Puerto Rican Boa

(*Chilabothrus inornatus*)

Species Status Assessment

Photo credit: Father A.J. Sánchez–Muñoz (www.kingsnakke.com/westindian)

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EXECUTIVE SUMMARY

This Species Status Assessment (SSA) reports the results of a comprehensive review for the Puerto Rican boa (PR boa, *Chilabothrus inornatus*). This endemic Puerto Rican endemic species has been listed as endangered since 1970 due to the rarity of the species. This SSA provides a thorough assessment of the species' biology, biological status, and influencing factors, and assesses the species' resource needs in the context of determining its viability and risk of extinction. Using this SSA framework, we consider what the species needs to maintain viability by characterizing its status in terms of its resiliency, representation and redundancy (together the 3Rs). This process used the best available information to characterize viability as the ability of the PR boa to sustain populations in its natural habitat over time.

The PR boa is a large, semi-arboreal nocturnal and nonvenomous snake with color variations from tan to very dark brown and some black body markings. Although the actual life span of PR boas in the wild is unknown, some information suggests they may live up to 20–30 years. The PR boa is considered a habitat generalist and tolerates a wide variety of habitat types (terrestrial and arboreal) from coastal forest to wet karst and montane forest, along streams, forest and road edges and within rural, suburban and some urban areas. Cave systems and their surrounding forests are identified as particularly important because of the ecological resources available (e.g., prey and shelter) for the PR boa.

The species is considered widely distributed, but not uniformly abundant across the island. It has been reported in all of the municipalities of mainland Puerto Rico. The PR boa was considered relatively rare by the 1900s and is probably less abundant now than it was in Pre-Columbian times, when Puerto Rico had an extensive forest cover. However, it is considered more abundant today than previously thought at the time of listing and more abundant in the karst region of the north and less abundant in the dry southern region of the Island. The PR boa has cryptic coloration and habits, and attempting to determine a population estimate for this widely distributed species is challenging.

Threats influencing the viability of the PR boa include habitat loss and fragmentation from human development, exotic mammals (namely cats, *Felis catus*), poaching and intentional killings, inappropriate management practices, emergent diseases, hurricanes and climate change. These threats involve a variety of impacts, which reduce or degrade available habitat and may have direct impacts on the species, for example, road mortality and human persecution. Some conservation actions that have benefited the PR boa include designation of protected areas all over Puerto Rico, research, and implementation of conservation measures during projects. Other influential factors include public attitudes towards snakes, education and outreach, and genetics.

For this SSA, we considered one island-wide PR boa population for Puerto Rico. This population may function more as several interbreeding groups, that are focused within certain habitat patches or landscapes that may or may not interact at different levels (low to high) via natural or human–facilitated dispersal. We determined population resilience by estimating the PR boa population abundance across its entire range using the available density estimates and predicted habitat model for the species. In combination with the known species high adult survival rate, we assigned a medium-high current resilience to the PR boa population. Resilience in general is expected higher where suitable habitat and resources are least fragmented, and occur the farthest away from human settlements and where exotic predators are fewer or absent. The abundance and distribution of the PR boa is expected to be directly related to the quality and quantity of its habitat.

Since only one PR boa population is being considered for this SSA, redundancy for the PR boa, a wide ranging endemic, is inherently low. The wide distribution of suitable habitat throughout the species' range may reduce the risk that any large portion of the species' range will be negatively affected by any catastrophic or anthropogenic event at any given time, except for hurricanes that may affect the entire island. Thus, we assigned a medium redundancy for the PR boa since the available information suggests that the current distribution is considered somewhat fragmented due to habitat degradation, the entire range is susceptible to hurricanes, and that the species is thought to have been more widely distributed across most of the Island before the 1900s.

To measure representation for the PR boa, we used the available species-specific genetic information in addition to the ecological variability along the species wide range (redundancy). Besides some reduced gene flow, in general, genetic studies for the PR boa have not yet indicated any critical genetic differences or significant concerns. Maintaining the species broad distribution across its range would help to retain the species' adaptive potential and current representation, which we assigned as medium–high.

In order to assess the future viability of the PR boa, we used a demographic matrix model and projected the overall population response to four different habitat change scenarios 30 years into the future: no further urbanization, reduced urbanization (8 percent urban growth per decade), status quo (16 percent), and increased urbanization (24 percent). These four scenarios provided a range of viability predictions for the species, and are intended to represent the PR boa population's response to key threats such as habitat loss, fragmentation, and human interactions.

Using variable initial population sizes, carrying capacities, and average demographic rates, we calculated the probabilities of population growth and decline for each scenario. We also assessed quasi-extinction risk at four thresholds (total population size 50, 500, 1,000, or 5,000) and calculated the probability of the population falling below these thresholds for each scenario as well.

Our projection model indicated that the PR boa population is most likely to decline over a 30-year period if the current rate of urbanization (16 percent Status Quo scenario) were to continue, with a 58 percent probability of decline and 42 percent probability of stability or growth. Lower rates of urbanization were associated with a slightly greater probability of population stability or growth, but the probability of growth was only 52 percent under the most optimistic scenario (no further urbanization scenario), which is unlikely to occur. However, quasi-extinction probability was low due to the possibility of a large current population size (up to 189,515 individuals) and was less than 5 percent for all scenarios and thresholds.

Based on the results of the projections, we can assume that the PR boa resiliency would be slightly lower than the current condition (medium to high) in the foreseeable future (year 2050), especially if we consider all factors that may influence resilience (e.g., development, protection, exotics, etc.). It is reasonable to assume that the status quo scenario (16 percent rate of urbanization per decade) will continue, resulting in a higher probability of decline (58 percent) than the probability of growth (42 percent), but with a very low probability of a precipitous decline within 30 years and very low probability of abundance reaching 5,000 individuals or less. The likely future scenario for the PR boa population is further habitat degradation, fragmentation and encroachment into protected areas that would hopefully sustain viable PR boa populations. That is, somewhat reduced resiliency, while redundancy and representation are not expected to be significantly lower in the foreseeable future. Areas of natural habitats, protected from roads and the fragmentation associated with development are needed to maintain viable PR populations.

1.0 INTRODUCTION

The Puerto Rican boa (PR boa, *Chilabothrus inornatus*) is endemic to Puerto Rico. It was first listed as endangered under the Endangered Species Act of 1973 (the Act), as amended, in 1970 (35 FR 16047) due to its decline in both population size and distribution caused by the widespread deforestation in Puerto Rico during the 1800s (USFWS 1986, p. 7). Challenges associated with its habitat and cryptic behavior (i.e., low detectability) have made it difficult to monitor and determine the island-wide population status of the PR boa. Since the completion of the recovery plan (USFWS 1986, entire), various investigations have been conducted contributing to the knowledge of the species' ecology. Even though the PR boa has a large distribution and is not as rare as previously thought, the latest (2011) 5-year status review for this species recommended no change to its endangered status due to remaining threats and lack of population data or models (USFWS 2011, p. 16–17).

The Species Status Assessment (SSA) framework (USFWS 2016, entire) 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 PR 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 U.S. Fish and Wildlife Service (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 PR 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 PR boa to sustain populations in the wild over time (USFWS 2016, p.9). 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, pp. 200–201; USFWS 2016, p. 10).

- **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. For the PR boa, the primary indicators of resiliency are population abundance and density, adult survival rates, and quasi–extinction risk.

- **Redundancy** describes the ability of a species to withstand catastrophic events; it's about spreading risk among multiple populations to minimize the potential loss of the species from 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). For the PR boa, we are using the geographic distribution from a predicted potential habitat model, as described by geospatial analysis, to measure redundancy.

- **Representation** describes the ability of a species to adapt to changing environmental conditions over time. It is characterized 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. In theory, the more representation or diversity a species has, the more it is capable of adapting to changes (natural or human caused) in its environment. For the PR boa, we use the species–specific genetic information and the extent and variability of habitat characteristics across the geographical range (predicted potential habitat).

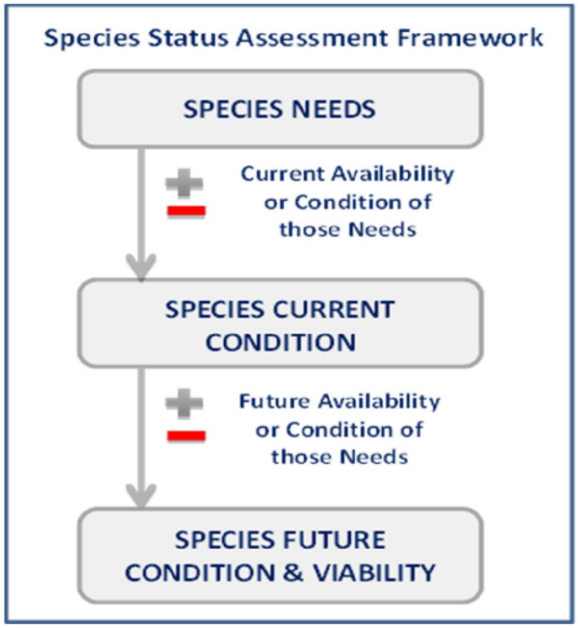


Figure 1. Species Status Assessment Framework

To evaluate the biological status of the PR 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 PR boa.

1.1 Species Federal Status

The PR boa was originally listed as an endangered species on October 13, 1970 (35 FR 16047). Available information suggest that the PR boa population declined in both size and distribution during a period of intense deforestation on Puerto Rico in the late 1800s (USFWS 1986, p.7). This decline and the species rarity prompted the Federal government to include the species in the Endangered Species list in 1970 as *Epicrates inornatus*. The 2011 PR boa 5-year status review described this species status as stable based on the broad distribution and apparent higher abundance than what was known (USFWS 2011, p. 1). In that review, the Service did not recommend a reclassification change (i.e., still endangered) due to remaining threats and lack of population data or models, and assigned a recovery priority number of 11c, representing a moderate degree of threat, high recovery potential and "c" designation because of conflict with construction or other development projects (USFWS 2011, p. 17). No critical habitat has been designated for the PR boa.

In addition to Federal protection, the PR boa is protected as 'vulnerable' under Regulation 6766, which regulates the management of threatened and endangered species in the Commonwealth of Puerto Rico (DNER 2004, p. 34). Also, the species is currently classified as *Least Concern* by the International Union for Conservation of Nature Red List, "due to its large distribution, lack of widespread threats, and ability to inhabit altered environments" (Rodriguez et al. 2018, entire).

2.0 SPECIES BIOLOGY

2.1 Taxonomy and Species Description

The PR boa was first described by Reinhardt (1843) as *Boa inornata*, subsequently placed in the genus *Chilabothrus* (Duméril and Bibron 1844), and then in *Epicrates* (Boulenger 1893) (Reynolds and Henderson 2018, p. 13). It is not until recently that the previous genus *Chilabothrus* was resurrected to reflect the more current taxonomy provided by Reynolds et al. (2013a, p. 461). Molecular phylogeny work has indicated that the genus *Epicrates* is paraphyletic (a group of animals that descend from a common evolutionary ancestor, but does not include all of the descendants), and the West Indian clade (as opposed to the mainland clade) was designated as *Chilabothrus*, recognizing the PR boa as *Chilabothrus inornatus* (Reynolds et al. 2013a, p. 461) and no subspecies identified (Reynolds and Henderson 2018, p. 13).

The currently accepted species classification is:

Class	Reptilia
Order	Squamata
Suborder	Serpentes
Infraorder	Alethinophidia
Family	Boidae
Genus	*Chilabothrus*
Species	*inornatus*

*Retrieved 07/01/2019 from the Integrated Taxonomic Information System on–line database, http://www.itis.gov.

2.2 Species Description

The PR boa is a large semi–arboreal nocturnal and nonvenomous snake endemic to Puerto Rico, with the largest recorded sizes around 2 meters (m) (6.6 feet [ft]) in length (Reagan 1984, p. 121; Wiley 2003, p. 192) and possibly capable of reaching larger sizes, particularly in captivity (Tolson, Toledo Zoo, 2018, pers. comm.). Most adult individuals in the wild will range between 1–2 m (3.3–6.6 ft) in length (Bird 1994, p. 34; Mulero-Oliveras 2019, pp. 24–25; Puente-Rolon 2012, p. 22–23; Reagan 1984, p. 121; Rivero 1998, p. 432; Wiley 2003, p. 192). For example, a couple of studies found snout to vent length (SVL) of adult males to vary between approximately 1.1 m to 1.69 m (3.6–5.5 ft), and adult females between approximately 1.14–1.75 m (3.7–5.7 ft), with no significant SVL differences between the sexes (Mulero-Oliveras 2019, pp. 24–25; Puente-Rolon 2012, pp. 22–23). Females, however, do tend to be more corpulent than males (Puente-Rolon 2012, p. 23).

Dorsal coloration of the PR boas is variable and has been described from tan to reddish brown to very dark brown, with several dark bars or spots along its body (cover photo and Figure 2), and juveniles may have reddish color (Rivero 1998, p. 432). Body markings are usually more pronounced in neonates and juveniles, but those markings tend to fade with age (Tolson and Henderson 1992, p. 44). The ventral scales also vary from gray to dark brown (Rivero 1998, p. 432).

The PR boa uses both ambush and active foraging modes, eating smaller prey when young and mostly rats as they get larger (Henderson and Powell 2009, p. 349; Rivero 1998, p. 432; Wiley 2003, p. 190). In general, prey items include rats, mice, bats, lizards, birds (including domestic fowl), frogs, and even land crabs and insect fragments have been found in stomach contents (Henderson and Powell 2009, p. 349; Puente-Rolón 2012, p. 54; Rivero 1998, p. 432; Rodríguez-Durán 1996, entire; Rodríguez and Reagan 1984, p. 219; Wiley 2003, p. 190). A couple of studies found that PR boas feed mainly on rodents (Puente-Rolón 2012, p. 54; Wiley 2003, p. 190) and there is one report of cannibalism in which an adult PR boa was eating a juvenile PR boa (Acevedo-Torres et al. 2005, p. 195). There is also one report of a captive PR boa that ate a cane toad (*Rhinella marina*) which proved fatal to the boa (Thomas and Gaa Kessler 1996, p. 359), and although cane toads are considered relatively common in Puerto Rico, this type of predation is unheard of in the wild and would be considered atypical.

Figure 2. A juvenile PR boa active at night at Fort Buchanan (Photo by Eneilis Mulero-Oliveras) and an adult basking on roadside vegetation debris after Hurricane María (Oct. 2017) at El Yunque National Forest (Photo by Jan P. Zegarra, USFWS).

2.3 Distribution

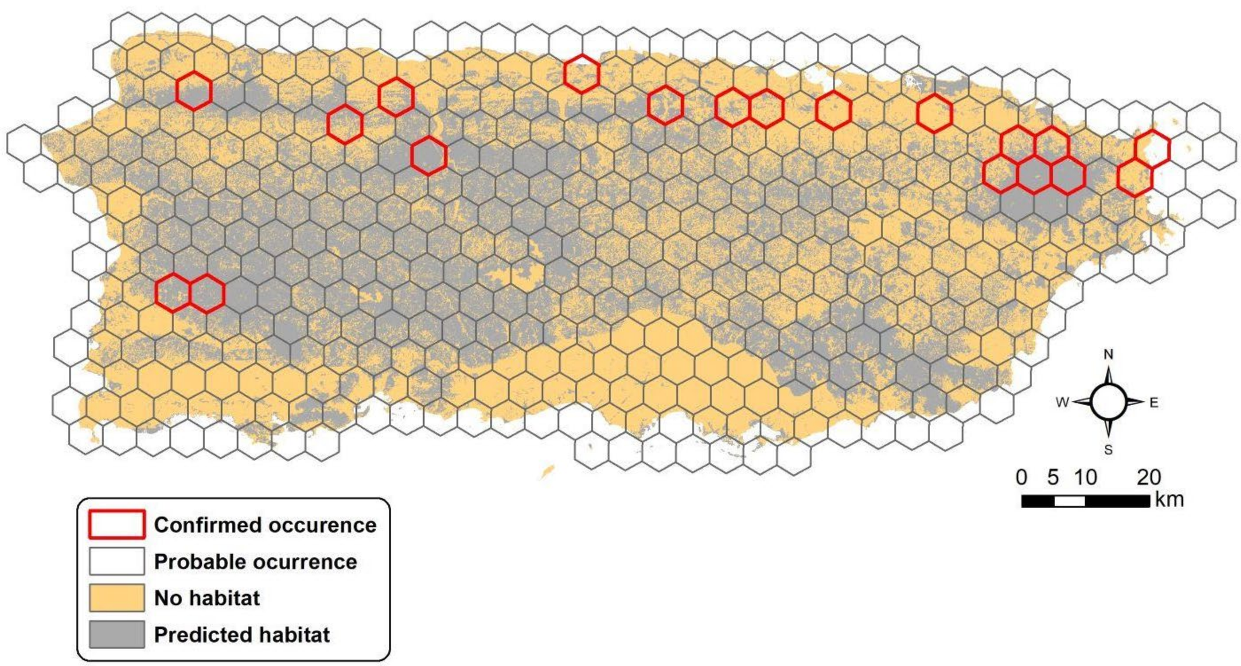
Although the PR boa is considered widely distributed, it is not uniformly abundant across the island, and has a reported elevation range from sea level to 1,050 m (3,445 ft) (Henderson and Powell 2009, p. 349). However, Henderson and Powell (2019, p. 349) does not provide specific details of where these elevation records come from and there seems to be only a couple of reports from El Yunque National Forest and another from Maricao that suggests the species has been detected above 500 m (1,640 ft) (Reagan 1984, p.123 Anadon, 2018, pers. comm.).

Earlier occurrence records for the PR boa already described its wide distribution including protected, rural and developed areas (Pérez-Rivera and Vélez 1978, p. 71). Later descriptions of its distribution increased the occurrence records for the species wide distribution (Bird-Picó 1994, p. 33; Rivero 1998 p. 433, Wiley 2003, p. 190). The PR boa has been reported in all of the municipalities of the main island of Puerto Rico (Puente, UPRM, 2018, pers. comm.). However, we do not know the specific details of these accounts or if they represent isolated occurrences in some municipalities. Despite several anecdotic reports of large snakes in Vieques Island, there is surprisingly only one confirmed PR boa sighting within the west side of the Vieques National Wildlife Refuge from 2010 (Barandiaran 2014, USFWS, pers. comm.). Reynolds and Henderson (2018, p. 13) do suggest the species was likely extirpated from Vieques, but do not provide further explanation. There is also only one confirmed PR boa sighting from Culebra Island in 2013, but genetic analysis suggests it may have been introduced by humans from Puerto Rico (Reynolds and Puente-Rolón 2014, p. 1), which could have been the same case for the Vieques sighting. Based on the available information, it is unlikely that there is a PR boa population in either Vieques or Culebra (Appendix A–1). The PR boa also does not occur in any other offshore island such as Mona or Desecheo Islands to the west, nor Caja de Muerto Island to the south (Appendix A–1). Only one live PR boa was found once in a mangrove cay approximately 500 m (1640 ft) from shore in the south coast (Wiley 2003, p. 190).

By 2008, the Puerto Rico Gap Analysis Project (PRGap) developed an occurrence (presence/absence) hexagon map and a predicted habitat model map for the PR boa (Figure 3; Appendix A–1 & A–2; Gould et al. 2008, pp. 49–50). They described the PR boa as widespread in its distribution, but uncommon, and obtained occurrence information from species locality records, expert opinion and pub range maps or range descriptions (Gould et al. 2008, pp. 42, 49). Even though the PRGap map illustrates the entire island of Puerto Rico as having a probable occurrence of boas, there were only a few (19 out of 443; 4.3 percent) confirmed hexagon areas (24 kilometers [km^2] or 6,178 acres [ac]) for the PR boa and mostly from the eastern half of the

Island (Figure 3; Appendix A–1; Gould et al. 2008, p. 49). The habitat map shows 414,379 hectares (ha) or 46.3 percent (9 percent within protected areas) of Puerto Rico as predicted habitat for the PR boa (Figure 3; Appendix A–2; Gould et al. 2008, p. 50). Land cover types at or below 1,000 m of elevation used for the predicted habitat map included: moist and wet forest, woodland, shrubland mangrove, *Pterocarpus*, and mature dry forest and dry forest near water bodies (Appendix A–2; Gould et al. 2008, p. 50). This PRGap predicted habitat model was used as a baseline for the current and future condition scenarios of the PR boa (Chapters 5 and 6).

Figure 3. PRGap predicted habitat and occurrence hexagons for the PR boa (modified from



Gould et al. 2008, pp. 49–50). Refer to Appendix A–1 and A–2 for original maps.

2.4 Habitat

The PR boa is considered a habitat generalist (Reynolds et al. 2016, p. 1883) and tolerates a wide variety of habitat types (terrestrial and arboreal), which have been well compiled in Tolson and Henderson (1992, p. 45), Joglar (2005, p. 143) and Henderson and Powell (2009, p. 349) and references therein. For example: rocky areas, rock walls and haystack hills ("mogotes"); tree branches, rotting stumps, caves (inside and entrances), plantations; various forested areas (wet montane forest, lowland wet forest, remnant coastal rainforest, mangrove forest, wet and dry limestone karst forests, pastureland with patches of exotic trees) and adjacent to forested areas; rural, urban and suburban areas, outbuildings and houses; and along streams, forest and road edges.

Cave systems and their surrounding forests are identified as particularly important because of the ecological resources available (i.e., prey, shelter, thermal gradients, copulation) for the PR boa (Puente-Rolón and Bird-Picó 2004, pp. 349–350), and the high genetic diversity of PR boas using cave habitats (Puente-Rolón et al. 2013, p. 7).

More specific habitat descriptions are available as well. For example, one habitat characterization study at Mata de Plátano Forest Reserve in the karst region identified a total of 47 plant species from 73 PR boa locations (Puente-Rolón 1999, pp. 46–48). While a study at El Yunque National Forest (volcanic) found most PR boas within the tabonuco (*Dacryodes excelsa*) and palo colorado (*Cyrilla racemiflora*) forest types (Wiley 2003, p. 190). Other studies described PR boas within a variety of microhabitats, including but not limited to: managed tree plantations, roadsides, virgin forest areas, light gaps and forest edges, vine enclosed broadleaf trees and shrubs, vine tangles, sierra palm (*Prestoea montana*), tree ferns (*Cyatheas sp*.), bamboo (*Bambusa vulgaris*), along streams, dead trees, buildings, and miscellaneous cultivated plants (Reagan 1984, p, 121; Wunderle et al. 2004, p. 564). One of these studies specifies that it was vine cover that especially characterized trees used by PR boas in El Yunque National Forest, since vines are important for gaining access to trees and provide dense cover for foraging and resting (Wunderle et al. 2004, p. 568).

Lastly, a more recent study within an urban fragmented karst landscape (i.e., Fort Buchanan US Army installation), described that in general, PR boas selected habitat with bigger vegetation clumps and with more canopy cover, litter depth, and woody material; and also preferred to be closer to or in larger and taller trees (Mulero-Oliveras 2019, p. i). Ultimately, PR boas in Fort Buchanan can persist in fragmented urban landscapes when suitable habitat is available, but preferred forest land cover over urban or grassland (Mulero-Oliveras 2019, p. i).

2.5 Activity and Spatial Ecology

The PR boa is considered mostly nocturnal, but can be seen basking during the day (Henderson and Powel 2009, p. 349; Mulero-Oliveras 2019, p. 23; Puente-Rolón 2012, p. 112; Puente-Rolón and Bird-Picó 2004, p. 349; Reagan 1984, p. 121). The PR boa can remain inactive for long periods of time and both sexes are more active during the reproductive period than during the non–reproductive period (Mulero-Oliveras 2019, pp. 26–27; Puente-Rolón and Bird-Picó 2004, p. 349; Reagan 1984, p. 122; Wunderle et al. 2004, pp. 566–567). One study found more juveniles during nocturnal surveys and more adults during diurnal surveys (Mulero-Oliveras 2019, p. 23). Also, adult PR boas found during the day were mostly female boas basking and most individuals (juveniles and adults) found during the night were moving (Mulero-Oliveras 2019, p. 23).

Only a few researchers have studied the home range of the PR boa. The average home range area for females and males within the Mata de Plátano Nature Reserve (karst forest landscape associated to a cave), was 0.79 ha (1.95 ac) and 0.50 ha (1.24 ac), respectively (Puente-Rolón and Bird-Picó 2004, p. 343); while a much larger home range was documented in El Yunque National Forest (rainforest landscape), that is, 10.3 ha (25.5 ac) for females and 13.3 ha (32.9 ac) for males (Wunderle et al. 2004, p. 561). Within Fort Buchanan (urban/karst forest landscape), average home range for females was 4.07 ha (10.1 ac) and 2.02 ha (5 ac) for males (Mulero-Oliveras 2019, p. 26).

In general, PR boas have smaller home ranges when associated to more productive habitats (e.g., concentrated food resources) like cave ecosystems (Puente-Rolón and Bird-Picó 2004, p. 349; Wunderle et al. 2004, p. 567). In areas where food resources are more dispersed or in lower densities, the PR boa needs larger home ranges (Puente-Rolón and Bird-Picó 2004, p. 349; Wunderle et al. 2004, p. 567). However, in urban landscapes (i.e., Fort Buchanan) research suggests that PR boas tend to have intermediate home range sizes that might be due to the scarcity and fragmentation of suitable habitat and the presence of other artificial barriers like roads (Mulero-Oliveras 2019, p. 33).

The home range of hard–released (no acclimation period) translocated PR boas has also been studied. One study in a karst forest landscape found no differences in microhabitat selection of resident versus translocated PR boas, but translocated boas moved more on average than resident snakes and had larger home ranges (Puente-Rolón 2012, p. 114). And at least one translocated male PR boa interacted with a resident female PR boa as evidenced by a copulation event (Puente-Rolón 2012, p. 113). Lastly, some of the translocated PR boas in Fort Buchanan were recaptured in their original capture location with days or months of their release (Mulero-Oliveras 2019, p. 34).

2.6 Life History

Although the actual life span of PR boas in the wild is unknown, Rivero (1998, p. 433) suggested they might live between 20 and 30 years. Also, there is a longevity reference of 23 years and 11 months for a PR boa in captivity (Henderson and Powell 2009, p. 349). The specific time for a PR boa to reach sexual maturity is also unknown, but its reproductive longevity is reported as high, with females still reproducing beyond 17 years of age or older (Tolson 1991, p. 100).

Courtship and mating of the PR boa is seasonal and reproduction appears to be mostly biennial in the wild (Huff 1978, p. 96; Tolson and Henderson 1992, p. 45; Tolson 1994, p. 355). Although there can be some variability on when the PR boa reproductive activity starts, research suggests that courtship for most *Chilabothrus* spp. starts in February (Tolson 1994, p. 355) and that mating for most PR boas is reported to occur at the beginning of the wet season, from late April to May (Tolson and Henderson 1992, p. 45). Young PR boas are born after a gestation period of approximately five to six months (Huff 1978, p. 97; Rivero 1998, p. 433). Puente-Rolón (2012, p. 85) reported PR boa courtship occurring between March and May, while most parturition occurs from August to November. Thus, the reproductive cycle of the PR boa is synchronized with the seasonal patterns of precipitation and temperature in Puerto Rico (Huff 1978, p. 96; Tolson and Henderson 1992, p. 45; Puente-Rolón 2012, p. 85).

Female PR boas do not lay eggs, but rather give birth to live young. The first recorded attempt to breed the species in captivity described that females with a minimum total length of 1.9 m

(5.24 ft) and approximate weight of 1,000 grams (35 ounces) were sexually mature and produced live young, while males were sexually mature at smaller sizes (Huff 1978, p. 97). In one study, gravid females ranged from 1.08 m to 1.85 m (0.26 ft to 6.06 ft) SVL, and the number of fetuses averaged 21.8 ± 6 per female (Wiley 2003, p. 190). Another study found gravid females averaged 143.9 cm SVL and gave birth to an average of 16.5 ± 6 live neonates (Puente-Rolón 2012, p. 82). In general, reported litter sizes for the PR boa range from 10 to 32 neonates (Huff 1978, p. 97; Joglar 2005, p. 144; Mulero-Oliveras 2019, p. 4; Puente-Rolón 2012, p. 80; Pérez–Rivera and Vélez 1978, p. 72; Tolson 1992, p. 171; Tolson and Henderson 1992, p. 45; Wiley 2003, p. 190) and approximately measure from 0.3 m to 0.4 m (0.98 ft to 1.31 ft) (Huff 1978, p. 97; Joglar 2005, p. 144; Mulero-Oliveras 2019, p. 4; Puente 2012, p. 82).

Based on the limited information available on the life stage-specific demographic rates for the PR boa, we elicited information from PR boa experts to help develop a basic life history profile for the species. For this SSA, we considered the PR boa to have four size-dependent life stages: young (<60 cm or 2 ft), juveniles (60–90 cm or 2–3 ft), subadults (90–110 cm or 3–3.6 ft), and adults (>110 cm or 3.6 ft). Also, we elicited information from the PR boa experts and available literature to describe the probabilities of annual survival, growth to the next size class, and fecundity (average number of offspring per individual) for each size class (Refer to Chapter 6.2 Demographic Matrix Model). At least within protected and prime habitat, adult PR boa survivorship is known to be high (Puente-Rolón 2012, p. 113). This information was used to build a model for the Future Condition section of this SSA (Chapter 6).

2.7 Abundance and Density

The PR boa was considered relatively rare by the 1900s (Stejneger 1904, p. 691) and is probably less abundant now than it was in Pre-Columbian times, when Puerto Rico had an extensive forest cover (Reagan 1984, p. 119). However, the PR boa is probably more abundant today than previously thought at the time of listing (USFWS 2011, p. entire), probably in part to the increase in forested areas in Puerto Rico (Lugo and Helmer 2004, p. 145; Kennaway and Helmer 2007, p. 356; Parés-Ramos et al. 2008, p. 1). In general, the species is more abundant in the karst region of northern Puerto Rico, and less abundant in the dry southern region of the Island

(Rivero 1998, p. 433). The northern karst belt covers an extensive region from parts of the municipality of Bayamón extending west towards the municipalities of Aguadilla and Moca.

The PR boa has cryptic coloration and habits, and attempting to determine a population estimate for this widely distributed species is challenging. In fact, the species is known to have a very low recapture rate (Mulero-Oliveras 2019, p. 24; Puente-Rolón 2012, p. 62, Tolson 1997, p. 5; Wunderle et al. 2004, p. 569), making mark and recapture estimates impracticable. Even when the observer knew the location of a radio–tagged PR boa, it was rarely visible (Mulero-Oliveras 2019, p. 27, Wunderle et al. 2004, p. 564). For example, Wunderle et al. (2004, p. 564) only visually detected an average of 15.3 percent of the radio–tagged boas. In addition, the few attempts to survey the PR boa do not reflect an island–wide estimate and are limited to specific areas on the northern half of the Island, thus inferences are made that the available estimates could be more or less the same across the species' range.

For example, in 1991, consultants conducted a study to determine the presence of the PR boa as part of the Costa Isabela development project in the coastal area between the municipalities of Isabela and Quebradillas (Lebrón Associates 1992, p. entire). Their surveys identified 45 PR boas and concluded there was an abundant population of boas, and that the species was widely distributed within their study area (Lebrón Associates 1992, pp. 45–46). This area has not been surveyed for the species since then. Another study suggested a larger population of PR boas than expected within the lowlands of El Yunque National Forest, documenting a total of 72 boas in the tabonuco (*Dacryodes excelsa*) forest from April 1997 to August 2001 (Wunderle et al. 2004, p. 569).

In the absence of sufficient recaptures for a reliable mark and recapture analysis, another PR boa survey yielded some density estimates based on direct counts and the number of boas encountered per man–hour (Tolson 1997, entire). This study found a total of 22 PR boas during four site visits. Eleven (11) of those were found within one transect karst area of 2,500 m^2 (Sabana Seca, Toa Baja), for a direct count density estimate of 44 boas/ha. The researcher specified that this estimate surpasses any other estimate described for Puerto Rico, except for the Culebrones Cave in the Mata de Plátano Nature Reserve (cover photo). For example, "a single cave may harbor more than 50 boas at any given time" (Puente-Rolón et al. 2013, p. 5). Ultimately, the more reasonable approach of a calculated per man hour estimate resulted in a general population estimate of 5.23 boas/ha within the haystack hills survey areas in Sabana Seca (Tolson 1997, p. 5). Another study using direct counts in transects within the same Sabana Seca area resulted in a similar estimate of 5.6 boas/ha within each of the three different habitat types where the species was found: karst hilltop (forested >65 years), old valley (30–40 secondary forest), and a valley that had been reforested just 13 months previous to the study (Ríos-López and Aide 2007, p. 40). In that study, no PR boas were found within the deforested valley (lawn area for >20 years) and karst hillside habitats (forested >65 years) (Ríos-López and Aide 2007, p. 40).

A more recent study within the urban landscape of Fort Buchanan documented a total of 50 live and 9 dead PR boas from 2013 to 2017 (Mulero-Oliveras 2019, p. 23). Thirty-eight (38) of the live individuals were used for the per man hour estimate of the PR boa population in Fort Buchanan, resulting in a general population density of 1.24 boas/ha, as well as 3.78 boas/ha within one karst forest fragment, considered a PR boa hot spot within Fort Buchanan (Mulero-Oliveras 2019, p. 24).

3.0 INFLUENCES ON VIABILITY

Influences on the PR boa viability will vary from location to location, but threats include habitat loss and degradation from development, predation and competition by exotic species, inadequate translocations, poaching and intentional killings, post–hurricane debris management, emergent disease (i.e., ophidiomycosis, formerly known as snake fungal disease) and potentially climate change. Positive influences on PR boa viability have been habitat protection, implementation of conservation measures during projects, and education.

3.1 Development and Habitat Protection

The PR boa occurs on both private and public land. Boas that occur outside of protected habitat may be more vulnerable to deforestation and land impacts mostly for commercial, industrial, highway, and urban development. In Puerto Rico, human activity has been described as "intense, pervasive, and fragments natural habitat" (Lugo and Helmer 2004, p. 156). And although forest areas have increased in Puerto Rico, unprotected forests are vulnerable to urban development, particularly those near or within urban centers (Kennaway and Helmer 2007, p. 376). One particular study on habitat loss found that that urban growth in Puerto Rico increased at a rate of 16 percent between the years 2000 to 2010 (Castro-Prieto et al. 2017, p. 476). By 2007, only about 5.2 percent of the Island was protected (Kennaway and Helmer 2007, p. 357). This later increased to 8 percent by September 2015 (Castro-Prieto et al. 2017, p. 474). By December 2016, there were 159 terrestrial protected areas in Puerto Rico or 16.1 percent of the Island, an increase mostly due to a broader definition of what a protected area is, which now includes the Restricted Zone within the Karst Special Planning Zone (Castro-Prieto et al. 2019, p. 54). Interestingly, the human population in Puerto Rico is decreasing, but development continues to increase around protected areas and island-wide (Castro-Prieto et al. 2017, pp. 476–478). In addition, protected areas in Puerto Rico are typically small, ranging from less than 1 km^2 to 115 km^2 (mean = 6 km^2) (Castro-Pietro et al. 2017, p. 474). As of December 2018, approximately 16.4 percent of terrestrial protected areas were classified as areas for conservation (PACAT 2018, online) including: Nature Reserves, State Forests, Wildlife Refuges (State and Federal), National Forest, Urban Forests, and lands under the Puerto Rico Department of Natural and Environmental Resources (PRDNER) Forest Legacy Program, among others (Appendix B; Ortíz-Maldonado et al. 2019, entire). However not all of these areas are occupied by the PR boa (e.g. it is not found on Culebra or Mona Island).

Consequences of human development on boa habitat include habitat loss and fragmentations as land is deforested for development (e.g., commercial, industrial, highway, and urbanization) and areas of suitable habitat are increasingly isolated from each other. Direct impacts on boas include: harassment, harm and mortality due to trampling with construction and vegetation clearing machinery, road kills, predation by domesticated and feral cats associated with human populations, competition with other exotic species (i.e., *Boa constrictor*), and persecution by the public and poachers (USFWS 2011, pp. 12–16). As PR boa habitat is modified and developed, it increases human-boa conflicts, thus exacerbating these direct impacts and also increasing the need to translocate PR boas out of harm's way (see Chapter 3.3 below). All of these factors have the potential to impact population resiliency by affecting its breeding and reproductive success, and limiting connectivity among suitable habitats.

Besides the Act, there are also Commonwealth laws and regulations (*e.g.*, Law 241 from 1999 and Regulation 6766) that promote the implementation of conservation measures and protective measures for the PR boa and its habitat. For example, although the PR boa has no critical habitat designated, Law No. 241 prohibits the modification of natural habitat without a mitigation plan approved by the PRDNER (USFWS 2011, p. 15). However, these measures are difficult to enforce. Moreover, there are actions and areas where PR boas occur where such regulatory mechanisms are not effective due to categorical exclusions, development of single lots, or other informal or unregulated development. Federal agencies are mandated to carry out programs for the conservation of endangered species under section 7 of the Act to ensure that any action authorized, funded or carried out by a Federal agency is not likely to jeopardize the continued existence of a federally listed species. Therefore projects with federal nexus provide for the implementation of conservation measures for the PR boa. Although the PRDNER has developed similar conservation measures to avoid and minimize potential effects of development projects on the PR boa, these measures are implemented with varying degrees of success and oversight (see also Chapter 3.3 Translocations). In addition, the fact that the PR boa is a cryptic species and difficult to detect, suggest that not all boas are detected in any given survey, thus, challenging to avoid and/or detect take of the species.

Fortunately, the PR boa occurs within several protected areas, for example, El Yunque National Forest, the largest reserve in Puerto Rico. The PR boa is also presumed to occur in all Commonwealth forests managed by the PRDNER (Rivera, PRDNER, 2019, pers. comm.) and although occurrence records are lacking for many of these areas, the PR boa has been reliably confirmed to occur within a few of these forests: Río Abajo, Guajataca, Camabalache, Vega, and Maricao (Appendix B). The species was also confirmed for the Guánica Commonwealth Dry Forest, but the only published PR boa records for that forest are from fossil records (Pregill 1981, p. 50) and another from 1974 (Wiley 2003, p. 190). Ultimately, PR boa records for the Gúanica Dry Forest are extremely rare (Canals, former PRDNER forest manager, 2019, pers. comm.).

This is consistent with the general description that the species is less abundant in the dry southern region of the Island (Rivero 1998, p. 433).

Within the karst region of Puerto Rico there is a large area with stricter land regulations named the Karst Restricted Zone designated by the Puerto Rico Planning Board (Appendix B; Ortiz–Maldonado et al. 2019, entire). This Zone represents 7.2 percent (647 km^2) of the total area of Puerto Rico, includes both public and private lands, and was designated as such for conservation purposes by prohibiting land exploitation of any type (Castro-Prieto et al. 2019, p. 59). The Puerto Rico Conservation Trust, through its unit *Para La Naturaleza* (PLN), also manages numerous protected natural areas throughout Puerto Rico where the PR boa has been confirmed as well: El Convento Caves, Cabezas de San Juan, Río Jacaboa, Río Encantado, Río Maricao, Hacienda La Esperanza, Cordillera Sabana Alta (Appendix B; Ortíz-Maldonado et al. 2019, entire). Other areas that are important for the PR boa are J.E. Monagas State Park, Mata de Plátano Nature Reserve (managed by the Inter American University of Puerto Rico), and El Tallonal Private Reserve (managed by the non-governmental organization Citizens of the Karst) (Appendix B; Ortíz-Maldonado et al. 2019, entire). Fort Buchanan as well is another privately managed land that is important for the PR boa and has an Endangered Species Management Plan in coordination with the Service and the PRDNER.

The occurrence of PR boa populations within areas designated for conservation is the most important positive influence towards species persistence and viability. However, research still highlights the need to permanently protect cave-associated areas that harbor PR boas (Puente-Rolón et al. 2013, p. 5). In addition, even within these protected areas, PR boas are still vulnerable to certain threats like road kill, intentional killings and cat predation, especially along the edges of forests close to human settlements. For example, a couple of studies have documented road kills within and outside El Yunque National Forest (Reagan 1984, p. 125; Wiley 2003, p. 189), with records as far back as the 1970s (Wiley 2003, pp. 191–192). PR boa deaths associated to roads and development continue to occur today, in some cases documented through social media and others through project consultation reports (Zegarra, USFWS, 2019, pers. comm.).

3.2 Exotic Species

One of the primary threats to the PR boa is the presence of exotic mammalian predators, namely cats (*Felis catus*) and mongoose (*Herpestes auropunctatus*). However, there is no specific data to accurately assess the level of impact of these exotic species on the PR boa population. Neonate and juvenile life stages are thought to be the most vulnerable to exotic predators and cats are thought to have a greater effect, since they hunt both by day and night. It is well known that Puerto Rico has a pervasive and unmanaged feral cat population associated to human settlements, even occurring within protected areas like in El Yunque National Forest (Engeman et al. 2006, p. 95) and Cambalache State Forest (Rodríguez-Velázquez et al. 2019, entire). Cats on islands are known to affect native vertebrates including reptiles such as the Jamaican boa, *Chilabothrus subflavus* (Medina et al. 2011, Appendix S1), the Virgin Island boa (*C. granti*) and the Mona boa (*C. monensis*) (Tolson 1996, p. 409). Domestic dogs are also known to kill PR boas.

Another introduced predator, the mongoose, does not appear to have caused serious losses to the PR boa population (Rivero 1998, p. 432). We do not disregard that a mongoose might occasionally eat a neonate or juvenile boa, but studies of mongoose food habits in Puerto Rico and throughout the Caribbean have not documented any such predation (Pimentel 1955, entire; Henderson 1992, entire). Remains of a dead PR boa were found once with tooth impressions consistent with mongoose depredation, but scavenging rather than predation was suggested (Wiley 2003, p. 193).

The relatively recent invasion of large snakes is also a concern. Possibly starting in the west side of Puerto Rico (Mayagüez) around the 1990s, there is currently a well-known and reproductively established population of *Boa constrictor* from a genetic lineage common to zoo and breeding collections (Reynolds et al. 2013b, entire). Researchers also suggest this species is spreading throughout the island facilitated by humans. In addition, there is an emerging population of the Reticulated python (*Malayopython reticulatus*), potentially the largest snake in the world (Reed and Rodda 2009, p. 75). These exotic snake species not only pose a threat to the PR boa populations, but are also considered a safety hazard for humans, especially the Reticulated python which is listed since 2015 as an Injurious Wildlife species under the Lacey Act (18 U.S.C. 42; 50 CFR Part 16). The potential specific risks associated with the PR boa population from these exotic snakes are competition for food resources, displacement, and may serve as vectors for pathogens or parasites. Exotic snake species also cause public confusion between which species are in need of conservation (native snakes) and which are not (exotic snakes). However, as with cats, there is no data to accurately assess the level of impact of these exotic snake species are having on the PR boa population.

There is also very little data to accurately assess the potential impacts of rodenticides on the PR boa. Since PR boas mostly feed on rats (refer to Chapter 2.2), boas are exposed to eating poisoned rats and its toxicants. The actual effects of anticoagulant rodenticides in reptiles are mostly unknown, but in general, reptiles seem to be more resistant to anticoagulant rodenticides than birds or mammals (Lettoof et al. 2020, p. 5; Lohr and Davis 2018, p. 8). In 1993, the Service included the PR boa in its Biological Opinion (BO) on *Effects of 16 Vertebrate Control Agents on Threatened and Endangered Species* (USFWS 1993, entire). In that BO, the Service concluded that the chance of exposure of the PR boa to certain rodenticides is considered minimal, but still a concern and recommended to prohibit the use of the some rodenticides within the known occupied habitat of the species (USFWS 1993, pp. II–36, 37, II–50, 51).

3.3 Translocations

For many years, the translocation of PR boas has been recommended and used as a management strategy to minimize conflicts with the public and minimize potential effects from development projects that disturb and modify PR boa habitat. It mostly consists of moving boas outside of the human–boa conflict areas into areas where these conflicts would be potentially reduced (e.g.,within suitable protected PR boa habitat). However, although this strategy has been used for a long time, implementation has been poorly documented. Critical information on how many, size class, when, how, and where these PR boas have been relocated is mostly unavailable and there is no information available on the condition nor on the survival of these animals or if they are being released within an appropriate setting (e.g., far from roads or other threats).

For example, one of the main concerns is that some PR boas captured for relocation are taken to the Cambalache Commonwealth Forest animal holding facility managed by the PRDNER (Puente-Rolón et al. 2013, p. 8). In 2019, the Service received information from visitors claiming that PR boas are not being adequately contained in these facilities and are being kept together with other exotic snake species. This is a biosecurity issue since exotic snakes may transmit diseases (e.g., ophidiomycosis) to PR boas that will be released into the wild (see Chapter 3.6). In addition, there are claims that the conditions where these snakes are being kept are not sanitary and safe for the PR boa. One study reported that in just 3 months (January to March 2012) at least nine PR boas were brought to the Cambalache facility (Puente-Rolón et al. 2013, p. 8). However, no records exist on the number of PR boas or other exotic snake species that enter the facility and what is being done with those individuals. This raises concerns about the impact these practices might have on wild PR boa populations, both in numbers being removed and in infectious diseases which might be introduced back into the wild. Recently the PRDNER Rangers office in Hormigueros has been coordinating with Dr. Puente-Rolón at the University of Puerto Rico (Mayagüez campus) for managing and euthanizing invasive species collected by them (Puente-Rolón, UPRM, 2020, pers. comm.), which should help better document these cases.

Despite inappropriate and poorly documented PR boa translocation practices, research has shown that translocation can work when conducted correctly (Puente-Rolón 2012, p. 116; Mulero-Oliveras 2019, p. 69) and "is not likely to disrupt any existing mitochondrial DNA phylogeographic structure" of the PR boa population (Puente-Rolón et al. 2013, p. 7). For example, the Fort Buchanan Environmental Division and Pest Control personnel maintain a record of PR boa sightings and translocations in their facility. They developed a protocol to capture and translocate PR boas that are found inside or around structures (houses and buildings) and construction sites. Captured boas are translocated to forested areas previously identified as boa habitat within Fort Buchanan. Although some PR boas tend to travel back to their original capture site, most boas would remain within their new transfer area. Thus, translocation strategies must consider the type and amount of habitat and its surroundings, and the distance to the location where the boa was found in order to minimize recapturing the snake in the same site (Puente-Rolón 2012, p. 116; Mulero-Oliveras 2019, p. 69). Management, research and education efforts in Fort Buchanan are examples of the positive influences on the PR boa viability and conservation. The US Forest Service (USFS) staff at El Yunque National Forest also successfully relocate live PR boas within the forest (Ilse, USFS, 2020, pers. comm.).

3.4 Poaching and Intentional Killings

The hunting of PR boas to extract their fat was reported since the 1930s due to the alleged medicinal properties of the snake "oil" (Grant 1933, 225; p. Rivero 1998, p. 433) and was identified as a factor contributing to the species' decline (Pérez-Rivera and Vélez 1978, p. 70). After conducting interviews with local people, other researchers report that the practice continued until the early 2000s (Reagan 1984, p. 119; Joglar 2005, pp. 162–163). In addition, one research reported a case in which snake meat was used for human consumption in the 1990's (Bird-Picó 1994, p. 35), and there are reports of PR boas collected to be kept as pets (Joglar 2005, p. 146). Based on the best available information, the practice of hunting or capturing PR boas may still occur, but probably to a lesser degree.

Killing of PR boas out of fear, religious prejudice, or ignorance is also considered a relatively common practice and may occur more than expected. However, most if not all of the available information on these killings is anecdotal and researchers have noted that there is no specific data to determine the level of impact this threat is having on the PR boa population (Puente-Rolón and Bird-Picó 2004, p. 343; Mulero-Oliveras 2019, p. 6). In addition, the influence of development and habitat destruction (Chapter 3.1) may also exacerbate killing of boas as it may increase human–boa interactions, especially if close to prime PR boa habitat. And even within protected habitat in El Yunque National Forest, one PR boa was recently found on a trail with its head chopped off (Ilse, US Forest Service, 2020, pers. comm.). Although both Federal and local laws and regulations currently prohibit killing the PR boa or commercial utilization of PR boas and their products, there are no reported cases in which law enforcement officials have intervened due to these incidents.

3.5 Hurricanes and Post–hurricane Restoration Actions

There is practically no information available on the potential direct effects of hurricanes on the PR boa. After Hurricane Georges in September 1998, one study found that some PR boas at El Yunque National Forest increased their movements and changed their habitat use, suggesting boas responded as expected to hurricane alterations in forest cover and prey distribution (Wunderle et al. 2004, p. 555). The same study suggested that hurricane damage (i.e., loss of leaves, vines and branches) may limit the arboreal use and movements of PR boas and suspected that Hurricane Georges may have caused one PR boa casualty in that forest (Wunderle et al. 2004, p. 569). Depending on the hurricane category and damages caused, we can expect that some PR boas, including adult and juvenile individuals, may die due to injury from falling debris or other unknown sources. For example, the category 4 Hurricane María in September 2017, caused more than 40,000 landslides in at least three–fourths of Puerto Rico's 78 municipalities (Bessette–Kirton et al. 2019, p. 4). Such landslides may have caused the death of PR boas in some areas.

In addition, more PR boa casualties were documented during post–hurricane restoration actions. For example, Hurricane Maria caused major damage to Puerto Rico's landscapes and infrastructure (e.g., electrical power grid) and left behind significant amounts of debris. Therefore, it was expected that infrastructure restoration (e.g., clearing or opening new right of ways), debris collection and disposal, and the associated reduction sites across the Island, would cause some impacts on this species. Projects with Federal nexus were evaluated through an emergency consultation under section 7 of the Act, and the proposed actions were expected to cause PR boa harm, specifically that boa individuals could be injured, crushed, and grinded, or transported from their usual habitat to other non–suitable habitats.

After the hurricane, we expected PR boas to move more than usual and that they would use debris piles for shelter, to find prey (rats) or even for basking especially along roads or forest edges. Although our emergency consultation process included PR boa conservation measures, debris management reports confirmed that PR boas were incidentally injured, killed and transported during post–hurricane debris management activities.

From November 2017 to February 2018, at least four PR boas were killed, at least six relocated, and three boas were handed to the PRDNER Rangers for relocation. Since PR boas are difficult to find, we suspect that more PR boas may have been killed during these actions. In addition, we do not know if the proposed conservation measures were being properly implemented across all sites. Moreover, since the consultation with the Service only covered projects with Federal nexus, it is likely that an unknown number of other hurricane–related restoration projects could have negatively impacted the species.

3.6 Emergent Disease

Initially observed in 2006, ophidiomycosis (formerly known as snake fungal disease and likely caused by the fungal pathogen *Ophidiomyces ophiodiicola*) is considered an emerging disease that by 2015 had been documented in both wild and captive snakes throughout most of the eastern United States, and it is known to have the potential to cause lethal infections and contribute to local extinctions of snake populations (Lorch et al. 2016, p. 2). Signs of ophidiomycosis include crusted, ulcerated and discolored scales, nodules under the skin, and swollen or disfigured face, leading to emaciation and death (McKenzie et al. 2019, p. 142; Thompson et al. 2018, p. 1), while secondary effects from the disease may include starvation, poor body condition and bacterial infection, possibly leading to mortality (Lorch et al. 2016, pp. 4–5; McKenzie et al. 2019, p. 142). Also, behavioral changes in infected individuals may include abnormal or excessive molting, decrease in activity, increase in basking, frequency in ecdysis (shedding of skin) and abnormal behaviors such as anorexia and basking in open and conspicuous areas which can increase the risk of mortality (Lorch et al. 2016, pp. 4–5; Thompson et al. 2018, p. 2).

Ophidiomycosis was recently confirmed for the PR boa population within Fort Buchanan (Allender et al. 2019, p. 20). Out of seven live PR boas sampled, one resulted in an apparent ophidiomycosis category, that is, it tested qPCR (quantitative Polymerase Chain Reaction DNA detection) positive and showed clinical signs (dermal lesions). Other samples from three PR boas, also from Fort Buchanan, were categorized as possible ophidiomycosis, that is, showing clinical signs, but qPCR negative. This is the first report of ophidiomycosis in Puerto Rico and in an endangered boa species (Allender et al. 2020, p. 5).

A particular concern is that this disease may be underreported in populations where it affects snakes infrequently or in species that develop less severe symptoms (Thompson et al. 2018, p. 1), which may be the case of the PR boa. Additional samples and information are needed in order to establish baseline information of this disease in Puerto Rico and its effect on the PR boa population. The Service is currently sponsoring a study on this effort.

3.7 Climate Change

The Intergovernmental Panel on Climate Change (IPCC) concluded that warming of the climate system is unequivocal (IPCC 2014, p. 2). 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 historical averages (Carter et al. 2014, entire; Knutson et al. 2010, entire). This is consistent with the predicted scenario of a gradual trend towards a dryer and hotter climate for Puerto Rico (Henareh et al. 2016, entire; Bhardwaj et al. 2018, entire).

Research suggests that the PR boa's reproductive cycle is synchronized with the seasonal patterns of precipitation and temperature in Puerto Rico (Huff 1978, p. 96; Tolson and Henderson 1992, p. 45; Puente-Rolón 2012, p. 85) and climate variations may vary availability of prey such as rats (Puente-Rolón 2012, p. 89). Thus, there is potential for climate change to alter certain critical aspects of the biology of the PR boa, for example, potentially reduce fitness and change the reproductive activity of adults. The PR boa habitat is also expected to change with the predicted shifts of the life zones, for example, shifting from rain, wet, and moist zones to drier zones (Henareh et al. 2016, p. 265), and thus, potentially reducing the PR boa available suitable habitat. In general, from coastal and lowland forests, to karst and lower montane forest, all are susceptible to one or more climate change stressors such as sea level rise, increased severity of storms (i.e., hurricanes), increased droughts, and higher temperatures (PRCCC Working Group 2 2013, pp. 157–168).

Species that are dependent on specialized habitat types, limited in distribution, or at the extreme periphery of their range are most susceptible to the impacts of climate change (Byers and Norris 2011, p. 22). However, this does not seem to be the case of the PR boa, considered a habitat generalist (Reynolds et al. 2016, p. 1883) with a wide distribution (see Distribution Chapter 2.3). In general, there is no certainty regarding the direction, magnitude and timeframe of any particular climate change impacts on the PR boa. The exact response of the PR boa to climate change is beyond this assessment. Several suggestions have been made though, for example, that climate change will cause an increased physiological stress on the PR boa and may exacerbate the species response to pathogenic infections (Puente-Rolón, pers. comm., in PRCCC Working Group 2 2013, p. 162). Climate change effects have also been suggested to affect the species' dispersal behavior, increase its feeding frequency, reduce the availability of prey, and increase water loss, further threatening the survival of the PR boa (PRCCC Working Group 2 2013, p. 162). Lastly, although sea-level rise is not specifically mentioned as a potential threat to the PR boa (PRCCC Working Group 2 2013, p. 164), we expect sea-level rise to reduce available coastal habitat where the species occurs, for example, within coastal mangrove forests. Sea-level rise projections for Puerto Rico are between 0.4 m to 1 m by year 2100 (PRCCC Working Group 2 2013, p. 67).

4.0 SPECIES NEEDS FOR VIABILITY

4.1 Individual Level

At the individual level, the PR boa requires suitable foraging and resting habitat to flourish during each life stage from birth to adulthood, and to successfully reproduce. Suitable habitat contains a diverse combination of forested landscapes and microhabitats, interconnected trees to facilitate arboreal movements, prey densities to support survival, growth, and reproduction; and underground (caves), terrestrial and arboreal niches that provide shelter, feeding, and basking options, particularly for gravid females. Individual boas are susceptible to mortality from habitat destruction, predators such as cats, human persecution, and road mortality. Also, other exotic snake species could be reducing the individual overall health of PR boas as they compete for resources, as well as translocation practices that may be influencing the survival of individual PR boas.

4.2 Population Level

For a resilient population to persist, the needs of individuals (foraging and suitable habitat, adequate prey base) must be met at a larger scale. Habitat connectivity must be adequate not only for an individual's foraging needs, but to connect individual boas to a larger interbreeding group. While the PR boa can persist in co–occurrence with humans and exotic predators like cats, the most resilient populations are expected to occur the farthest away from human settlements, recreational areas and where exotic predators are few or absent.

4.3 Species Level

For the species to be viable, there must be adequate redundancy (i.e., occurrences, 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 persistence of interbreeding groups distributed across the species range, and connectivity (either natural or human-facilitated) that facilitates PR boa movements to connect with each other after catastrophes. Representation improves with increased genetic and/or ecological diversity within and among interbreeding groups. Long-term viability of the species will require resilient interbreeding groups in locations that are protected to withstand present and future effects of known or new threats. See Figure 4 below for a summary of how the discussed biological needs and external influences impact the PR boa viability.

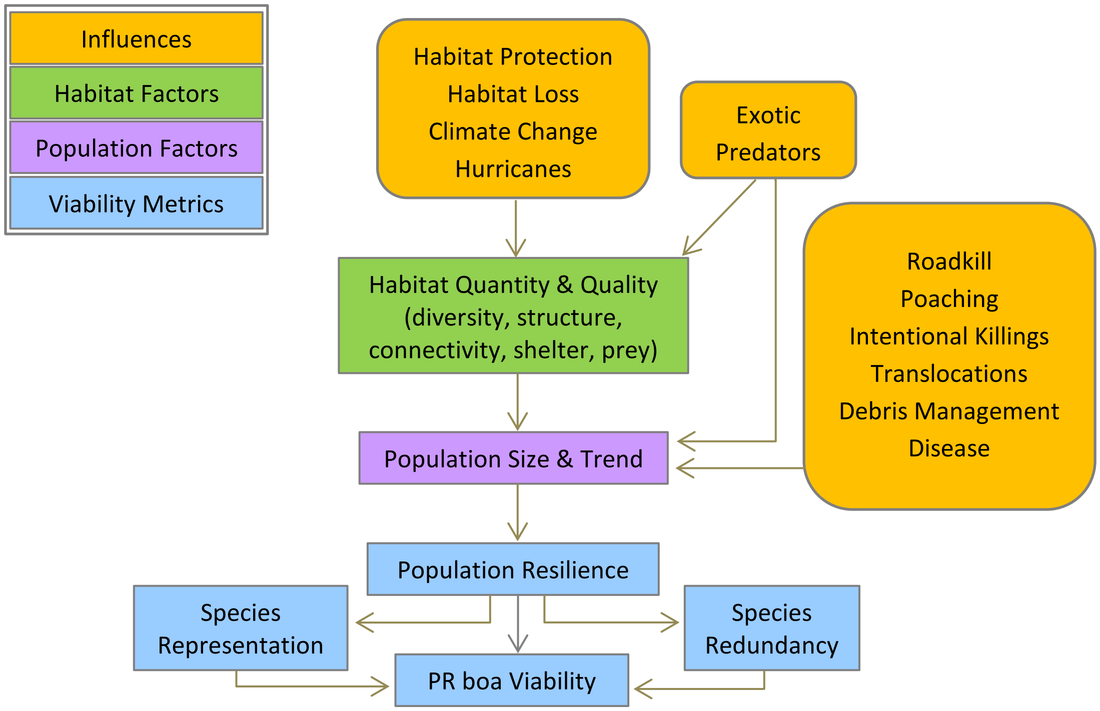


Figure 4. Summary of key habitat factors, population factors, and influences on viability used to assess resilience, redundancy, and representation for the PR boa.

5.0 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. For this SSA, we considered one island-wide PR boa population for Puerto Rico. This population may function more as several interbreeding groups occurring within certain habitat patches or landscapes that may or may not interact at different levels (low to high) via natural or human–facilitated dispersal (e.g., translocations). In addition, research suggests that no distinct populations or lineages have been identified for the PR boa, and mountain ranges are not necessarily considered barriers to prevent gene flow (Puente-Rolón et al. 2013, p. 7). Lastly, there is only one confirmed occurrence of a PR boa in Vieques and another in Culebra, so these offshore islands are not being considered as additional separate populations (refer to Chapter 2.3 Distribution). Analyzing one population unit for this SSA is consistent with experts' opinions for analyzing the PR boa's viability. For example, it was described that historical clines in the population structure (genetic, morphological, intraspecific behavior) no longer exist (Bird, UPRM, 2018, pers. comm.). In addition, the artificial movement of boas through intentional releases has introduced a diversity of alleles across Puerto Rico, and today PR boas are a homogenous population with high genetic diversity (Puente, UPRM, and Reynolds, UNCA, 2018, pers. comm.).

5.2 Current Resilience

For the PR boas to maintain its viability, its population must be able to withstand stochastic events (e.g., demographic, environmental, anthropogenic). To be resilient to stochastic events, this species needs an adequate number of individuals (abundance) from all life stages (breeding adults, juveniles, and hatchlings). The population extent should be large enough such that localized events do not cause extirpation. We used a projected PR boa population abundance and density across its entire range, and adult survival rates as the primary indicators of resilience for the species, because these are positively related to resilience (USFWS 2016, p. 10). We also used quasi–extinction risk as a measure for future resilience (Chapter 6.4) under different scenarios. In general, the higher the projected abundance and survival rates, and the lower the risk of quasi–extinction, the higher the resilience of the PR boa.

Based on the available information we can initially provide a qualitative resilience description for the island-wide PR boa population. Prior to Puerto Rico's historical deforestation, the PR boa probably occurred in almost all habitats below 500 m elevation (Puente-Rolón et al. 2013, p. 7). Based on the available information, it was recently suggested that the PR boa "… is widely considered to have recovered from the near-complete deforestation of the island of Puerto Rico in the early 20th century (Reynolds and Henderson 2018, p. 13)". This alone suggests that the PR boa population is able to withstand certain levels of natural and anthropogenic disturbances through long periods of time. Recent research also suggest that PR boa populations can persist in urban fragmented landscapes even in low densities, but not without certain costs, for example, smaller home range sizes, decreased abundances and higher exposure to threats (Mulero-Oliveras 2019, pp. 58–59).

In the absence of a precise island-wide abundance for the PR boa, we assessed the population's resiliency by using the available density estimates (1.2 to 5.6 boas/ha) in combination with the species' PRGap predicted habitat model (Figure 3 and Appendix A–2; Gould et al. 2008, p. 50). This would allow the calculation of a rough estimate of an island–wide PR boa potential population size. The PRGap predicted an estimated 414,379 ha of PR boa habitat, that is, 46.3 percent of the Island from sea level to 1,000 m (3,281 ft) (Figure 3 and Appendix A–2; Gould et al. 2008, p. 50). We used this as our baseline model to assess the variability of the quality of habitats available for the PR boa across Puerto Rico. Since there are no clear records of PR boas above 700 m (2,297 ft), we reduced the PRGap model and only considered areas below 700 m (2,297 ft) as predicted suitable habitat, resulting in an estimated 379,029 ha (936,601 ac) of predicted PR boa habitat.

We used this resulting raster dataset (reduced PRGap model) to assess the total area of available habitat, which was then used to estimate minimum and maximum bounds for the current and maximum population sizes. We were also interested in determining the proportion of habitat that fell in developed and urban areas, as experts believed PR boas experience different pressures in those areas. We used a raster dataset developed by Martinuzzi et al. (2007, p. 294) to determine the proportion of suitable habitat falling within developed areas (Figure 5).

The researchers used remote sensing data and information from the U.S. Census Bureau to define three land use types: urban, densely–populated rural, and sparsely–populated rural. Human conflicts with snakes is a key threat to this species, so we considered habitat within sparsely populated areas to be "natural" (i.e., minimally disturbed), and habitat within either urban or densely populated areas to be "developed" (Martinuzzi et al. 2007, pp. 293–294). Of the estimated 379,029 ha (936,601 ac) of suitable PR boa habitat, 43 percent falls within developed areas and 57 percent within "natural" areas (Figure 5). Since PR boas are not uniformly distributed within the predicted habitat, and we do not know how many individuals occur within each particular area of the predicted habitat, we used a conservative approach and combined the reduced predicted habitat with a rough initial population size estimate to assess the current resiliency of the PR boa population. The lowest recorded density estimate is 1.24 boas/ha for the area of Fort Buchanan (Mulero-Oliveras 2019, p. 24), considered an urban and fragmented habitat. Using a conservative approach and assuming a lower density range of 0.1 to 0.5 boa/ha (i.e. 10 percent of the current density estimates) across all available habitat, would account for variations in density, habitat quality and threats across the entire Island (i.e., conservative approach). Thus, with this lower density range, we intend to capture uncertainties related to differences in population size across the different landscapes, and any other uncertainties related to, for example, how the population would respond to certain threats and the degree to which threats are acting in different areas. At least within protected and prime habitat, adult PR boa survivorship is known to be high (Puente-Rolón 2012, p. 113).

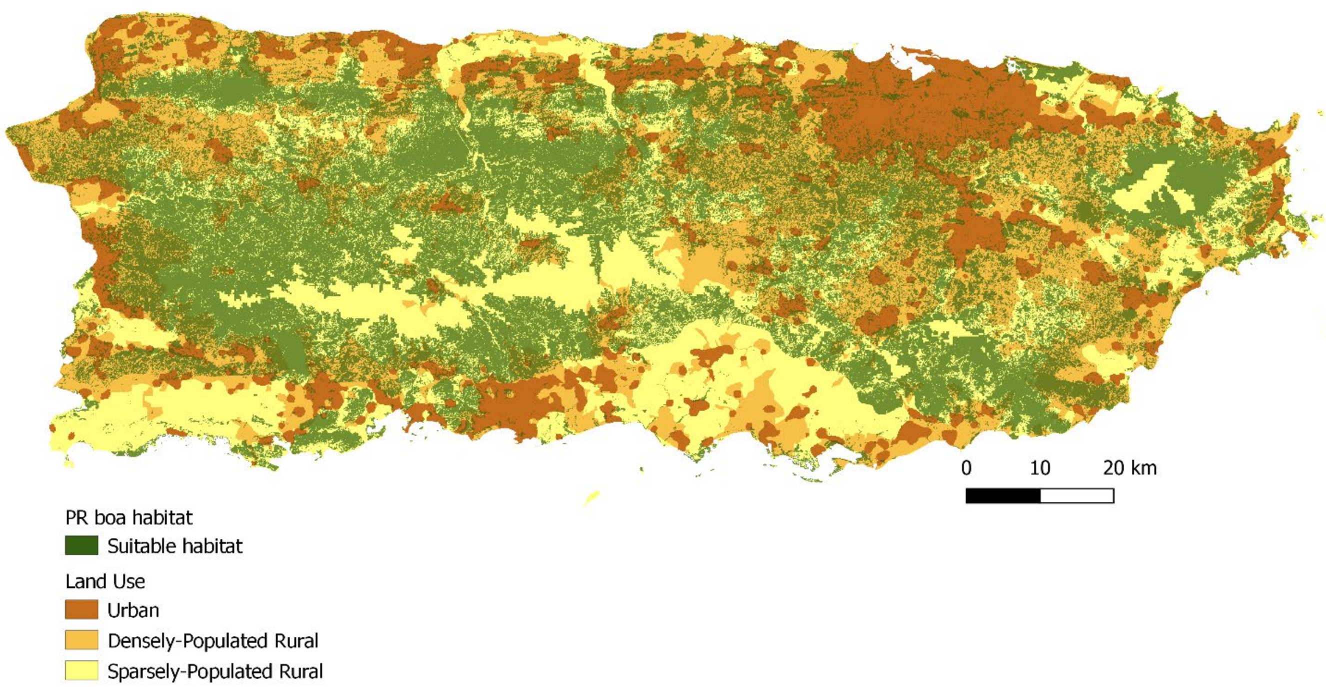


Figure 5. Habitat availability for Puerto Rican boas. Suitable habitat (green) was based on the PRGap Analysis and only includes pixels at less than 700 m (2,297 ft) elevation. Land use raster based on remote sensing and U.S. Census Bureau data was used to determine the proportion of habitat falling within developed (urban and densely-population rural; 43 percent) versus natural (sparsely-populated rural; 57 percent) areas (Martinuzzi et al. 2007).

Based on the above, the resulting current initial population size of the PR boa could range from 37,903 to 189,515 boas (0.1 and 0.5 boa/ha multiplied by 379,029 ha of PR boa suitable habitat) for the entire Island. Knowing PR boas occur in higher densities in some areas, the 37,903 number can be used as the current lower end rough estimate of the amount of PR boas in Puerto Rico. This range of initial population size was then used to present the future projections results as the change in population size for the first year (refer to Future Condition Section 6).

Using the lower end estimate combined with the known species high adult survival rate, we assigned a medium-high current resilience to the PR boa population. That is, the PR boa population has a medium-high ability to withstand stochastic events (demographic, environmental, and anthropogenic). We could assume that the most resilient interbreeding groups occur where suitable habitat and resources are least fragmented, occur the farthest from human settlements, and where exotic predators are few or absent. This is a reasonable assumption given our understanding of the ecology of the species.

5.3 Current Redundancy

Redundancy reduces the species' extinction risk if a portion of the species' range is negatively affected by a natural or anthropogenic catastrophic disturbance. For the PR boa to withstand catastrophic events such as hurricanes, it needs to have an overall resilient population across its range. Thus, we mainly used the geographic distribution from the predicted potential habitat and other sources to assess redundancy. The exact historicaldistribution (redundancy) of the PR boa is unknown, but their present seemingly fragmented distribution suggests that they occupied more areas than their current range, which may have been subject to localized extirpations mostly due to habitat degradation and human persecution.

Since only one PR boa population is being considered for this SSA (refer to Section 5.1 Delineating Populations), its redundancy is inherently low, but with a medium–high resiliency across the species' entire distribution. The wide distribution and the presence of suitable habitat throughout its range reduces the risk that any large portion of the species' range will be negatively affected by any catastrophic or anthropogenic event at any one time (USFWS 2016), except for hurricanes which can have island wide effects.

Given the amount of suitable habitat available for the PR boa (Figure 5), the species would seem well buffered against the effects of catastrophic events. Catastrophic events that could affect a particular PR boa habitat include but are not limited to hurricanes, and emergence of new threats like snake fungal diseases. We previously discussed the hurricane and post-hurricane effects on the species (refer to Chapter 3.5), thus, an increase in the frequency of these types of events may reduce the species resilience in the future. The vulnerability of the PR boa habitat to a hurricane is well illustrated by the path of Hurricane Maria in 2017 (Appendix C). The entire range of the PR boa was subjected to hurricane force winds (>64 knots or >74 miles per hour) as the hurricane passed mostly as a Category 4 hurricane over the Puerto Rico mainland. Despite direct impacts from past and more recent hurricanes, and post-hurricane debris management on the species habitat, the PR boa continues to be reported throughout its range.

In an attempt to increase the documented confirmed accounts for the distribution of the PR boa, we used the same approach as the PRGap to collect occurrence records (Figure 3 and Appendix A–1), and included records since 1990 from unpublished reports, online databases, social media, and a few from PRDNER and USFWS biologists. If an additional PR boa occurrence record was confirmed for a probable hexagon in the PRGap model, we then changed the category of that probable hexagon (Figure 3 and Appendix A–1) to a confirmed hexagon. The resulting exercise added an additional 61 confirmed occurrence hexagons (Figure 6) to the 19 presented by the PR Gap in 2008 (Figure 3 and Appendix A–1), thus increasing the total confirmed PR boa occurrence hexagons to 80 (80 out of 422; 18.9 percent; Figure 6). Only four of those hegaxons were added as confidently assumed to occur within and surrounding areas of the Guajataca Commonwealth Forest, and Río Encantado and El Convento Caves Natural Protected Areas (Appendix B). The hexagon added in Vieques is considered unexpected, as it is the first confirmed PR boa report for that island from 2010 (Barandiaran 2014, USFWS, pers. comm.). However, based on the available information, it is unlikely that there is a PR boa population in Vieques (see Distribution Chapter 2.3).

Based on the above, since only one PR boa population is being considered but with a medium–high resiliency across the species' entire distribution, we assign a medium current redundancy for the PR boa population. The available information suggests that the current distribution for this island wide population is considered somewhat fragmented due to habitat degradation and that the species is thought to have been more widely distributed across most of the Island, particularly before the 1900s.

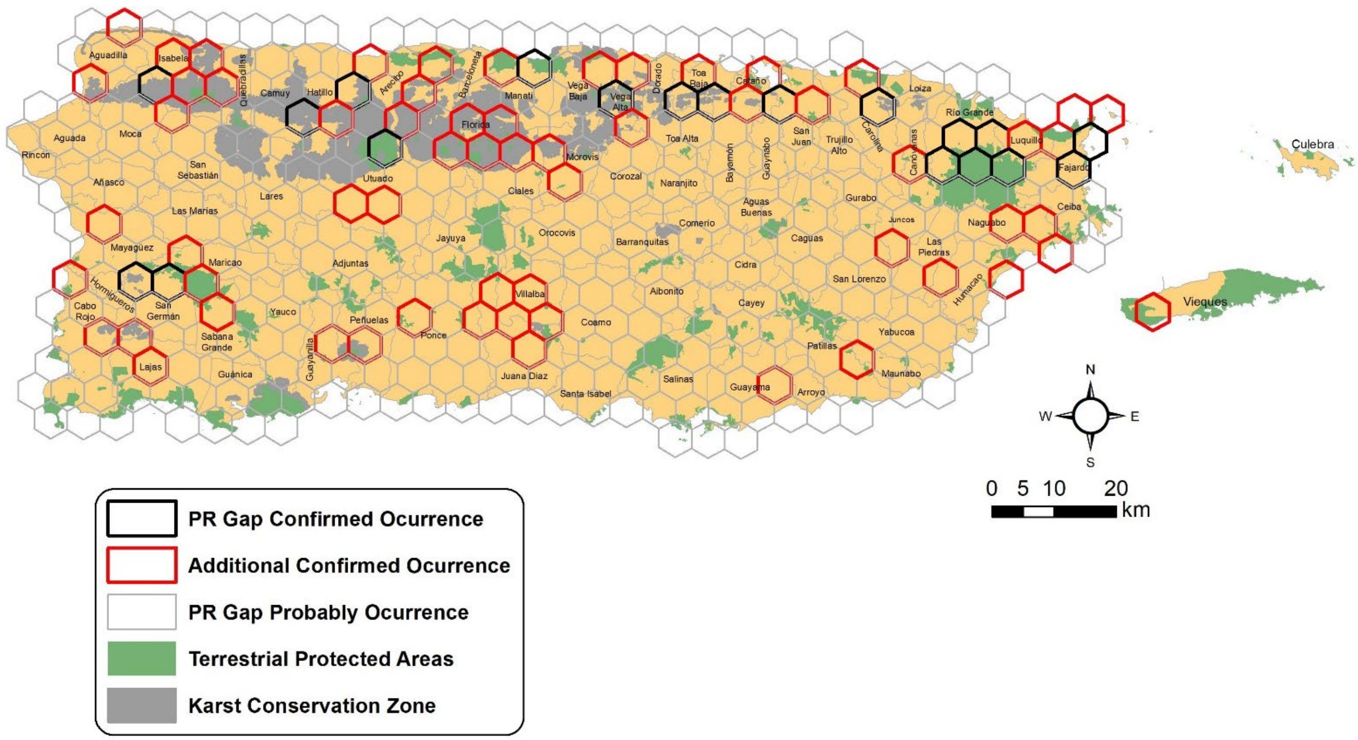


Figure 6. Additional (red) and previous (black) PRGap occurrence hexagon records for the PR boa (modified from Gould et al. 2008, p. 49) and terrestrial protected areas in Puerto Rico. Refer to Appendix A–1 for the original PRGap hexagon map and Appendix B for original protected areas of Puerto Rico map (Ortíz-Maldonado et al. 2019, entire).

5.4 Current Representation

Representation describes the ability of a species to adapt to changing environmental conditions over time, and is characterized by the genetic structure of the species and the environmental diversity within and among populations (USFWS 2016, p. 10). The more representation, or diversity, a species has, the more it is capable of adapting to changes (natural or anthropogenic) in its environment. Thus, to measure representation for the PR boa, we used the available species–specific genetic information. In addition, the ecological variability of the PR boa was previously described in the Habitat Chapter 2.4 of this SSA.

The genetics of the PR boa had not been assessed until recently. With a total of 86 samples from 15 municipalities (not the entire range) in Puerto Rico, researchers identified three clear haplogroups and no distinct phylogeographic structure across the island; which suggest a relatively high level of genetic diversity within the areas sampled, and an overall high haplotype diversity (Puente-Rolón et al. 2013, p. 7). In addition, and although not genetically different from PR boas that occur in other habitats, this study emphasized the conservation of caves, as they harbor multiple genetic lineages and represent a large proportion of the genetic diversity of PR boas (Puente-Rolón et al. 2013, p. 5).

Additional genetic samples have been analyzed and researchers reiterate on the importance of conserving caves used by the PR boa; specify that PR boas move widely across Puerto Rico (both naturally and human–facilitated); suggest that PR boas have declined both in numbers and genetic diversity; and that the northern karst region contains the greatest genetic diversity for the PR boa (Reynolds and Puente-Rolón 2014, p. 1). Lastly, the results also showed that at least one location in the north (municipality of Dorado) may have reduced gene flow and may be experiencing genetic drift, potentially due to habitat fragmentation or isolation and possibly affecting the species ability to naturally disperse (Puente-Rolón et al. 2013, p. 6). This may be the case for other areas where genetic samples were not obtained and where the species may occur within similar fragmented landscapes.

The available genetic studies have not yet indicated that critical genetic differences currently exists across the range of the PR boa, for example, no evolutionary significant units nor unique genetic clusters were identified for the species (Puente-Rolón et al. 2013, entire). In addition, there is no evidence that any genetic abnormalities have emerged nor that overall fitness of the PR boa population has decreased. Moreover, although the PR boa occurs in a wide range of ecological conditions, areas like the northern karst forests and El Yunque National Forest represent some of the most important habitats for the species. Thus, maintaining the species broad distribution across its range would help to retain the species' adaptive potential and current representation.

Although the entire species range has not been genetically sampled, and there are reports of some reduced gene flow in certain areas, overall, the PR boa population seems well represented across the species range. Based on the above and the species medium–high resilience and medium redundancy across the species range and ecological gradients, we assign a high representation for the PR boa population.

6.0 FUTURE CONDITION

6.1 Future Considerations

To assess the future viability of the PR boa, we used a demographic matrix model and projected the overall population response to four different habitat change scenarios 30 years into the future. These four scenarios provide a range of viability predictions for the species and are intended to represent PR boa population response to key threats such as habitat loss, fragmentation, and human interactions. These habitat and human related influences can be related to increased development, conversion of natural areas into urban areas for residential and commercial development, road construction and expansion (roadkill), and even development for energy purposes. Human caused habitat loss can also be related to other threats such as increased need for translocations, human-boa conflicts and intentional killings, and predation by cats (refer to Chapter 3.1).

Based on the available information, potential future impacts that we do not explicitly consider include hurricanes, emergent diseases, genetics and climate change impacts directly on the boas or their habitat. Each of these is explained under the influences on viability Chapter 3, where the information available is uncertain or there is not enough information to assess the specific impacts these will have in the future scenarios on the viability of the PR boa population. However, and although the species currently has adequate representation, it is important to recognize that increased urbanization is also likely to have genetic implications on the PR boa population, as habitat fragmentation may reduce gene flow (Puente-Rolón et al. 2013). Also, climate change is expected to at least degrade the quality of available habitat (Refer to Chapter Climate Change), while hurricanes and diseases may lower species resilience as well.

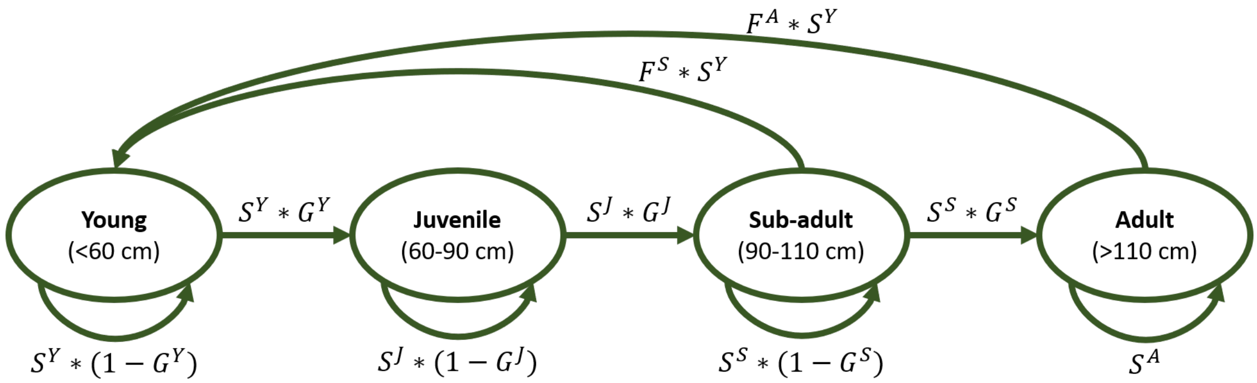
We predicted resilience at 30 years into the future (2050) considering: input from species experts; and the information available to reasonably predict changes into the future. This time frame reflects multiple generations of PR boas, which may live past 20 years (Rivero 1998, p. 433, Henderson and Powell 2009, p. 349).

Our Future Condition models were developed by Tucker et al. 2020 (entire) for the purposes of this SSA. The following sections were taken directly from the Tucker et al. 2020 (entire), peer-reviewed paper. In some instances, we provided brief descriptions of the methodologies used for model development. For a full description of the models, see Tucker et al. 2020 (entire).

6.2 Demographic Matrix Model

We used a stage-based Lefkovitch matrix model (Caswell 2001, pp. 56–109) that groups individuals into stages based on size (Figure 7). This model was chosen to represent the growth and maturation process because it allows us to account for stage–specific differences in survival and reproductive output into the future. We considered four life stages based on size: young (<60 cm or 2 ft), juveniles (60–90 cm or 2–3 ft), subadults (90–110 cm or 3–3.6 ft), and adults (>110 cm or 3.6 ft). We elicited the probabilities of annual survival, growth to the next size class, and fecundity (average number of offspring per individual) for each size class from the expert team or drew values from the available literature (Table 1). The experts used personal information, unpublished data and inference from captive zoo populations to determine productivity and survival rates. The experts also directed us to graduate theses and dissertations that were completed but not widely available through literature searches (Puente-Rolón 2012, entire, Mulero-Oliveras 2019, entire).

The probabilities of transitioning between size classes was determined by estimating the length of time spent in each age class. For example, PR boa experts believed that snakes remained in the juvenile age class for slightly less than two years on average, so the mean transition rate from juvenile to sub-adult was 0.55 (Table 1). In other words, 55 percent of the animals in the juvenile age class transitioned to the subadult stage in each year.



$$\begin{bmatrix} N_t^Y \\ N_t^J \\ N_t^S \\ N_t^A \end{bmatrix} = \begin{bmatrix} S^Y * (1 - G^Y) & 0 & F^S * S^Y & F^A * S^Y \\ S^Y * G^Y & S^J * (1 - G^J) & 0 & 0 \\ 0 & S^J * G^J & S^S * (1 - G^S) & 0 \\ 0 & 0 & S^S * G^S & S^A \end{bmatrix} x \begin{bmatrix} N_{t-1}^Y \\ N_{t-1}^J \\ N_{t-1}^S \\ N_{t-1}^A \end{bmatrix}$$

Figure 7. Life cycle and stage–based matrix model for the Puerto Rican boa, based on an annual time step and pre-breeding census. In each time step, the probabilities of survival are denoted using the letter *S*, probabilities of growth from one stage to the next is denoted *G*, and the average fecundity (number of offspring produced per individual) is denoted *F*.

Table 1. Stage–specific demographic rates. Average values were determined by the expert team or drawn from the available literature.

Demographic rate	Stage	Model input (SD)	Rationale
Survival (*S*)	Young of the year (S^Y)	0.3	Expert opinion, informed by studies of Cuban boa[a]
	Juvenile (S^J)	0.9	Expert opinion
	Subadult (S^S)	0.72	Expert opinion – survival of this stage is lower than the juvenile or adult stage because individuals begin dispersing widely and face more threats

	Adult (S^A)	0.9	Expert opinion and estimates from radio–tracked snakes[b]
Growth (G)	Young to Juvenile (G^Y)	0.67	Expert opinion – approximately 2/3 of the young of the year grow enough to become juveniles in the next year.
	Juvenile to Subadult (G^J)	0.55	Expert opinion – juvenile stage typically lasts two years
	Subadult to Adult (G^A)	0.25	Expert opinion – subadult stage typically lasts four years
Fecundity (F)	Subadult (F^S)	2	Expert opinion – some larger subadults may breed, but with a much lower breeding probability
	Adult (F^A)	4.5	Average clutch size is 18 (range = 12–32)[b,c] This clutch size is multiplied by 0.5 because only females produce young (assumes a 50:50 sex ratio) and multiplied by 0.5 again because females reproduce biennially[d]

[a]Tolson, Toledo Zoo, 2018, pers. comm.; [b]Puente-Rolón 2012, pp. 80 & 113; [c]Tolson 1992, p. 171; [d]Huff 1978, pp. 96–97.

We used the stage-specific estimates of survival and growth (Table 1) to calculate the transition rates in the diagram and matrix in Figure 7. For example, the probability that a young of the year in year *t* will become a juvenile in year *t+1* is equal to the probability of surviving the year ($S^Y = 0.3$) multiplied by the probability of growth from young to juvenile ($G^Y = 0.67$).

$$S^Y * G^Y = 0.3 * 0.67 = 0.2$$

The probability of a young of the year remaining in the young stage is equal to the probability of surviving the year (S^Y) and *not* growing enough to reach the juvenile stage ($1 - G^{YJ}$).

$$S^Y * (1 - G^Y) = 0.3 * (1 - 0.67) = 0.1$$

The transition rates for each stage were calculated following this framework. The realized fertility rates (F^S and F^A) in the matrix model are calculated by multiplying the estimated reproductive output for each stage class by the survival rate of neonates, which was estimated as 0.3 (*i.e.*, new young of the year must survive one year before entering the population).

These transition rates are summarized in a matrix (Appendix D):

$$\begin{bmatrix} N_t^Y \\ N_t^J \\ N_t^S \\ N_t^A \end{bmatrix} = \begin{bmatrix} 0.1 & 0 & 0.6 & 1.35 \\ 0.2 & 0.41 & 0 & 0 \\ 0 & 0.50 & 0.54 & 0 \\ 0 & 0 & 0.18 & 0.9 \end{bmatrix} x \begin{bmatrix} N_{t-1}^Y \\ N_{t-1}^J \\ N_{t-1}^S \\ N_{t-1}^A \end{bmatrix}$$

For each projection we assumed that the population started at the stable stage distribution, calculated using the popbio package for R (Stubben and Milligan 2007, entire; R Core Team 2016, unpaginated). The stage distribution is the proportion of the population in stage class, and most populations will converge on a stable stage distribution if demographic rates remain relatively constant for a sufficiently long time (Caswell 2001, pp. 56–109). Before reaching the stable stage distribution, the population may exhibit erratic growth patterns that are an artifact of the stage imbalance. By starting the population projection at the stable stage distribution, we sought to minimize these effects.

6.2.1 Uncertainty and Temporal Variation in Demographic Rates

At the PR boa expert meeting, the team approximated the average value of each demographic rate, but we did not conduct a formal elicitation to obtain estimates of uncertainty in those estimates (Burgman 2005, pp. 62–124). To incorporate uncertainty in our estimates of the average demographic rates, we assumed that the error in our mean estimate was 15 percent of the average value approximated by the team. For example, the team estimated average adult survival probability as 0.9, so we assumed a standard deviation of $0.9 * 0.15 = 0.135$. For each transition probability from one life stage to the other, we randomly drew an average value for each iteration from a Beta distribution, using the method–of–moments method to calculate the shape parameters. For the fecundity rates, we randomly drew an average value from a Log–normal distribution. Refer to the table in Appendix D that specifies the transition rates used in the population matrix derived from Table 1.

An additional variation was incorporated into the model because realized demographic rates often vary annually based on stochastic variation in environmental conditions. Thus, to allow for temporal variation in realized rates, we assumed the standard deviation in realized annual rates was 15 percent of the mean. We used these replication–specific mean and standard deviation to define the distributions from which annual rates were drawn. Transition probabilities were drawn from a Beta distribution and fecundity rates were drawn from a Log-normal distribution. Refer to the following Figure 8 for an example of how the uncertainties and temporal variation in demographic rates were incorporated into the model.

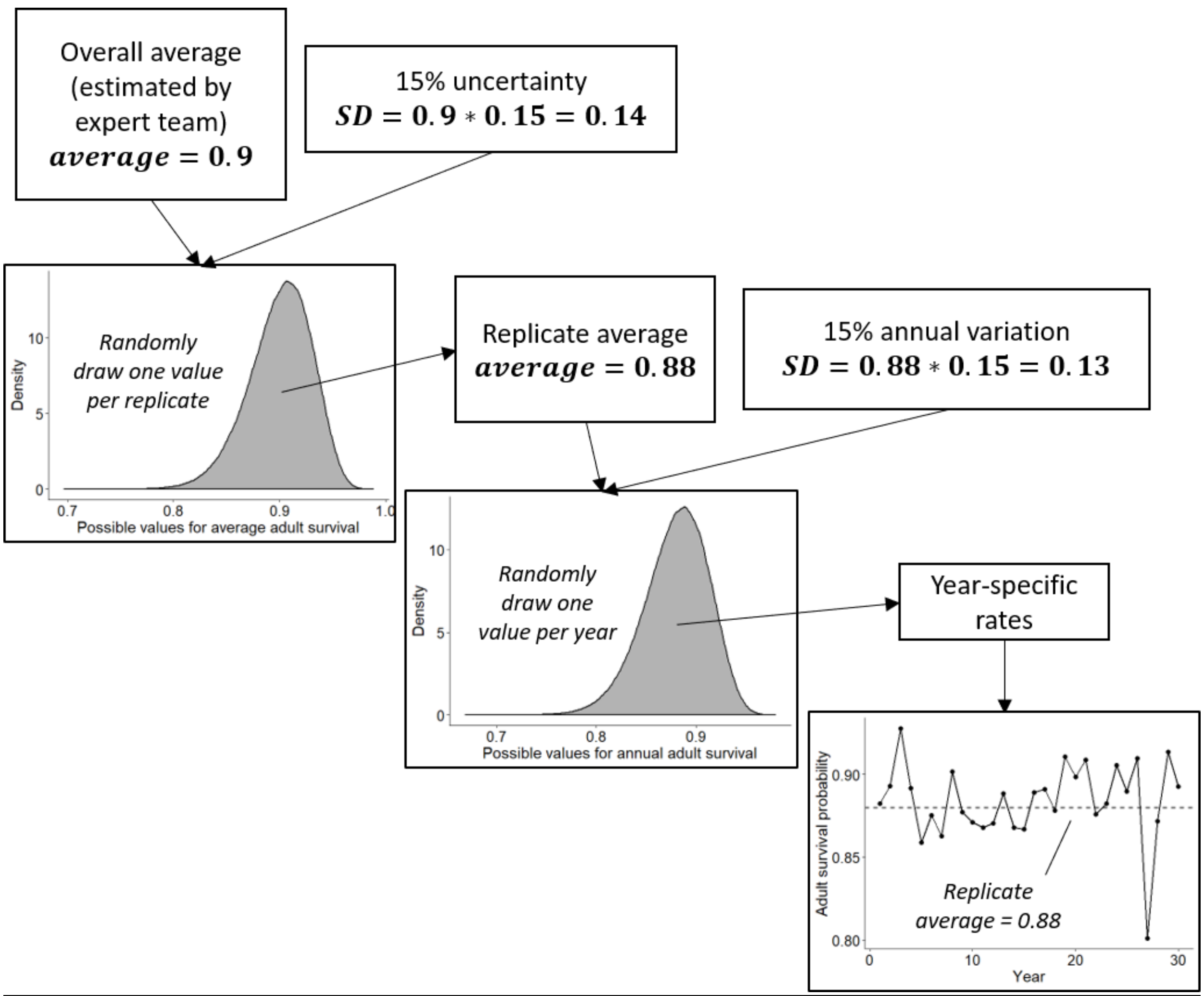


Figure 8. Simulation diagram depicting how annual demographic rates were simulated incorporating both parametric uncertainty in the true overall values and annual variation, using survival of the smallest age class (S^Y) as an example. This process was used to simulate all demographic rates (Table 1).

6.2.2 *Demographic Rates between Natural and Urban Habitat*

The PR boa may occur in many different habitats across the island and experience different conditions in each habitat type. For this projection, we assumed that boas could occupy either natural or developed habitat (Figure 5; see Chapter 5.2 Current Resilience). Natural habitat was defined as all PR boa suitable habitat that was not adjacent to development. Developed habitat was defined as all PR boa suitable habitat falling within either urban or densely populated rural areas, as defined by Martinuzzi et al. (2007, p. 291) (Figure 5; see Chapter 5.2 Current Resilience). Experts believed that in more developed areas, PR boas may experience higher mortality due to human interactions, road kills, and the occurrence of feral cats (see Chapter 3.1). Therefore, we assumed that realized demographic rates would be lower in urban habitats than in natural (baseline) conditions. To include the effect of developed habitat and all of its related influences (see Chapter 3.1), for each iteration we calculated average rates in urban habitats as the average baseline rate multiplied by a randomly drawn habitat effect with a minimum of 0.5 and a maximum of 1. This allowed the demographic rates in urban areas to be lower than those in natural settings by up to 50 percent.

6.2.3 *Carrying Capacity*

Most wildlife populations face constraints on the maximum number of individuals that can be supported by local resources. We imposed density dependence on this population in the form of a simple population ceiling. The most recent estimates of PR boa density range between 1–3 boas/ha within an urban fragmented landscape (Mulero-Oliveras 2019, p. 24). If all available habitat was used (Figure 5), this corresponds to a maximum population size ranging from 379,029 to 1,137,087 individuals. Although some studies have estimated higher boa densities in some areas (Tolson 1997, p. 5; Ríos-López and Aide 2007, p. 40), all available estimates are from the northern karst region where, in general, the species is more abundant than in the drier southern regions of the Island (Rivero 1998, p. 433).

Thus, to account for variation in density and habitat quality and threats across the Island, we chose to set the maximum island–wide density at 3 boas/ha, which we feel is a more conservative approach. Similarly, we set the maximum current density lower than that estimated by published studies from the north to account for the fact that densities are likely lower in other parts of the range (see Chapter 5.2 Current Resilience). We compared model outputs for simulations with varying maximum densities and found that these input values had minimal effect on probabilities of population growth or quasi–extinction (Appendix E: Sensitivity Analysis).

For each model replication, we randomly drew a carrying capacity from a Uniform distribution bounded by this minimum and maximum (379,029 to 1,137,087 individuals). We assumed that reproduction would cease if the ceiling was reached, and therefore imposed a rule that set fecundity equal to zero if the total population size reached the ceiling. This approach is a simplified model of how carrying capacity would affect population demographics. It is likely that approaching and exceeding carrying capacity would affect multiple demographic processes, but we do not have data to estimate these effects and so implementing a simple fecundity reduction ceiling function allows us to limit population growth without speculating on the functional form of density dependence (Morris and Doak 2002, pp. 310–324, McGowan et al. 2017, p. 123).

6.3 Future Scenarios

We considered future scenarios that included changes in land cover such that developed areas would encroach upon natural areas, resulting in both an increased proximity of development to natural areas and loss of overall PR boa habitat. With these scenarios we sought to indirectly capture key threats due to habitat loss and increased conflicts with humans and cats (refer to Chapter 3.1). Some PR boa populations are known to persist when suitable habitat and prey are available within a managed urbanized matrix like Fort Buchanan (Mulero-Oliveras 2019, p. 35), but not in a purely developed landscape.

We considered four potential future scenarios based on an analysis of past rates of urbanization in proximity to protected natural areas in Puerto Rico (Castro-Prieto et al. 2017), which found that urban growth increased at a rate of 16 percent over a decade (years 2000–2010). One of the scenarios includes no change in urbanization rate, while the other three scenarios include different changes in urbanization rate. Urbanization rate was implemented as the rate at which both overall suitable PR boa habitat declined and the rate at which the percent of available habitat that fell within developed areas increased (Figure 9). By simulating simultaneous habitat loss and land cover change, these scenarios represent the most extreme way that urbanization could impact PR boa populations, and indirectly including habitat loss related influences such as increased human–boa conflicts, roadkill, and increased predation by cats (refer to Chapter 3.1).

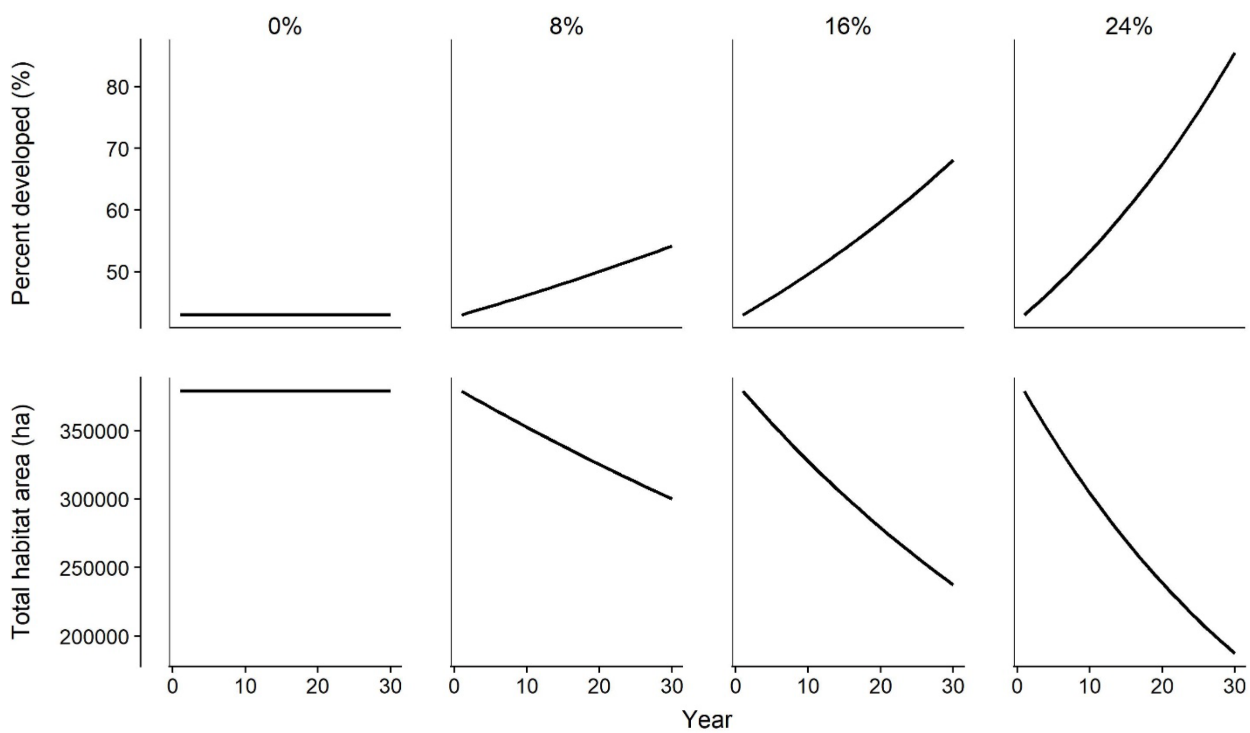


Figure 9. Change in the total PR boa habitat area and the proportion of PR boa habitat falling within an urban area under four future scenarios, each representing a different rate of urbanization (0 percent per decade, 8 percent per decade, 16 percent per decade, or 24 percent per decade). These scenarios are based on an analysis by Castro-Prieto et al. (2017, entire) and described in text.

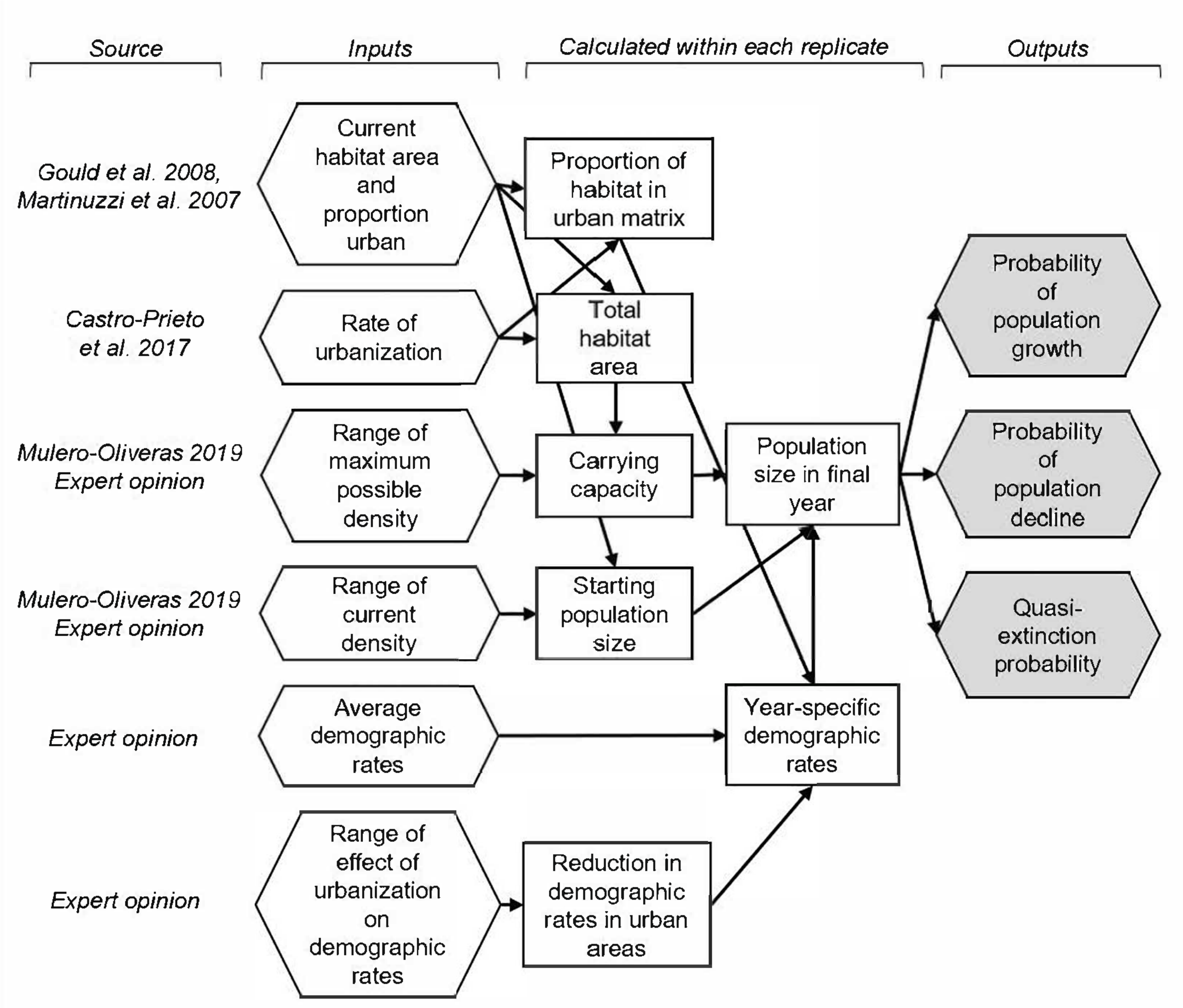
Table 2 specifies the values used for each of the four potential future scenarios: no further urbanization (0 percent), reduced urbanization (8 percent), status quo urbanization (16 percent), and increased urbanization (24 percent). The best-case scenario assumes no future urban growth, and therefore that the proportion of PR boa habitat in natural and urban areas would remain the same as current conditions (0.43) and that the total amount of habitat would remain constant (Table 2). We next considered a reduced urbanization scenario of 8 percent per decade, and therefore that both the proportion of PR boa habitat falling in an urban matrix would increase by 8 percent every ten years and the total PR boa habitat area would decrease by 8 percent every ten years. The third scenario or status quo, assumes the rate of urbanization would continue at 16 percent per decade, and the total amount of available PR boa habitat would decrease by 16 percent every ten years. Lastly, the worst–case scenario, assumes that the rate of urbanization would increase by half to a rate of 24 percent per decade. To implement all of scenarios in the model, we calculated the expected rate of development per year and used this to calculate the predicted total PR boa habitat availability and proportion in urban areas. This assumes that development occurs gradually each year (Figure 9).

Table 2. The total PR boa habitat area and proportion of habitat falling within an urban area in 30 years under four potential rates of urban growth.

Scenario	Urban growth per decade	Total habitat area in 30 years (ha)	Percent developed habitat in 30 years	Total natural habitat in 30 years (ha)	Total developed habitat in 30 years (ha)	Total habitat area lost (ha)
1. No further urbanization	0 percent	379,029	43 percent	215,046	163,983	0
2. Reduced urbanization	8 percent	300,269	54 percent	138,124	162,145	78,760
3. Status quo	16 percent	237,427	58 percent	99,719	137,708	141,602
4. Increased urbanization	24 percent	187,377	86 percent	25,233	162,144	191,652

6.3.1 Population Projection

Figure 10 illustrates the conceptual diagram of the stochastic simulation model used to assess the future condition of PR boas under different rates of urbanization. We projected the population for 100,000 replicates per scenario. For each replicate, we randomly drew the initial population



size (range 37,903 to 189,515 boas), carrying capacity (range 379,029 to 1,137,087 boas), and average demographic rates (Table 1; Tucker et al. 2020, pp.3–4). The initial population size in each habitat type was equal to the randomly selected initial population size multiplied by the proportion of the available habitat in that type. We projected each population for 30 years, starting in the stable stage distribution (calculated from the average demographic matrix). For each year, we calculated annual demographic rates as described above (see Chapter 6.2.2) and calculated the population size by multiplying the year–specific matrix by the population size in the previous time step. Refer to Appendix F for a step-by-step example of how the stochastic population projection was done.

Figure 10. Conceptual diagram of the stochastic simulation model used to assess the future condition of PR boas under different rates of urbanization. White hexagons on the left represent model inputs and gray hexagons on the right represent model outputs. Rectangles represent values calculated within each replication of the simulation. Current habitat area and proportion

of urban areas were estimated based on suitable habitat analyses performed by the PRGap (Gould et al. 2008) and land use analysis by Martinuzzi et al. (2007, entire), while urbanization rates are based on estimates in Puerto Rico by Castro-Prieto et al. (2017, entire). All other inputs (ranges for current and maximum density, average demographic rates, and effect of urbanization on demographics) were determined based on expert opinion.

We summed the number of individuals in each stage to determine the total population size and calculated the change in population size from the first year by subtracting the initial population size from the projection population size. We calculated the average population growth rate (λ) for each replicate by finding the geometric mean of the year–specific growth rates $\left(\lambda_t = \frac{N_{t+1}}{N_t}\right)$. When population growth rate (λ) is equal to 1, the population is stable. We calculated the probabilities of population growth and decline for each scenario as the proportion of replicates in which the average population growth rate was greater than or equal to 1 or less than 1, respectively.

6.3.2 Quasi–extinction Threshold

Many population viability analyses use a quasi–extinction threshold to assess extinction risk. The quasi–extinction threshold is the population size below which either the population cannot recover because it enters an "extinction vortex" (Gilpin and Soulé 1986, pp. 19–34), or the plausible management alternatives would drastically change (*e.g.*, switching from habitat management to captive breeding). Selecting an appropriate quasi–extinction threshold for a specific population is often challenging due to uncertainties about both how demographic feedbacks and management actions influence realized population dynamics. Therefore, we assessed quasi–extinction risk at four thresholds, chosen to address four levels of risk tolerance: total population size of 50, 500, 1,000, or 5,000. For each scenario, we calculated the probability of the population falling below these thresholds as the proportion of replicates in which this occurred.

6.3.3 Population Projection Results

Our projection model indicated that the PR boa population is most likely to decline over a 30–year period under the status quo scenario (Table 3 and Figure 11). Under the status quo scenario that used the current rate of urbanization of 16 percent per decade, the model predicted a 64.3 percent probability of decline and 35.7 percent probability of stability or growth. Higher probabilities of population stability or growth were close to 50 percent only when urbanization rates fell to 0 percent under the best–case scenario, which may be unlikely to occur (Table 3). As expected, the highest probability of decline (72 percent) resulted from the worst-case scenario of increased urbanization rates of 24 percent per decade (Table 3). However, quasi-extinction probability was less than 5 percent for all scenarios and thresholds within 30 years (Figure 12) and all potential rates of decline are considered low (Figure 12). Refer to Appendix F for a step-by-step example of how the stochastic population projection was done.

Table 3. The probabilities of quasi-extinction, population growth, and population decline for each scenario. We evaluated quasi-extinction probability at four thresholds due to our uncertainties about how that threshold should be determined. The probability of population growth and decline are the proportion of replicates in which the average population growth rate (λ) was greater than 1 or less than 1, respectively. Average population growth rate is presented as the median and 95 percent quantiles among all replicates.

Scenario	Urban growth per decade	Quasi-extinction probability				Probability of population stability or growth	Probability of population decline	Average Population growth rate (λ)
		50	500	1000	5000			
1. No further urbanization	0 percent	0	0	0	0.005	0.502	0.499	1.0 (0.933, 1.06)
2. Reduced urbanization	8 percent	0	0	0	0.006	0.435	0.565	0.994 (0.927, 1.06)
3. Status quo	16 percent	0	0	0	0.011	0.357	0.643	0.987 (0.921, 1.05)
4. Increased urbanization	24 percent	0	0	0	0.015	0.285	0.715	0.98 (0.916, 1.04)

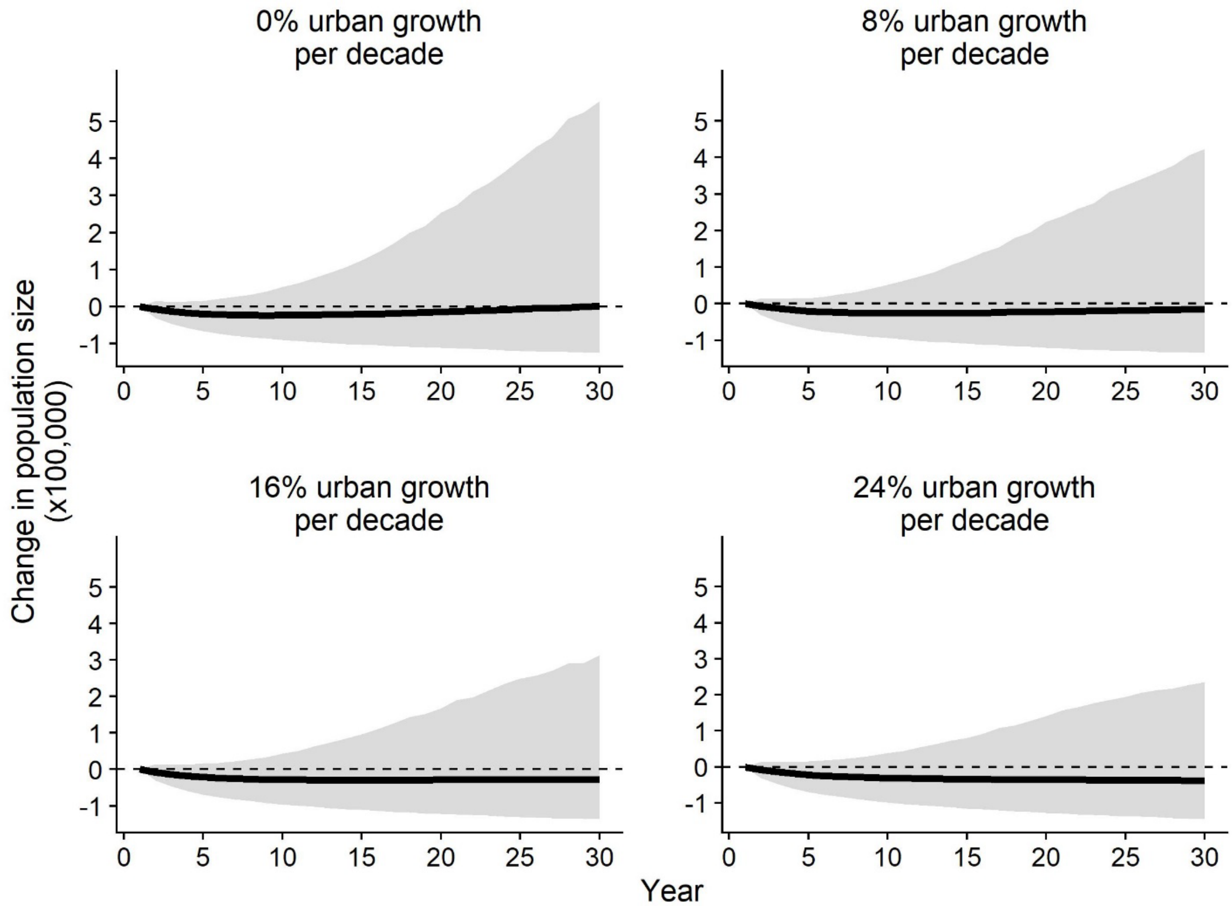


Figure 11. Projected change in population size over 30 years for four potential scenarios of land cover change. Solid black lines show the medians among all replicates, and shaded gray regions show the 95 percent quantiles (95 percent of replications fell within this range). The dashed line is at 0, indicating no change in population size.

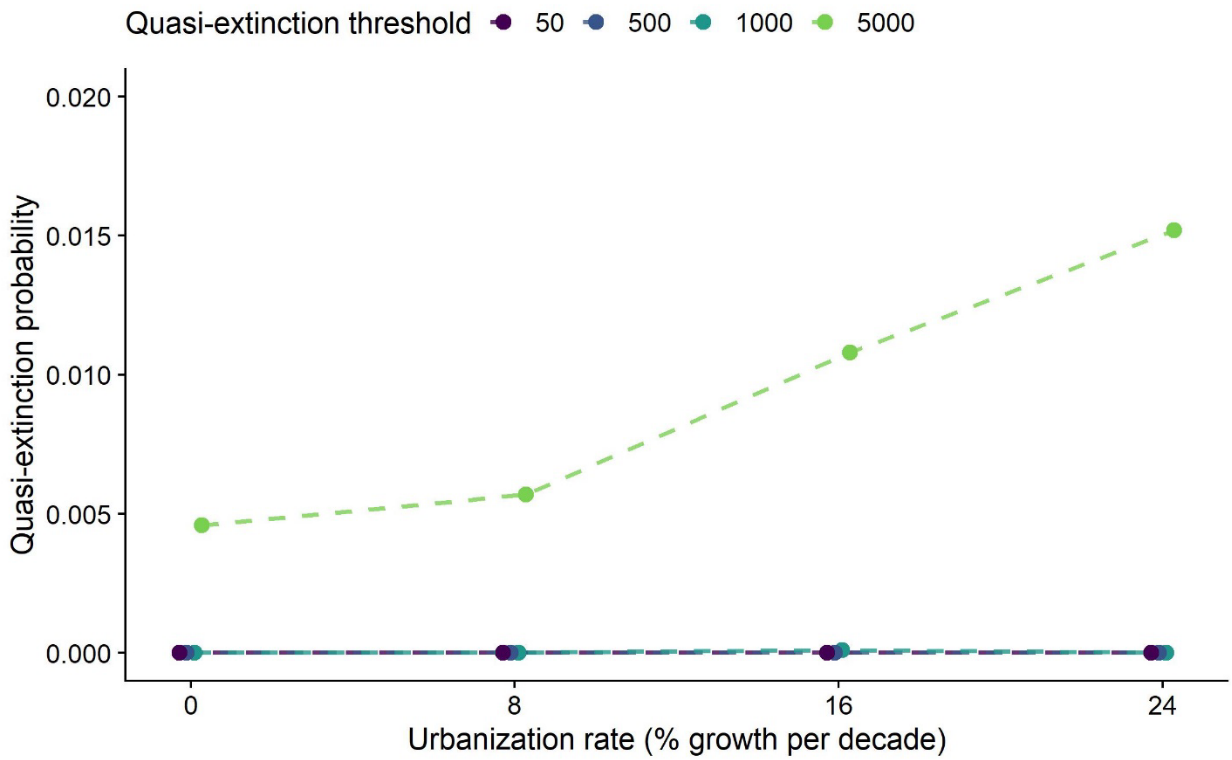


Figure 12. Predicted quasi-extinction probability for the PR boa under four scenarios of future urbanization, evaluated at four different quasi-extinction thresholds (50, 500, 1,000, and 5,000).

6.4 Future Viability

This analysis does not define precise (quantitative) viability thresholds for low, medium or high resiliency, redundancy and representation. Thus, qualifying these in the current and future timeframes are based on interpretation of the current condition versus the population projection results and predicted quasi–extinction probabilities. For example, we do not exactly know how much lower the resiliency and representation of the PR boa population may be in the foreseeable future. But based on the results under the status quo scenario, we expect resiliency to be slightly lower (medium) than the current condition (high to medium) in the foreseeable future (year 2050), especially if we consider all factors that may influence resilience (e.g., development, protection, exotics, disease, etc.). We do not expect changes to redundancy since the single PR boa population would likely persist across its range. Possible changes to resiliency are expected to be related to numerous parameters such as the quality and quantity of its habitat, and both of those are expected to deteriorate with time, more so at the edges and outside of protected habitat.

In addition, our analysis does not predict how the current occurrence of the PR boa might fragment into smaller, potentially less resilient and more isolated groups because of urbanization. For example, the PR boas sampled in the Dorado municipality that may be experiencing genetic drift, potentially due to habitat fragmentation or isolation and possibly affecting the species ability to naturally disperse (Puente-Rolón et al. 2013, p. 6).

The demographic projection model developed for the PR boa incorporates many sources of uncertainty regarding current population status and population vital rates (Table 1). Using this model, we simulated population dynamics over 30 years under four scenarios of future urbanization. Quasi-extinction probabilities were low (Figure 12) for all scenarios due to the possibility of a large initial population size (i.e., from 37,903 to 189,515 individuals, see Chapter 5.2 Current Resilience), which buffers the population from falling below the quasi-extinction thresholds within 30 years. If the true current population size was lower than our projected minimum of 37,903, quasi-extinction probability may be greater.

It is reasonable to assume that the status quo scenario (16 percent rate of urbanization per decade) will continue as peer reviewed literature notes that regardless of growth/decline in the overall human population, residential construction in natural areas is expected to continue (Castro-Prieto et al. 2017, p. 474). The status quo scenario resulted in a higher probability of population decline (64.3 percent) than the probability of population stability or growth (35.7 percent) (Table 3). However, the projection shows that the PR boa population has a very low probability of a precipitous decline within 30 years (Figure 11) and very low probability of abundance reaching 5,000 individuals or less (Figure 12). Since population size is not expected to abruptly change into the foreseeable future, neither is the viability of the species as a whole within a 30 year timeframe.

With a continued increase of an urban landscape (status quo), we may expect PR boa density and distribution to slowly decrease and would be exacerbated by other influences on viability, such as exposure to cats, need for translocations, intentional killings, road kill, among others. In addition, habitat fragmentation is also expected to increase and thus, we may expect further reduction in gene flow within highly urbanized areas, which may also lower the species representation. Of special concern is the fact that lands around protected areas in Puerto Rico are extremely vulnerable to development (Castro-Prieto et al. 2017, p. 478). Even with the reduced urbanization scenario (8 percent per decade), there was still a 57 percent chance of decline (Table 3).

This reiterates the fact that habitat protection is one of the most important positive influences for the PR boa population. However, some important habitats, such as caves (Puente-Rolón et al. 2013, entire) do not all occur within state forest designations or private reserves, but rather under the Karst Conservation Zone (Figure 6; Special Restricted Karst Planning Zone as defined by Regulation #8486, PRPB and DNER 2014, p. 1). As previously described (refer to Chapters 2.4 and 3.1), this zone contains some of the most important habitats for the PR boa. This zone includes both public and private owned lands, and does not allow certain development activities unless the project has PRDNER authorization, for example, extraction of karst material for commercial purposes, or construction of roads and towers or antennas for communication or electrical transmission lines (PRPB and DNER 2014, pp. 17–18). Thus, conservation within this zone cannot be considered conclusive since permits for certain activities within this zone are subject to PRDNER evaluation and thus, uncertain if activities will be allowed or not. In addition, "Puerto Rico's economic and fiscal crisis has created a new layer of uncertainty as to how public lands will be governed and has opened the door to many questions about the future use of public protected areas on the island" (Castro-Pietro et al. 2019, p. 20). Lastly, several recent proposed amendments to the current Puerto Rico Land Use Plan (PRPB 2015, entire) has generated mayor concerns and opposition, particularly because of the proposed land use changes within natural protected areas. Ultimately, the effectiveness of land use plans depends on proper implementation by agencies and citizens, and is susceptible to changes in government policies and priorities (Castro-Prieto et al. 2019, p. 92).

There are some unique urban and highly modified landscapes like Fort Buchanan where the PR boa has persisted for more than 30 years (Pérez and Vélez 1978, p. 71), but with a lower density (Mulero-Oliveras 2019, p. 24) than in other less modified landscapes. The Fort Buchanan population is an example of how the species has responded to the influences on viability (Figure 4). Maintaining the remnant forest fragments in that area has proved vital for the PR boa's persistence, but it has also required adequate and continued management efforts from the Fort Buchanan staff and cooperators. Even within this managed and controlled military installation, future modifications may include improvement of structures or further development (Mulero-Oliveras 2019, p. 9).

This demographic projection model is largely built based on the personal knowledge and opinion of species experts, with support from some published studies. The sensitivity analyses described in Appendix E evaluates the effect of key model inputs on our estimates of the probability of quasi–extinction or population growth. These exercises indicated that outputs were sensitive to our input of adult survival probability; if the true adult survival probability is much less than our estimate of 0.9 (Table 1), then the quasi-extinction probability would be greater. Additionally, the sensitivity analysis identified a fecundity threshold: when fecundity fell below approximately three offspring per adult per year, there was a sharp increase in quasi-extinction probability. The estimate used in the model presented here falls very close to that threshold at 4.5 offspring per adult per year (Table 1). If true fecundity was less than this, then quasi-extinction risk would increase. Sensitivity analysis on the input current and maximum densities for boas indicated that the model outputs were not as sensitive to these values (Appendix E).

Based on all of the above, the likely future scenario for the PR boa population is further habitat degradation, fragmentation and encroachment into suitable areas that would seemingly sustain a viable PR boa population. That is, slight reductions more so in resiliency than in redundancy and representation. However, the current condition of the PR boa population is encouraging, particularly when compared to the available information when the species was listed and the amount of available habitat and protected areas today. This analysis synthesized information from published and grey literature with expert opinion to develop a quantitative projection model despite many uncertainties about current population status and demographic rates. Because we explicitly incorporated those uncertainties in the simulation model, the outputs reflect our best predictions given those uncertainties.

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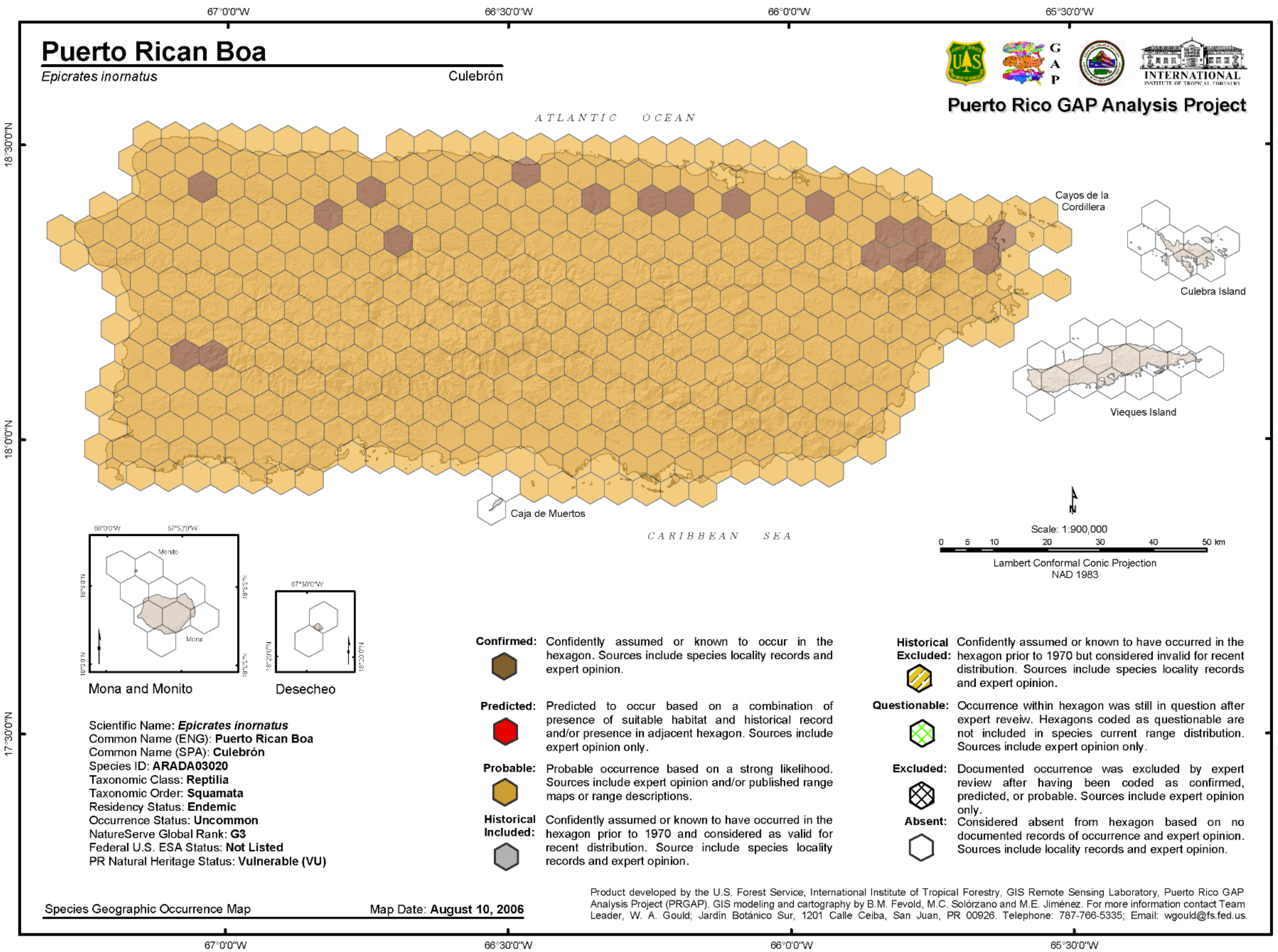
APPENDIX A-1: Puerto Rican Boa Geographic Occurrence Map (Gould et al. 2008).

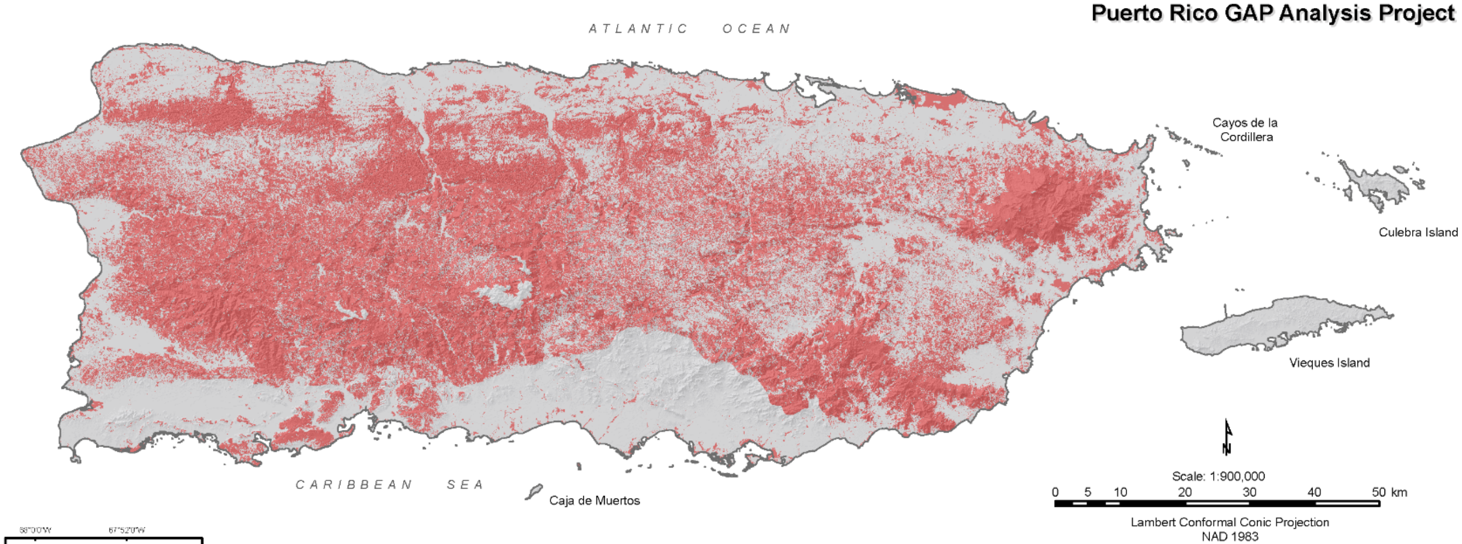


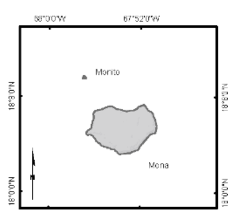
APPENDIX A-2: Puerto Rican Boa Predicted Habitat Map (Gould et al. 2008).

Puerto Rican Boa

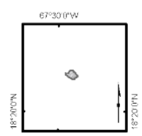
Epicrates inornatus Culebrón

Puerto Rico GAP Analysis Project





Mona and Monito



Desecheo

Photo courtesy of Javier Mercado

Scientific Name: ***Epicrates inornatus***
Common Name (ENG): **Puerto Rican Boa**
Common Name (SPA): **Culebrón**
Species ID: **ARADA03020**
Taxonomic Class: **Reptilia**
Taxonomic Order: **Squamata**
Residency Status: **Endemic**
Occurrence Status: **Uncommon**
NatureServe Global Rank: **G3**
Federal U.S. ESA Status: **Not Listed**
PR Natural Heritage Status: **Vulnerable (VU)**

Species Predicted Habitat Map — Map Date: **November 7, 2006**

Species Predicted Habitat:

Predicted habitat model includes the following landcover types: Moist and wet forest, woodland, and shrubland, mangrove, Pterocarpus, and mature dry forest and dry forest near water bodies, at or below 1000 m of elevation. This species habitat includes 46.3% (414379 ha) of the island, of which 9% occurs in protected areas (PRGAP Status 1 and 2).

Species Accounts Summary:

The Puerto Rican Boa is more commonly found in the northern limestone karsts belt extending from the town of Bayamón west to Aguadilla and less abundant in the dry southern region[1], although there are collection records from the towns of Cabo Rojo, Lajas, Ponce, Salinas and Guayama[1]. For this reason it is believed that this boa is widespread in its mainland distribution[3]. It occupies wet montane forest to dry forest environments[1] and also lowland wet forest, mangrove forest, wet limestone karst, and offshore cays, remnant coastal rainforest, pastureland with patches of exotic trees, tabonuco and palo colorado forest types, plantations, and second growth forests[3]. It is known to feed on domestic fowl, bats, rodents, lizards, insects and other invertebrates[1,2].

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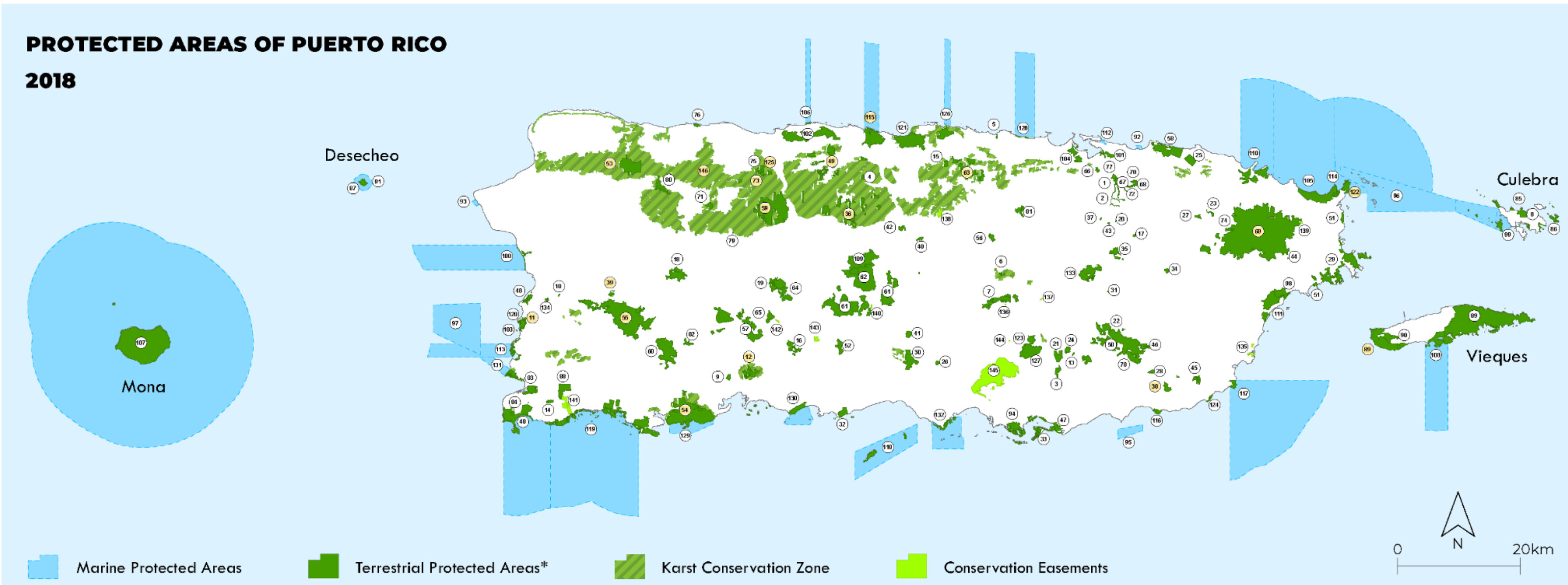
Product developed by the U.S. Forest Service, International Institute of Tropical Forestry, GIS Remote Sensing Laboratory, Puerto Rico GAP Analysis Project (PRGAP). GIS modeling and cartography by M.Jiménez, S. Martinuzzi, M. Solorzano and B. Fevold. For more information contact Team Leader, W. A. Gould; Jardín Botánico Sur, 1201 Calle Ceiba, San Juan, PR 00926. 787-766-5335; Email: wgould@fs.fed.us.

APPENDIX B: Protected areas of Puerto Rico (Ortíz-Maldonado et al. 2019). Highlighted (yellow) names and numbers refer the protected areas mentioned in the SSA report.

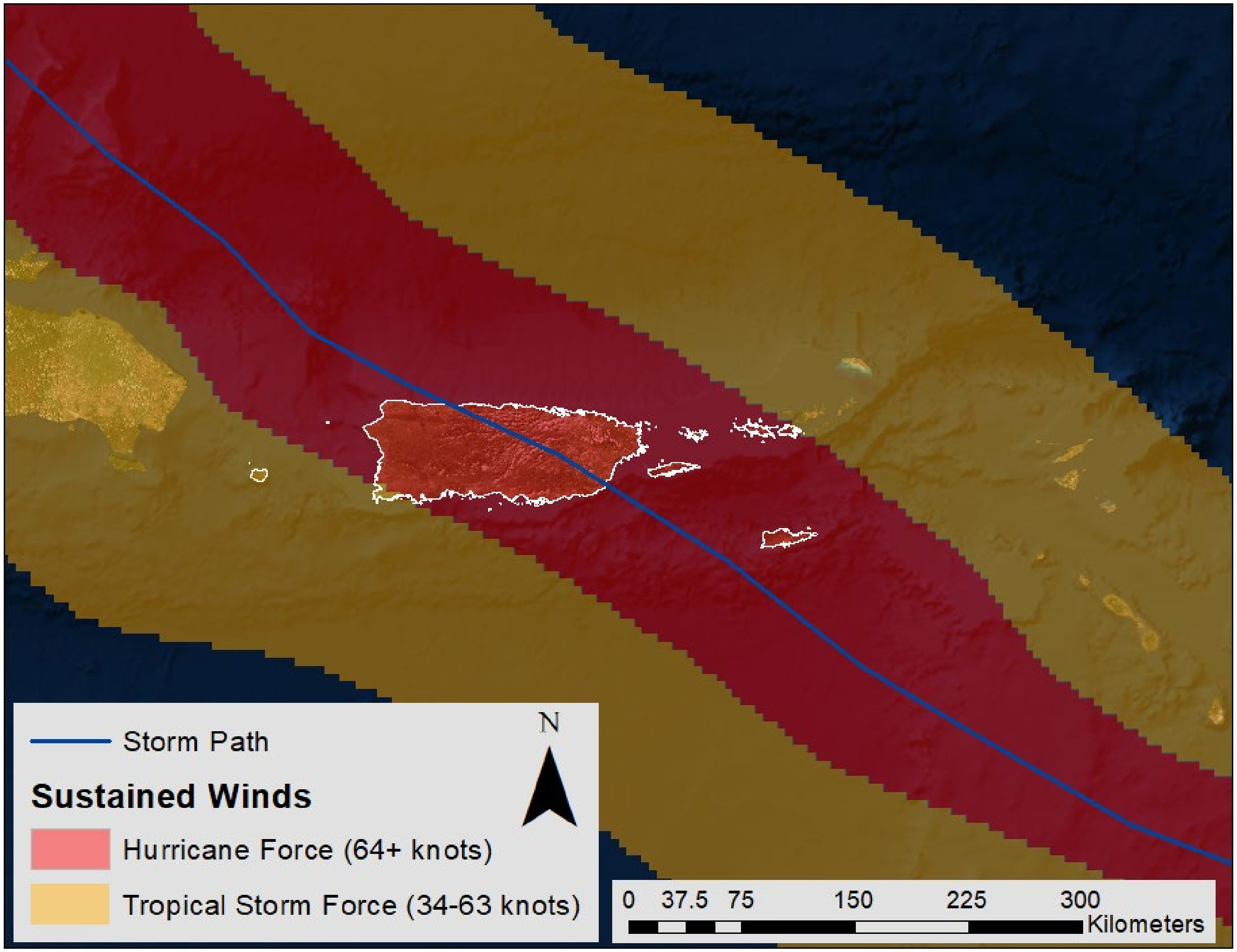


* Terrestrial protected areas include: Nature Reserves, State Forests, Wildlife Refuges (state and federal), National Forest, Urban Forests, National Estuarine Research Reserve, among others. DNER lands acquired through the Forest Legacy Program and other mechanisms have been added to the management unit of the nearest Commonwealth.

1 . Antiguo Acueducto del río Piedras / SJEC
2 . Cupey Arboretum/ SJEC
3 . Guayama Research Area
4 . Manatí Research Area
5 . Bosque de Pterocarpus de Dorado Protected Natural Area
6 . Cañón Las Bocas Protected Natural Area
7 . Cañón San Cristóbal Protected Natural Area
8 . Cerro Feliz Protected Natural Area
9 . Cerro La Tuna Protected Natural Area
10 . Cerro Las Mesas Protected Natural Area
11 . Cordillera Sabana Alta Protected Natural Area
12 . Cuevas El Convento Protected Natural Area
13 . Culebras Protected Natural Area
14 . El Conuco Protected Natural Area
15 . Freddie Ramírez Protected Natural Area
16 . Hacienda Buena Vista Protected Natural Area
17 . Hacienda Lago Protected Natural Area
18 . Hacienda Margarita Protected Natural Area
19 . Hacienda Pellejas Protected Natural Area
20 . Hermanas Sendra Protected Natural Area
21 . Jájome Protected Natural Area
22 . Jorge Sotomayor del Toro Protected Natural Area
23 . La Pitahaya Protected Natural Area
24 . La Robleda Protected Natural Area
25 . Los Frailes Protected Natural Area
26 . Los Llanos Protected Natural Area
27 . Luz Martínez de Benítez Protected Natural Area
28 . Marín Alto Protected Natural Area
29 . Medio Mundo y Daguao Protected Natural Area
30 . Ojo de Agua Protected Natural Area
31 . Paraíso de las Lunas Protected Natural Area
32 . Punta Cabullones Protected Natural Area
33 . Punta Pozuelo Protected Natural Area
34 . Quebrada Janer Protected Natural Area
35 . Río Bairoa Protected Natural Area
36 . Río Encantado Protected Natural Area
37 . Río Guaynabo Protected Natural Area
38 . Río Jacaboa Protected Natural Area
39 . Río Maricao Protected Natural Area
40 . Río Sana Muerto Protected Natural Area
41 . Río Toa Vaca Protected Natural Area
42 . Río Toro Negro Protected Natural Area
43 . San Juan Park Protected Natural Area
44 . Shapiro Protected Natural Area
45 . Sierra La Pandura Protected Natural Area
46 . Ulpiano Casal Protected Natural Area
47 . Aguirre Commonwealth Forest
48 . Boquerón Commonwealth Forest
49 . Cambalache Commonwealth Forest
50 . Carite Commonwealth Forest
51 . Ceiba Commonwealth Forest
52 . Cerrillos Commonwealth Forest / Cerrillos Wildlife Refuge
53 . Guajataca Commonwealth Forest
54 . Guánica Commonwealth Forest
55 . Maricao Commonwealth Forest
56 . Monte Choca Commonwealth Forest
57 . Monte Guilarte Commonwealth Forest
58 . Piñones Commonwealth Forest
59 . Río Abajo Commonwealth Forest
60 . Susúa Commonwealth Forest
61 . Toro Negro Commonwealth Forest
62 . Tres Picachos Commonwealth Forest
63 . Vega Commonwealth Forest
64 . Bosque del Pueblo de Adjuntas Commonwealth Forest
65 . La Olimpia Commonwealth Forest
66 . San Patricio Commonwealth Forest
67 . Bosque Urbano del Nuevo Milenio Commonwealth Forest / SJEC
68 . Los Capuchinos Forest
69 . El Yunque National Forest
70 . Doña Inés Mendoza Urban Forest / SJEC
71 . Río Camuy Cave System
72 . San Juan Ecological Corridor (SJEC)
73 . El Tallonal
74 . Finca El Verde
75 . Finca José Santiago
76 . Finca Nolla
77 . Botanical Garden of the University of Puerto Rico
78 . Las Casas de la Selva
79 . Caguana Indigenous Ceremonial Park
80 . Guajataca Wildlife Refuge
81 . La Plata Wildlife Refuge
82 . Luchetti Wildlife Refuge
83 . Iris Alameda Wildlife Refuge in Boquerón
84 . Cabo Rojo National Wildlife Refuge
85 . Culebra National Wildlife Refuge
86 . Culebra National Wildlife Refuge / Culebrita Lighthouse
87 . Desecheo National Wildlife Refuge
88 . Laguna Cartagena National Wildlife Refuge
89 . Vieques National Wildlife Refuge
90 . El Buey Nature and Wildlife Refuge
91 . Desecheo Coastal Waters Marine Reserve
92 . Arrecife de Isla Verde Marine Reserve
93 . Tres Palmas Marine Reserve
94 . Jobos Bay National Estuarine Research Reserve
95 . Arrecifes de Guayama Nature Reserve
96 . Arrecifes de La Cordillera Nature Reserve
97 . Arrecifes de Tourmaline Nature Reserve
98 . Bosque Pterocarpus Nature Reserve
99 . Canal Luis Peña Nature Reserve
100 . Caño La Boquilla Nature Reserve
101 . Caño Martín Peña Nature Reserve
102 . Caño Tiburones Nature Reserve
103 . Cayo Ratones Nature Reserve / Boquerón CF
104 . Ciénaga Las Cucharillas Nature Reserve
105 . Northeast Ecological Corridor Nature Reserve (NECNR)
106 . Cueva del Indio Nature Reserve
107 . Isla de Mona y Monito Nature Reserve
108 . Vieques Bioluminiscent Bays Nature Reserve
109 . Río Cialitos Nature Reserve
110 . Río Espíritu Santo Nature Reserve
111 . Efraín Archilla Diez Nature Reserve in Humacao
Pantano, Bosque de Pterocarpus, Lagunas Mandry y Santa Teresa
112 . Laguna del Condado Estuarine Reserve
113 . Finca Belverede Nature Reserve / Boquerón CF
114 . Finca Seven Seas Nature Reserve / NECNR
115 . Hacienda La Esperanza Nature Reserve
116 . Humedal de Punta Vientos Nature Reserve
117 . Inés María Mendoza (Punta Yeguas) Nature Reserve
118 . Isla Caja de Muertos Nature Reserve
119 . La Parguera Nature Reserve / Boquerón CF
120 . Laguna Joyuda Nature Reserve / Boquerón CF
121 . Laguna Tortuguero Nature Reserve
122 . Las Cabezas de San Juan Nature Reserve
123 . Las Piedras del Collado Nature Reserve
124 . Manglar de Punta Tuna Nature Reserve
125 . Mata de Platano Field Station and Nature Reserve
126 . Pantano Cibuco Nature Reserve
127 . Planadas - Yeyesa Nature Reserve
128 . Playa Grande El Paraíso Nature Reserve
129 . Punta Ballenas Nature Reserve / Guánica CF
130 . Punta Cucharas Nature Reserve
131 . Punta Guaniquilla Nature Reserve / Boquerón CF
132 . Punta Petrona Nature Reserve
133 . Aguas Buenas Cave System Nature Reserve
134 . Río Hondo Community Forest
135 . Tropical Forest at Palmas del Mar Conservation Easement
136 . Centro Espriritu Santo Conservation Easement
137 . El Rabanal Conservation Easement
138 . El Tambor Conservation Easement
139 . Finca Gulín Conservation Easement
140 . Finca Ledesma Moulier Conservation Easement
141 . Finca María Luisa Conservation Easement
142 . Foreman Conservation Easement
143 . Picaflor Conservation Easement
144 . Siembra Tres Vidas Conservation Easement
145 . Montes Oscuros Scenic Easement
146 . Karst Conservation Zone

Ortiz-Maldonado, C., Quiñones, M., Castro-Prieto, J. & Gaztambide-Arandes, S. 2019. Protected Natural Areas of Puerto Rico. In: Castro-Prieto, Jessica; Gould, William A.; Ortiz-Maldonado, Coralys; Soto-Bayó, Sandra; Llerandi-Román, Ivan; Gaztambide-Arandes, Soledad; Quiñones, Maya; Cañón, Marcela; Jacobs, Kasey R. 2019. A Comprehensive Inventory of Protected Areas and other Land Conservation Mechanisms in Puerto Rico .Gen. Tech. Report IITF-GTR-50. San Juan, PR: U.S. Department of Agriculture Forest Service, International Institute of Tropical Forestry.166 p.

APPENDIX C: Path and wind speed of Hurricane Maria in September 2017. Puerto Rico and the US Virgin Islands are outlined in white. (Data accessed from National Hurricane Center, National Oceanic and Atmospheric Administration, https://www.nhc.noaa.gov, March 27 2018).



APPENDIX D: Transition rates used in the population matrix. Transition rates were derived from the demographic rates estimated by experts and presented in Table 1. To allow for parametric uncertainty, we assumed that the standard deviation was 15% of the average.

Transition rates	**Average**	**SD (15% of Average)**
Probability that a young snake in year *t* will remain in the young stage in year *t+1*	0.1	0.015
Probability that a young snake in year *t* will survive and become a juvenile *t+1*	0.2	0.030
Probability that a juvenile snake in year *t* will remain in the juvenile stage in year *t+1*	0.41	0.061
Probability that a juvenile snake in year *t* will survive and become a subadult in year *t+1*	0.50	0.074
Probability that a subadult snake in year *t* will remain in the subadult stage in year *t+1*	0.54	0.081
Probability that a subadult snake in year *t* will survive and become an adult in year *t+1*	0.18	0.027
Probability that an adult snake in year *t* will remain in the adult stage in year *t+1*	0.9	0.14
Number of new young snakes alive in year *t+1* per subadult in the population in year *t*	0.6	0.090
Number of new young snakes alive in year *t+1* per adult in the population in year *t*	1.35	0.203

APPENDIX E: Sensitivity Analysis

Demographic Rates

Most of the demographic rates used in this model have not been empirically estimated for this population, therefore we relied on approximation by the expert team. To evaluate the sensitivity of model outputs to these input values, we ran simulations in which we randomly drew values for survival and fecundity from a wide range of possible values. For survival rates, we drew values between 0.01 and 0.99, and for fecundity, we drew values between 1 and 20. For each demographic rate we randomly drew 100 values, holding all other rates constant at the average demographic rate values in Table 1 of the SSA (Chapter 6.2). We then ran 1000 replications of the population projection at each value. For these model sensitivity tests, we were interested in evaluating the sensitivity of model outcomes to changes in demographic rates, and therefore we kept the initial population size and carrying capacity fixed at 113,708 and 758,058, respectively, which are the midpoints in the ranges used in the full model run described in text. For each projection we determined whether the population remained stable or grew by determining whether the population size in the final year was greater than or equal to the initial population size. We also calculated the probability of quasi-extinction at the most conservative threshold (5000 individuals) by finding the proportion of replicates in which the population size fell below 5000.

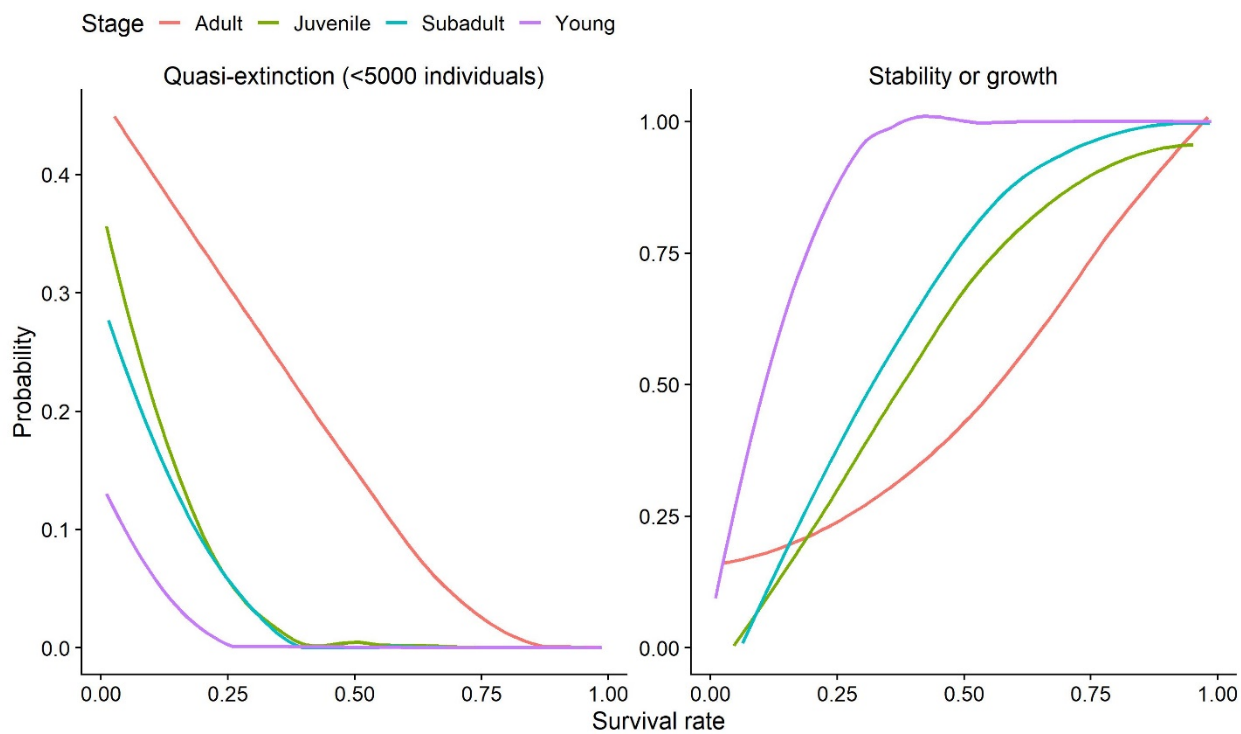


Figure E1. Simulated probabilities of quasi-extinction and of population growth over the range of possible survival rates for each stage (adult – orange, subadult – blue, juvenile – green, young – purple).

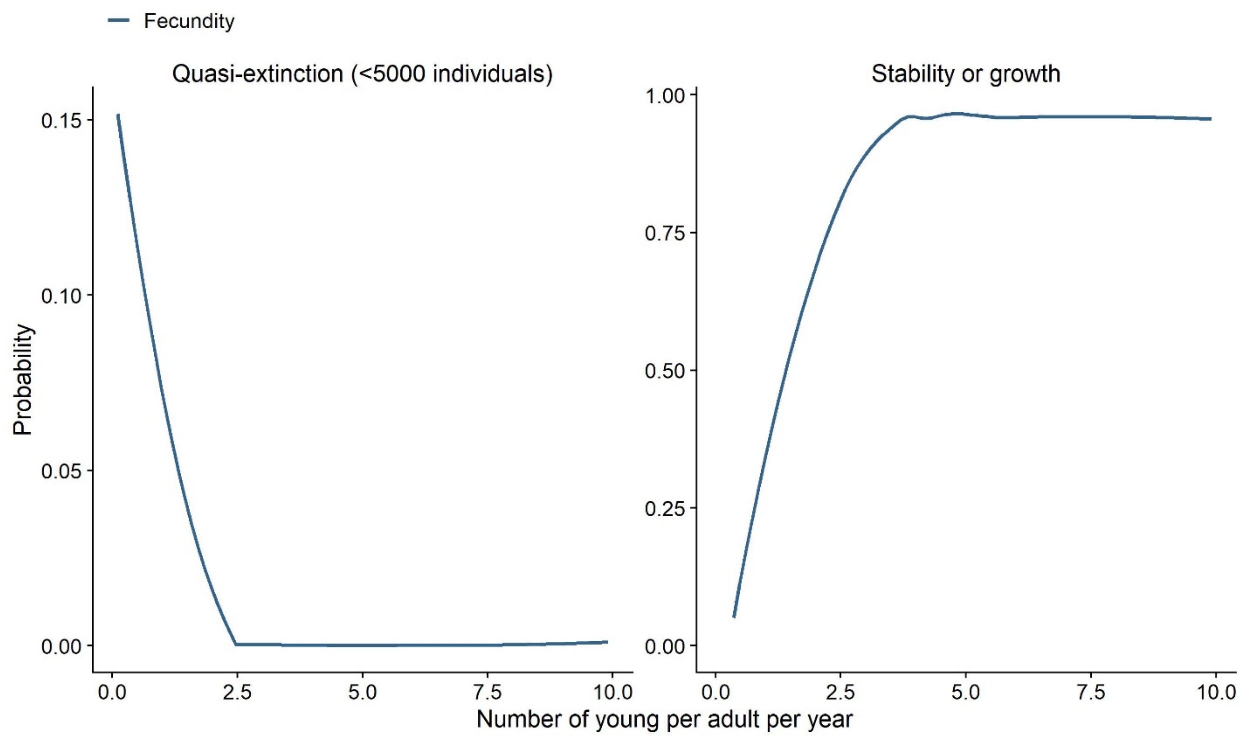


Figure E2. Simulated probabilities of quasi-extinction and population stability/growth over the range of possible fecundity values.

Changes in adult survival probability had the strongest influence on both the probability of quasi-extinction and of population growth (Figure E1). Quasi-extinction probability was ~0 for all iterations in which average adult survival was > 0.85. This analysis also indicated some thresholds at which would expect population dynamics to change. For example, the probability of population growth declined drastically as fecundity fell below ~3 young per adult per year (Figure E2). We note that this sensitivity analysis is conducted assuming that only one demographic rate changes independent of the others, while in reality threats may influence more than one rate simultaneously.

Maximum Density & Carrying Capacity

Initially we defined the range of possible current population sizes by assuming that boa density across all suitable habitat ranged from 0.1-1 boas/ha. We defined the range of possible carrying capacities by assuming that the maximum density of boas we could find across all suitable habitat ranged from 1-6 boas/ha. Based on our habitat analysis, we estimated 379,029 ha of suitable habitat. This corresponds to a maximum current population size of 379,029 boas, and a maximum possible carrying capacity of 2,274,174 boas. There was some concern that these estimates might be too large and relying too heavily on information from the northern part of the range where habitat quality and boa density are expected to be greater than in the southern drier areas of the island. Thus, a more conservative approach would be to assume a lower upper bound for both current population size and carrying capacity. Here I compare four different iterations (Table E1) of the simulation model that reduce either the upper bound for current population size (N) (from 1 boa/ha to 0.5 boa/ha), the upper bound for carrying capacity (K) (from 6 boas/ha to 3 boas/ha), both, or neither. We ran the simulation model described above for 1,000 replicates per scenario.

Table E1. Scenarios used to evaluate the effect of assuming a lower maximum density on model outputs.

Scenario	Maximum density – current population size (boas/ha)	Maximum current population size (boas)	Maximum density – carry capacity (boas/ha)	Maximum carrying capacity (boas)
Reduce both N & K	0.5	189,515	3	1,137,087
Reduce maximum current N	0.5	189,515	6	2,274,174
Reduce maximum K	1	379,029	3	1,137,087
Reduce neither (original)	1	379,029	6	2,274,174

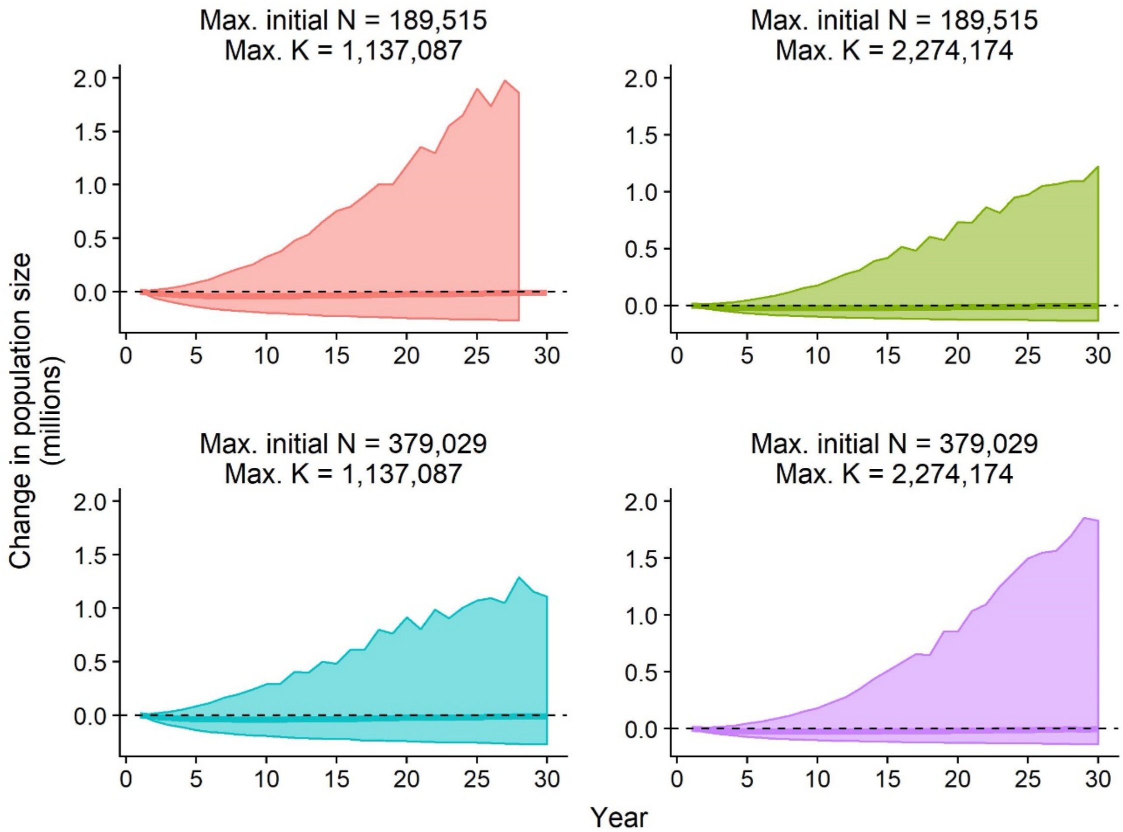


Figure E3. Projected change in population size under four different inputs for maximum current and carrying capacity density. Solid lines are the median and shaded regions represent the range in which 95% of the replications fell. The dashed horizontal line at 0 indicates no change in population size.

Table E2. Probabilities of quasi-extinction, growth, and decline under four potential density thresholds. The model presented above is based on the first combination of inputs, with a maximum current density of 0.5 boas/ha and a maximum carrying capacity density of 3 boas/ha.

Maximum current density (boas/ha)	Maximum carrying capacity density (boas/ha)	Quasi-extinction probability				Probability of population growth	Probability of population decline
		50	500	1000	5000		
0.5	3	0	0.001	0.001	0.009	0.48	0.52
0.5	6	0	0.001	0.003	0.021	0.49	0.51
1	3	0	0.001	0.001	0.009	0.48	0.52
1	6	0	0.001	0.003	0.021	0.49	0.51

Changing the input for maximum current density and maximum carrying capacity density had little effect on simulation model outcomes (Figure E3, Table E2). Reducing the upper bound for initial population size (current density) resulted in slightly higher quasi-extinction probabilities, but the maximum probability of quasi-extinction was ~1% at the highest threshold. Reducing the upper bound for carrying capacity resulted in slightly lower probabilities of population growth and lower probabilities of population decline.

Current Population Size

For this projection, we used a minimum current population of 37,903 individuals based on area of suitable habitat and estimates of population density, as described in text. However, if the true population size is lower than this, the above projection could underestimate quasi-extinction risk. To evaluate the relationship between current population size and quasi-extinction probability, we conducted a sensitivity analysis in which we fixed the initial population size at one of 80 input values between 500 and 40,000 (increasing by 500). For each initial population size, we replicated the projection 1,000 times and calculated the quasi-extinction probability at each of the four thresholds: 50, 500, 1000, and 5000 individuals (Figure E4).

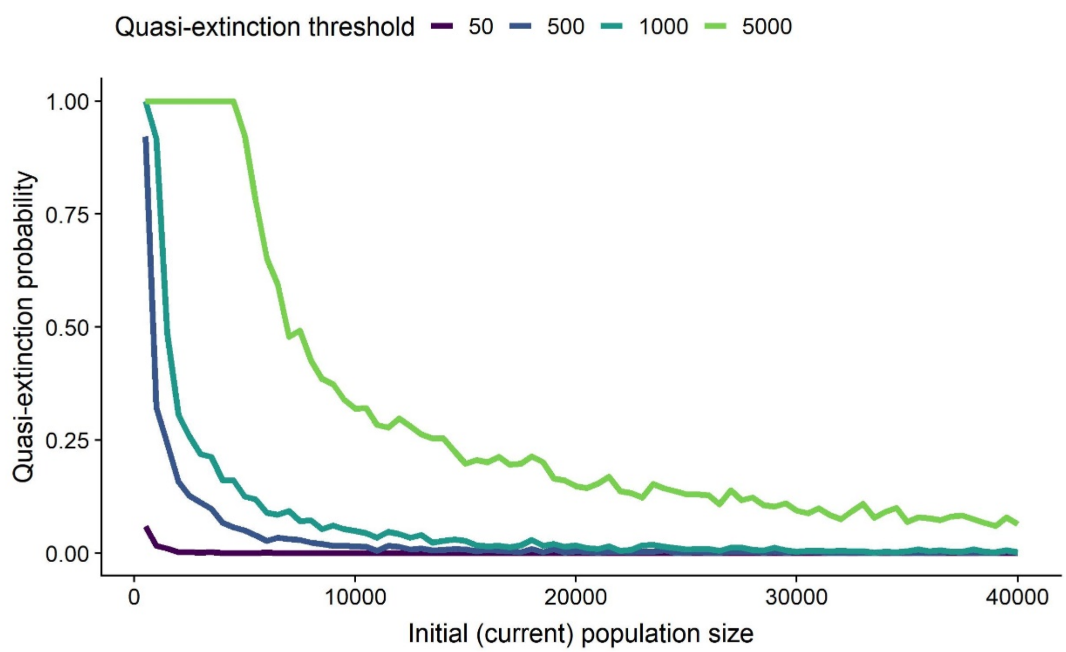


Figure E4. Association between current population size and quasi-extinction probability. Each color line represents a different quasi-extinction threshold. Quasi-extinction probability was calculated by replicating the population projection 1,000 times for each initial population size and determining the proportion of replicates in which the population size fell below the quasi-extinction threshold.

Quasi-extinction probability declined as the current population size increased (Figure E4). In this projection, the probability of falling below 5000 individuals was greater than 5% for all initial population sizes (Table E3). The probability of falling below 1000 individuals was less than 5% for initial population sizes greater than or equal to 10,000 individuals. The probability of falling below 500 individuals was less than 5% for initial population sizes greater than or equal to 5,500 individuals. The probability of falling below 50 individuals was less than 5% for initial population sizes greater than or equal to 1,000 individuals.

Table E3. Estimated quasi-extinction probabilities under a range of initial population sizes. The value in each cell is the probability of the population falling below a given quasi-extinction threshold in 30 years for a given starting population size in the first year.

Initial population size	**Quasi-extinction threshold**				
	50	**100**	**500**	**1000**	**5000**
5000	0	0	0.05	0.13	0.49
10000	0	0	0.02	0.05	0.31
15000	0	0	0.01	0.03	0.20
20000	0	0	0	0.02	0.15
25000	0	0	0	0.01	0.13
30000	0	0	0	0	0.09
35000	0	0	0	0	0.07
40000	0	0	0	0	0.06

PR boa projection example

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PR boa projection

This document walks through the stochastic population projection developed for the PR boa. It follows the modeling methods included in the SSA and provides example calculations to demonstrate each aspect of the model.

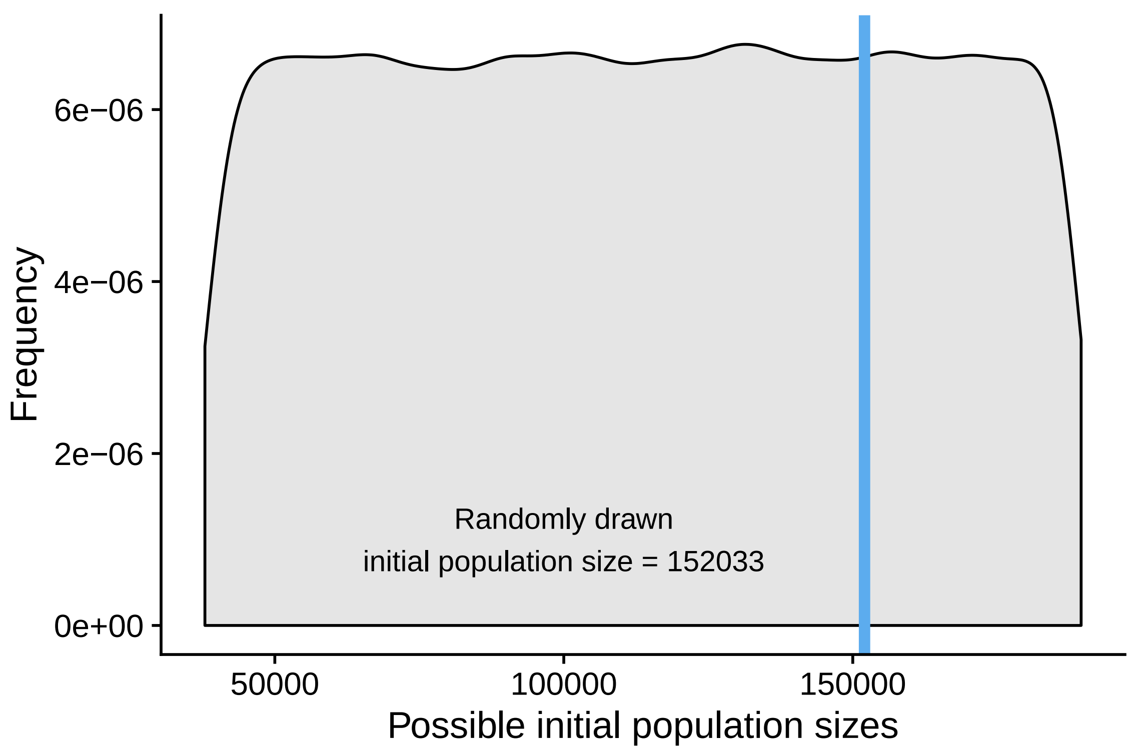
Demographic matrix model

The overall average demographic rates were calculated using the survival, growth, and fecundity rates estimated by the expert team.

```
##       [,1]  [,2] [,3] [,4]
## [1,] 0.099 0.000 0.60 1.35
## [2,] 0.201 0.405 0.00 0.00
## [3,] 0.000 0.495 0.54 0.00
## [4,] 0.000 0.000 0.18 0.90
```

Initial population size

The initial population size was drawn randomly for each replication from a range based on a density of 0.1-0.5 boas/ha and the total available habitat. Below I've plotted the distribution of 100,000 possible initial population sizes, and the blue vertical line is the initial population size that was randomly drawn for this example replication of the model.



Because we want to account for two different habitat types, we determine the initial number in each type by multiplying the initial population size by the proportion of habitat that falls in each type. Under the baseline conditions, the habitat is 91.3% natural and 8.7% urban.

```
## [1] "Total initial population size = 152033"
```

```
## [1] "Initial natural population = 152033 x 0.57 = 86659"
```

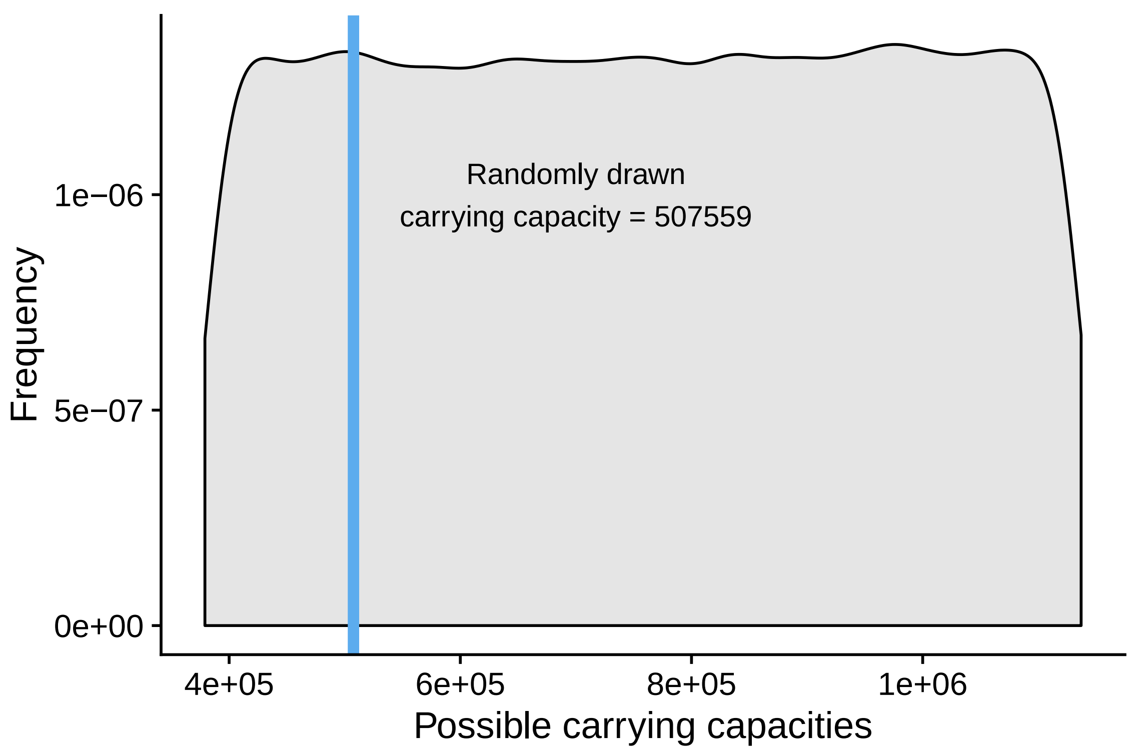
```
## [1] "Initial urban population = 152033 x 0.43 = 65374"
```

Because we are using a stage-based model, we also need to determine the initial number of individuals in each stage. To do this, we calculate the stable stage distribution, which is the proportion of the population in each stage when the population has reached stable dynamics. Below I've calculated the stable stage distribution based on the average values above:

Stage	Proportion in each stage	Initial number, natural habitat	Initial number, urban habitat
Young	0.455	39425	29742
Juvenile	0.150	12960	9777
Subadult	0.155	13464	10157
Adult	0.240	20809	15698
Total	1.000	86659	65374

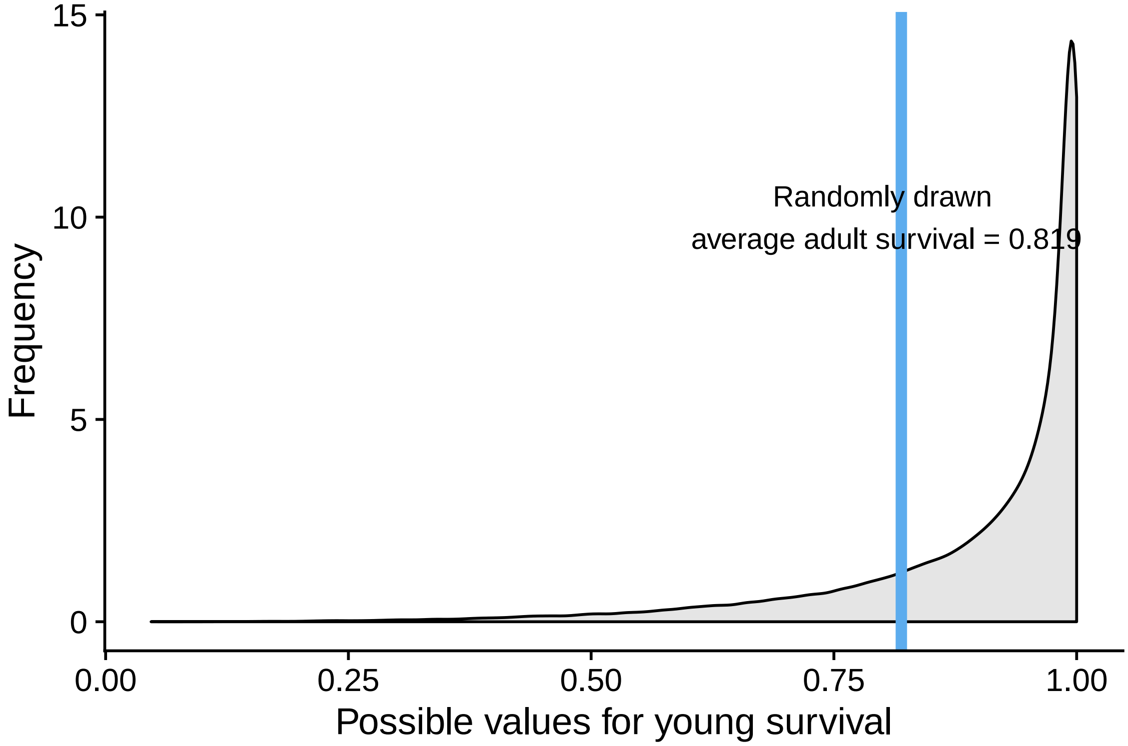
Maximum population size

The maximum population size (carrying capacity) was drawn randomly for each replication from a range based on a density of 1-3 boas/ha and the total available habitat. Below I've plotted the distribution of 100,000 possible carrying capacities, and the blue vertical line is the maximum population size that was randomly drawn for this example replication of the model.



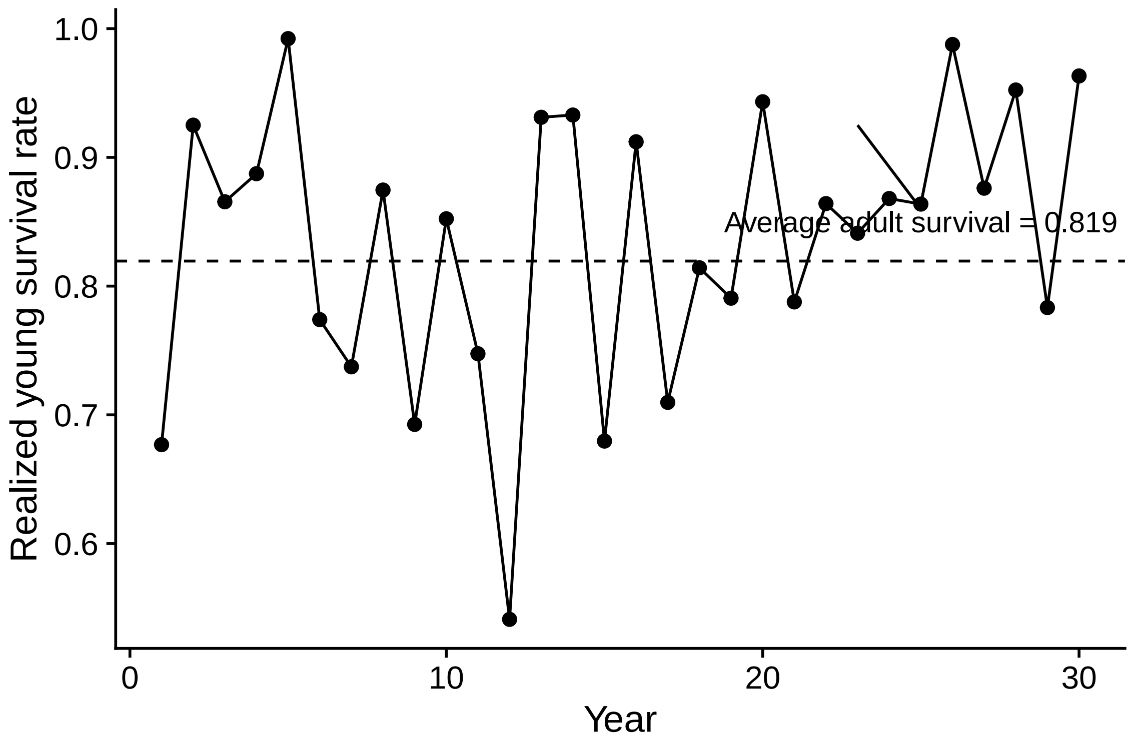
Uncertainty in demographic rates

We did not conduct a formal elicitation to obtain estimates of uncertainty in the experts' estimates of each demographic rate. Therefore, we assumed the error of our mean estimate was 15% of the average for each rate. This was used to define a distribution of possible values for each rate. For each replication, we randomly drew a value from this distribution to represent the overall average value for that rate. I'll demonstrate this with adult survival. A similar distribution exists for each demographic rate in the model.



Temporal variation in demographic rates

In most wild populations, rates of survival and fecundity vary stochastically among years due to random variation in the environment. We often refer to the rates experienced by a population in a given year as the "realized" annual vital rates (as opposed to the overall average rates). If we had long-term monitoring data such as mark-recapture data, we might be able to estimate the annual variation in survival, growth, and fecundity. However, since we do not have those data, we assumed that all demographic rates varied randomly each year within 15% of the average. Again we define a distribution of possible realized rates, and randomly draw a value from that distribution for each year. For adult survival, that looks like this:



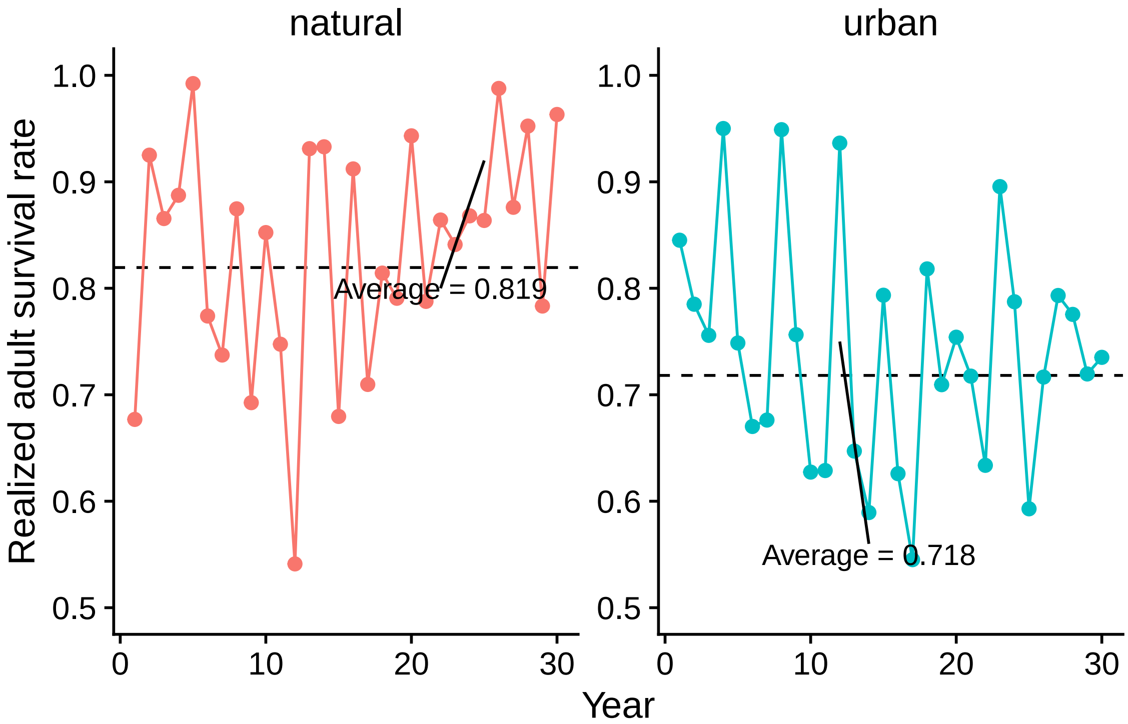
Differences between natural and urban habitat

We also sought to capture the differences between natural and urban habitat. Because the effect of living in close proximity to developed areas is not known but thought to be negative, we assumed that the rates of growth, survival, and fecundity would be lower in urban areas than natural areas by up to 10%. For each replication, we randomly drew a number between 0.9 and 1. We multiply this "urban effect" by each demographic rate to calculate the average rates for urban areas. We then randomly drew the year-specific rates in the same way as above.

```
## [1] "Natural average adult survival = 0.819"
```

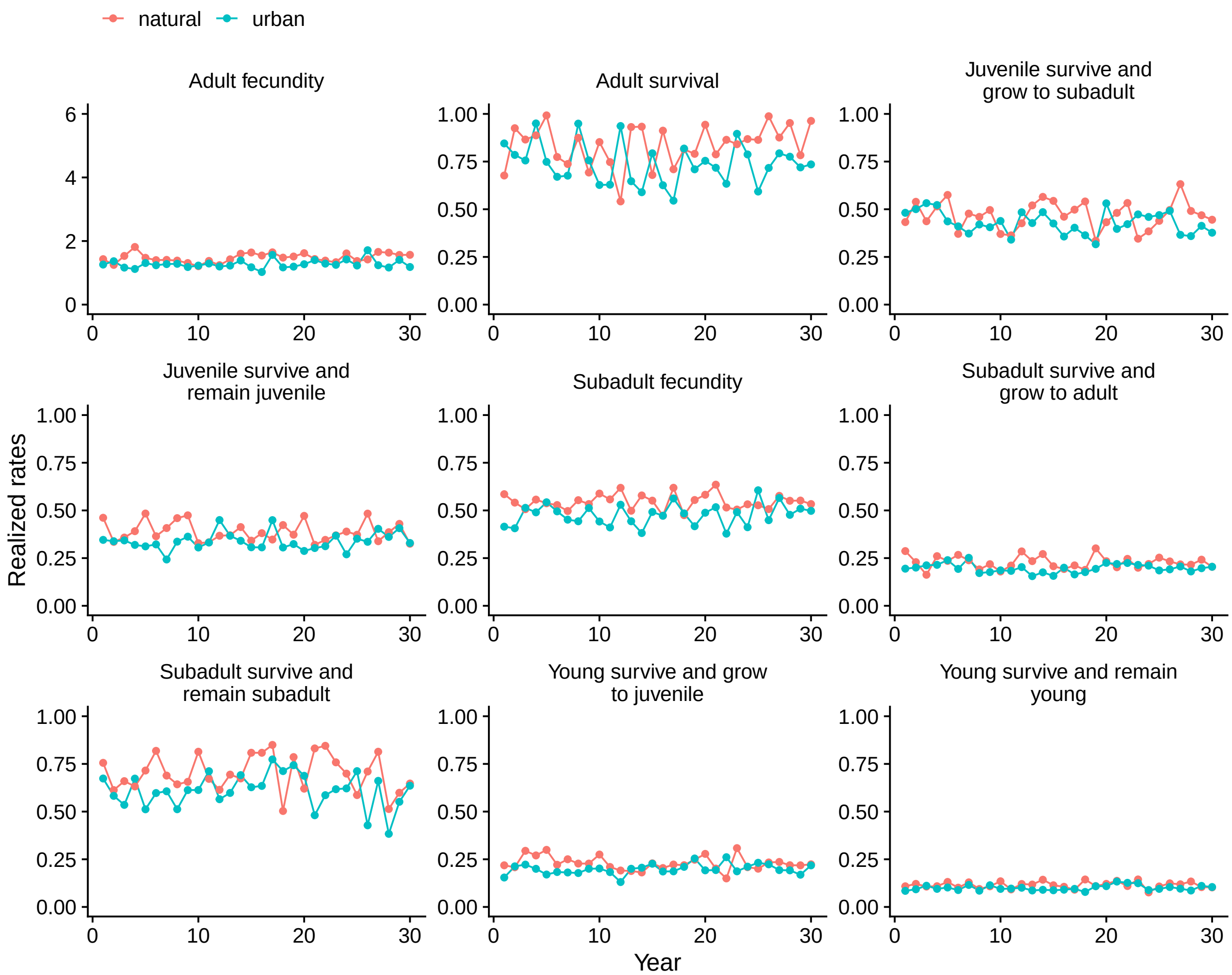
```
## [1] "Urban effect = 0.876"
```

```
## [1] "Urban average adult survival = 0.819 x 0.876 = 0.718"
```

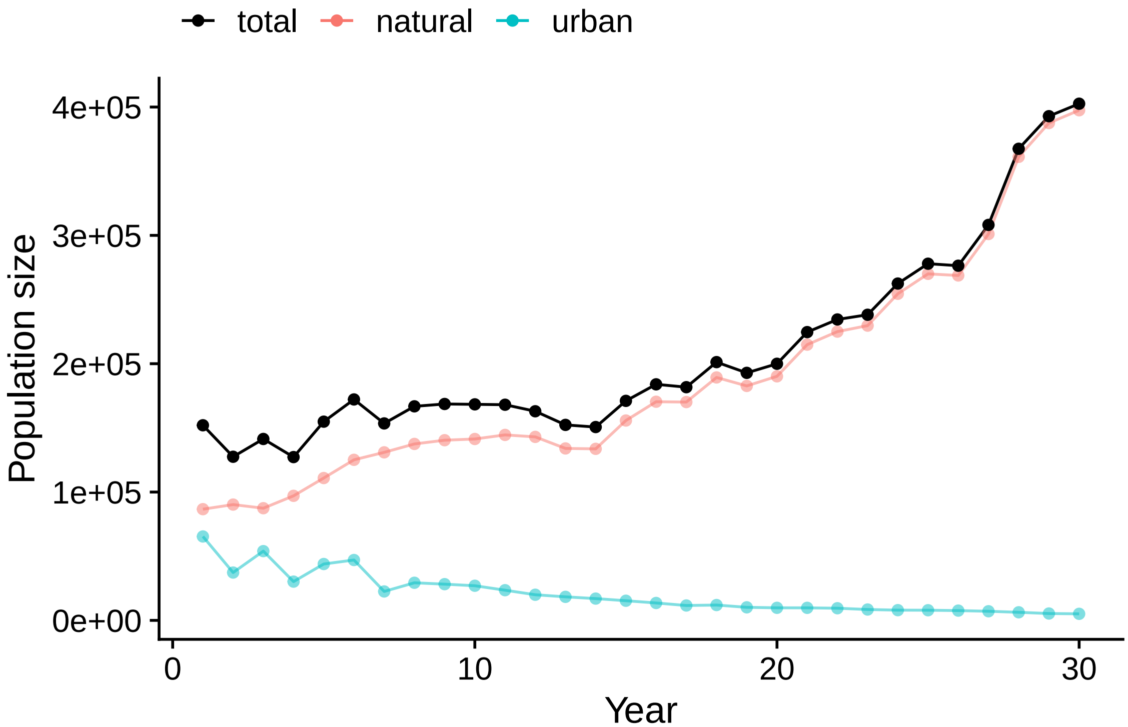


Population projection

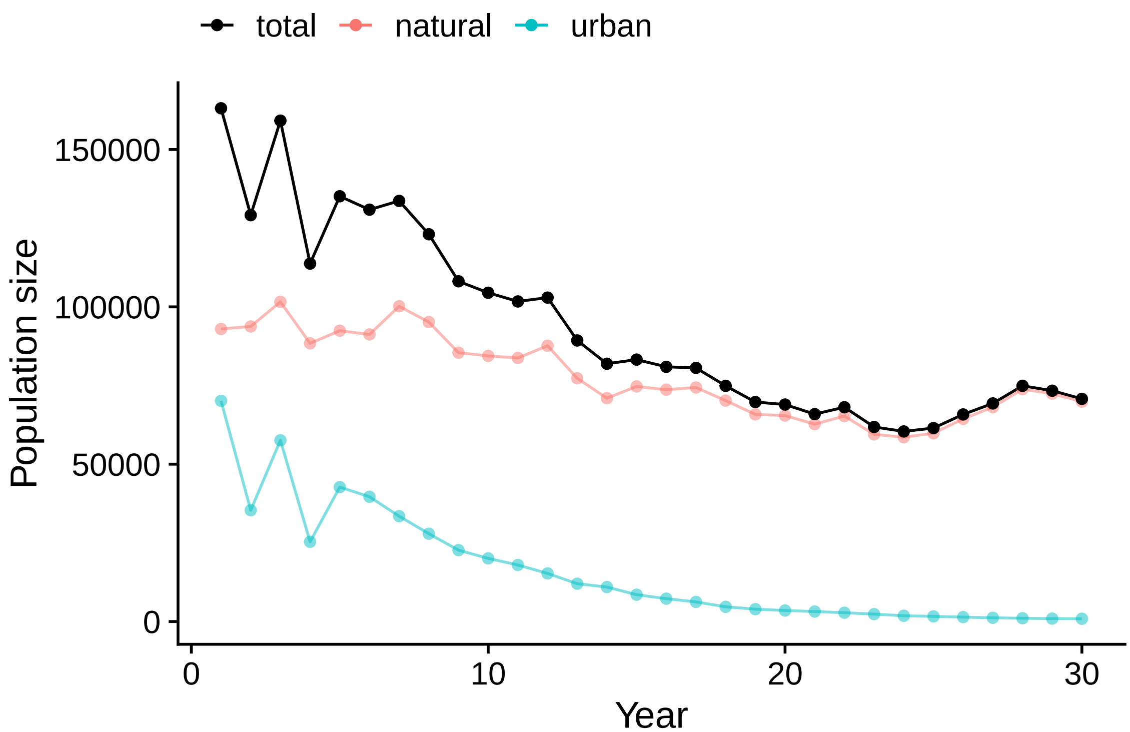
We repeat the process of drawing an average value, calculating the adjusted value for urban habitat, and then randomly drawing the year-specific realized rates for all demographic rates. For this replicate of the model, those values are below:



If we take those rates and the initial population size from above, we can project the population size over 30 years. If the total population size exceeds the carrying capacity drawn for this replicate, then fecundity will be set equal to 0 for that year.



Let's run another replicate: 1. Draw initial population size and allocate individuals to habitat and stage
2. Draw a carrying capacity
3. Draw average values for all demographic rates
4. Draw the effect of urbanization and calculate average rates for urban habitats
5. Draw year-specific realized rates
6. Project the population for 30 years



And repeat that 1000 times: