo (Current resilience = Moderately High)

2048 – Under the Status Quo future scenario, resilience on Cayo Diablo in 2048 is expected to remain **moderately high**. The cay is protected for conservation, so development is not a risk, and there are not currently exotic cats and rats on the island. The vulnerability to hurricane storm surges and the current population size/trend remain the same as the current condition. Under the Conservation scenario, factors are the same as under the Status Quo scenario, with the exception of population size/trend; ideally with better outreach, education, enforcement, and population monitoring, the population will be revealed to grow or remain stable, increasing resilience to **high**. Under the Pessimistic scenario, rats colonize the cay and are expected to cause dramatic population declines, potentially leading to extirpation; predicted resilience is **low/extirpated**.

Although a major hurricane coupled with 0.31 meters of SLR could have catastrophic effects on up to 1/3 of the island, large regions of connected habitat are likely to remain, and the habitat has proven to be resilient to hurricanes in the past. Thus, we believe that SLR and hurricanes will not likely lead to extirpation on Cayo Diablo by 2048, but they can still influence population resilience on this low-lying cay. Scenarios are summarized for Cayo Diablo in Table 5.

Table 5. Current and future resilience scores under 3 future scenarios for Cayo Diablo.

	Habitat Metrics			**Population Metric**	
Cayo Diablo	**Habitat**	**Exotic Mammals**	**Storm Surge Risk**	**Population Size/Trend**	**Resilience**
Scenario	Protected or Development Risk	Present or Absent	Low or High	Description	Category
Current Condition	Protected (+1)	Absent (+1)	High (-1)	Potentially Declining (0)	Moderately High (+1)
Status quo	Protected (+1)	Absent (+1)	High (-1)	Potentially Declining (0)	Moderately High (+1)
Conservation	Protected (+1)	Absent (+1)	High (-1)	Growth (+1)	High (+2)
Pessimistic	Protected (+1)	Present (-1)	High (-1)	Declining (-1)	Low/ Extirpated (-2)

2100 – By 2100, 8-10% of Cayo Diablo is expected to be below water level for 0.61-0.91 meters of SLR, respectively. With major hurricanes striking at high tide on top of SLR, large amounts of connected habitat (up to 75% of the island) are expected to become inundated in the storm surge. Importantly, inundation is not the only risk of SLR to terrestrial habitat; erosion and salt water intrusion/inundation can also permanently destroy habitat. Because Cayo Diablo will lose some habitat to SLR, and is at risk of losing habitat from hurricane storm surges, potentially enough habitat to devastate the VI boa population, we classify Cayo Diablo as having **high risk** from SLR. Whether or not hurricanes will actually devastate this population is highly uncertain, depending on the frequency, strength, and path of future hurricanes, which we cannot precisely predict.

Cayo Ratones (Current resilience = Low)

2048 – Under the Status Quo and Pessimistic scenarios, resilience on Cayo Ratones in 2048 is expected to be **low/extirpated**. The cay is protected for conservation, so habitat loss from development is not a risk, but rats have recolonized the island, and no boas were found during 3 survey nights in April 2018. If not already extirpated, this population is at high risk of further declines and extirpation. Under the Conservation scenario, where rats are removed from the island and supplemental translocation, if necessary, is conducted, the population is expected to once again flourish as it did post reintroduction and resilience is expected to be **high**. As evidenced by the recolonization of rats on Cayo Ratones, ongoing monitoring for rat recolonization is necessary and would be conducted under the Conservation scenario so recolonization by rats is prevented or caught early in the future.

Sea level rise and hurricane storm surges are not likely to destroy or inundate a catastrophic amount of VI boa habitat and lead to extirpation on Cayo Ratones by 2048, but they can still influence population resilience on this low-lying cay. Four percent of the island is expected to be inundated by SLR alone. A Category 5 hurricane on top of SLR is expected to leave about 75% of the island above water level, and the habitat has proven to be resilient to hurricanes in the past. Scenarios are summarized for Cayo Ratones in Table 6.

Table 6. Current and future resilience scores under 3 future scenarios for Cayo Ratones.

	Habitat Metrics			**Population Metric**	
Cayo Ratones	**Habitat**	**Exotic Mammals**	**Storm Surge Risk**	**Population Size/Trend**	**Resilience**
Scenario	Protected or Development Risk	Present or Absent	Low or High	Description	Category
Current Condition	Protected (+1)	Present (-1)	High (-1)	Declining, no boas detected 2018 (-1)	Low (-2)
Status quo	Protected (+1)	Present (-1)	High (-1)	Declining, likely extirpated (-1)	Low (-2)
Conservation	Protected (+1)	Absent (+1)	High (-1)	Growth (+1)	High (+2)
Pessimistic	Protected (+1)	Present (-1)	High (-1)	Declining, likely extirpated (-1)	Low (-2)

2100 – By 2100, 8-11% of Cayo Ratones is expected to be below water level for 0.61-0.91 meters of SLR, respectively. With 2 feet of SLR, some of this area is inland, and may or may not permanently flood, depending on hydrologic connectivity. With 0.91 meters of SLR, the low-lying inland area does become connected to the ocean. Even with intense hurricanes striking at high tide, large amounts of connected habitat are expected to remain above the high water mark. Importantly, inundation is not the only risk of SLR to terrestrial habitat; erosion and salt water intrusion/inundation can also permanently destroy habitat. Because Cayo Ratones will lose some habitat to SLR, and is at risk of losing habitat from hurricane storm surges, but likely not enough habitat to completely devastate the VI boa population, we classify Cayo Ratones as having **moderate risk** from SLR.

USVI Cay (Current resilience = Moderate)

2048 – Under the Status Quo and Conservation scenarios, resilience on the USVI Cay in 2048 is expected to be **moderate** and **high**, respectively. The cay is protected for conservation, so development is not a risk, and there are not currently exotic cats and rats on the island. The difference in resilience between the two scenarios depends on whether the population size remains relatively low in response to a smaller prey base, or if the population grows or remains stable and abundant. Under the Pessimistic scenario, rats recolonize the cay and are expected to cause dramatic population declines, potentially leading to extirpation; predicted resilience is **low/extirpated**. This cay does exist in a shipping lane, and is within 1 km of an island with rats, increasing its risk of being encountered by rats.

Although a major hurricane coupled with 0.30 meters of SLR could have catastrophic effects on up to half of the island (for a Category 5 hurricane striking at high tide), large regions of connected habitat are likely to remain, and the habitat has proven to be resilient to hurricanes in the past. Thus, we believe that SLR and hurricanes will not likely lead to extirpation on USVI Cay by 2048, but they can still influence population resilience on this low-lying cay. Scenarios are summarized for the USVI Cay in Table 7.

Table 7. Current and future resilience scores under 3 future scenarios for the USVI Cay.

	Habitat Metrics			Population Metric	
USVI Cay	**Habitat**	**Exotic Mammals**	**Storm Surge Risk**	**Population Size/Trend**	**Resilience**
Scenario	Protected or Development Risk	Present or Absent	Low or High	Description	Category
Current Condition	Protected (+1)	Absent (+1)	High (-1)	Potentially Declining, loss of 2 prey species, possible decline of body size (-1)	Moderate (0)
Status quo	Protected (+1)	Absent (+1)	High (-1)	Potentially Declining, loss of 2 prey species, possible decline of body size (-1)	Moderate (0)
Conservation	Protected (+1)	Absent (+1)	High (-1)	Growth or Stable Abundance (+1)	High (+2)
Pessimistic	Protected (+1)	Present (-1)	High (-1)	Declining, likely extirpated (-1)	Low/ Extirpated (-4)

_2100_ – By 2100, 12-23% of the USVI Cay is expected to be below water level for 0.61-0.91 meters of SLR, respectively. Much of this area is inland, and may or may not permanently flood, depending on hydrologic connectivity. With major hurricanes striking at high tide on top of SLR, large amounts of connected habitat (up to 83% of the island) are expected to become inundated in the storm surge. Importantly, inundation is not the only risk of SLR to terrestrial habitat; erosion and salt water intrusion/inundation can also permanently destroy habitat. Because this cay will lose some habitat to SLR, and is at risk of losing habitat from hurricane storm surges, potentially enough habitat to devastate the VI boa population, we classify the USVI Cay as having **high risk** from SLR. Whether or not hurricanes will actually devastate this population is highly uncertain, depending on the frequency, strength, and path of future hurricanes, which we cannot precisely predict.

Culebra, Río Grande, and St. Thomas (Current resilience = Low)

2048 – Under the Status Quo and Pessimistic scenarios, resilience of the Culebra, Río Grande, and St. Thomas populations in 2048 are expected to be **low/extirpated**. The boa habitat here is unprotected and susceptible to development, and exotic cats and rats are present, although cat predation on rats may help lessen the threat from rats (P. Tolson, pers. communication). These population are at high risk of further declines and extirpation. Under the Conservation scenario, efforts to protect and/or restore habitat, augment populations, control predators, and perform community outreach are expected to prevent extirpation, but still result in **moderately low** (Culebra) or **low** (Río Grande and St. Thomas) resilience. These populations occur on large islands, with high potential for population expansion, especially on Culebra where about 160 hectares of habitat are protected; VI boa populations hypothetically could grow to much larger sizes than on the smaller offshore cays. However, based on current understanding, it is currently unlikely that the risk of exotic mammals and human development likely cannot be eliminated to a point where resilience would be considered high within 30 years, even with reasonable conservation efforts. Improved regular monitoring of these populations could change the understanding of how VI boas persist on developed islands with exotic mammals.

Due to the elevation, topography, and size of Culebra Island, the Puerto Rico mainland around the Río Grande population, and St. Thomas, and the distribution of VI boas, these populations are not at risk from SLR. Scenarios are summarized for the these populations in Tables 8 and 9.

Table 8. Current and future resilience scores under 3 future scenarios for Culebra.

	Habitat Metrics			**Population Metric**	
Culebra	**Habitat**	**Exotic Mammals**	**Storm Surge Risk**	**Population Size/Trend**	**Resilience**
Scenario	Protected or Development Risk	Present or Absent	Low or High	Description	Category
Current Condition	Both (0)	Present (-1)	Low (+1)	Rare, trend unknown, no boas detected 2018 (-1)	Moderately Low (-1)
Status quo	Both (0)	Present (-1)	Low (+1)	Declining, likely extirpated (-1)	Low/ Extirpated (-4)
Conservation	Both (0)	Present (-1)	Low (+1)	Rare but stable (-1)	Moderately Low (-1)
Pessimistic	Both (0)	Present (-1)	Low (+1)	Declining, likely extirpated (-1)	Low/ Extirpated (-4)

Table 9. Current and future resilience scores under 3 future scenarios for Río Grande and St. Thomas.

	Habitat Metrics			**Population Metric**	
Río Grande and St. Thomas	**Habitat**	**Exotic Mammals**	**Storm Surge Risk**	**Population Size/Trend**	**Resilience**
Scenario	Protected or Development Risk	Present or Absent	Low or High	Description	Category
Current Condition	Development Risk (-1)	Present (-1)	Low (+1)	Rare, trend unknown (-1)	Low (-2)
Status quo	Development Risk (-1)	Present (-1)	Low (+1)	Declining, likely extirpated (-1)	Low/ Extirpated (-4)
Conservation	Development Risk (-1)	Present (-1)	Low (+1)	Rare but stable (-1)	Low (-2)
Pessimistic	Development Risk (-1)	Present (-1)	Low (+1)	Declining, likely extirpated (-1)	Low/ Extirpated (-4)

2100 – Due to the elevation, topography, and size of Culebra Island, the Puerto Rico mainland around the Río Grande population, and St. Thomas, and the distribution of VI boas, these populations are at **low risk** from SLR and hurricane storm surges.

New Reintroductions

2048 – New sites for reintroductions should be selected based on habitat factors that will favor VI boa persistence and population growth, including habitat availability, connectivity, and protection, prey availability, absence of exotic mammals, and safety from rising sea levels. Assuming that sites are selected well, and reintroduced populations are monitored to identify problems that may arise, all new reintroduced populations are expected to attain **high** resilience under these scenarios. Under the Pessimistic scenario, no new populations are reintroduced, in the Status Quo scenario, 1 new population is introduced, and in the Conservation scenario, 3 new populations are introduced at a rate of 1 per decade.

2100 – Ideally, sites for new reintroductions will be selected so that the elevation and topography of the site protects future VI boa populations so they are at **low risk** from rising sea levels.

British Virgin Islands

Although information was not available to explicitly assess future VI boa resilience on the British Virgin Islands, boas there, on Tortola in particular, likely face a similar situation as boa populations on the developed islands that we did assess: Culebra, Río Grande, and St. Thomas (M. Garcia-Bermudez, pers. communication).

6.3.1 Future Resilience Summary

Range-wide future resilience is summarized below in Table 10. All 3 populations on developed islands are predicted to remain at low resilience or become extirpated by 2048. Even with conservation efforts to prevent extirpation, they are not expected to become highly resilient because of the magnitude of the threats facing them. Ironically, these are the populations least at risk from SLR by 2100. The two populations with the highest current resilience (Cayo Diablo and USVI Cay) are the 2 populations most at risk from SLR by 2100. Cayo Diablo, the population with the highest resilience, is expected to remain highly resilient unless colonized by rats, which could drive the population to extirpation. Cayo Ratones, which presently has a robust rat population, will remain at low resilience and potential extirpation unless rats are eradicated; supplemental translocations may also be necessary, but more surveys are necessary to determine the needs of the population. Given that the threats facing populations on developed islands will be very difficult to surmount, the most effective way to increase the overall resilience of populations range-wide is to reintroduce new populations in quality protected habitat. However, conservation of existing populations of VI boas and their habitat on developed islands, via population augmentation, and habitat restoration (in occupied areas and to establish migration corridors) is still important to contribute to redundancy and representation for the species.

Table 10. Summary table of future resilience for VI boa populations in 2048 under 3 scenarios, and a longer-term assessment of risk from sea level rise (SLR) by 2100. Values reflecting good conditions for boas are shaded green (darker green for better conditions), while values reflecting unfavorable conditions are shaded red (darker red for worse conditions), and moderate values are shaded yellow.

Population	Current Resilience	Future – Status Quo (2048)	Future – Conservation (2048)	Future – Pessimistic (2048)	SLR Risk (2100)
Cayo Diablo	Moderately High	Moderately High	High	Low/Extirpated	High
Cayo Ratones	Low	Low/Extirpated	High	Low/Extirpated	Moderate
Culebra	Moderately Low	Low/Extirpated	Moderately Low	Low/Extirpated	Low
Rio Grande	Low	Low/Extirpated	Low	Low/Extirpated	Low
St. Thomas	Low	Low/Extirpated	Low	Low/Extirpated	Low
USVI Cay	Moderate	Moderate	High	Low/Extirpated	High
New populations	None	1 High	3 High	None	3 Low
Summary (# pops)*	Low: 4 Moderate: 1 High: 1	Low/Extirpated: 4 Moderate: 1 High: 2	Low: 3 High: 6	Low/Extirpated: 6 High: 0	Low: 6 Moderate: 1 High: 2

*Low and Moderately Low combined in summary as 'Low', High and Moderately High combined in summary as 'High'

6.4 Future Redundancy

Redundancy of highly and moderately highly resilient populations might increase under the Status Quo scenario with a new reintroduction, but the 4 populations currently with low resilience run the risk of extirpation. The total number of populations under the Status Quo scenario is 3-7 depending on whether those extirpations indeed occur. Under the Pessimistic scenario, no highly resilient populations remain, and all are at risk of extirpation, for a total of 0-6 populations. The Conservation scenario improves redundancy via 3 new introductions that become highly resilient, the rescue of the Cayo Ratones population by eradicating rats and providing translocations if needed, and by preventing low-resilience populations from becoming extirpated, for a total of 9 populations. Although conservation can improve redundancy, it will remain inherently low because of the limited range of the species. As time goes on after the horizon of our 30-year scenarios, SLR becomes more important to consider, as current populations with the highest resilience potential are the same populations that will be most at risk from SLR.

6.5 Future Representation

Several ideas were presented in the Current Conditions section about how representation could be considered, and we went forward with considering each natural (not introduced) population as a representative unit. Under this concept, a reintroduced population is of the same representative unit as the source population used for the reintroduction, and reintroductions are the only source of redundancy within representative units. Because of this, future representation for the species depends highly on how reintroductions are carried out (Table 11).

The Status Quo scenario includes one reintroduction sourced from the USVI cay, which was originally sourced from the St. Thomas population. The Conservation scenario includes 2 additional reintroductions, which could be sourced from any other population. Sourcing new reintroductions from Culebra or Río Grande would improve redundancy within representative units, but other factors like geographic proximity to the reintroduction site and availability of source boas also factor into the decision of where to source reintroductions from. As mentioned in the current representation section, isolated populations with no gene flow between them would be expected to diverge genetically over time, and could at some point be considered distinct representative types. Based on the models from Reynolds et al. (2015), this divergence could take decades to centuries depending on the number of breeders. Due to small population sizes, much of this genetic divergence is likely to occur in the form of non-adaptive loss of alleles from genetic drift. Human-mediated gene flow however could serve to maintain genetic diversity within populations and prevent the genetic divergence between populations; the need for this kind of intervention should be monitored with period genetic sampling of populations and examinations for evidence of inbreeding depression.

Table 11. Number of current and future VI boa populations of each resilience class (high which includes moderately high, or low/ext, which includes low, moderately low, and low/extirpated, moderate column shown only for scenarios with moderately resilient populations) within each representative unit, corresponding to natural (not introduced) populations, which correspond to unique genetic signatures. One reintroduction using St. Thomas representation is planned under the Status Quo scenario. Two additional highly resilient populations exist under the Conservation scenario, but the source populations for those reintroductions are not predicted, so the values in the high resilience column are minimums.

Natural Population (Genetic Signature)	Current Condition			Future – Status Quo			Future – Conservation		Future – Pessimistic	
	High	Mod	Low/Ext	High	Mod	Low/Ext	High	Low/Ext	High	Low/Ext
Cayo Diablo	1	0	1	1	0	1	≥ 2	0	0	2
Culebra	0	0	1	0	0	1	≥ 0	1	0	1
Río Grande	0	0	1	0	0	1	≥ 0	1	0	1
St. Thomas	0	1	1	1	1	1	≥ 2	1	0	2

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