



Initial Population Study of the *Iguana iguana* across San Juan National Historic Site (SJNHS)

San Juan, Puerto Rico



Green Iguana cooling off on a hot day, resting on the San Felipe Del Morro Fortification

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Abstract

The green iguana (*Iguana iguana*) is an invasive reptile species in Puerto Rico whose population has increased exponentially since the 1990s and has been seen occupying many areas of the San Juan National Historic Site (SJNHS) in Old San Juan, Puerto Rico. Their presence poses numerous risks to public health, environmental health, and cultural resources at SJNHS. There are currently no studies regarding *I. iguana* natural history or population demographics in Old San Juan, PR or across SJNHS. Hence, natural resource managers at SJNHS have an incomplete understanding of crucial information regarding the invasive green iguana's population dynamics and impacts across the historical park. To fill this information gap and to help prevent and assess risks SJNHS completed an initial green iguana population study from March 2026–April 2026. During this sampling period, 32 Visual Encounter Surveys (VES) were conducted across four different sites within SJNHS to inform management decisions, make abundance estimates, and determine any variables that may impact population dynamics across SJNHS. The VES were conducted along ~130 m transects, twice daily (AM/PM), eight occasions per week, over the five weeks. Each iguana we sighted, we recorded age (neonate/juvenile/adult), sex (male, female, undetermined), and status (alive, dead, dying/unhealthy). During each survey we also collected anthropogenic disturbance (low, medium, high), and climate variables (temperature, relative humidity, dew point, wind speed). Data were captured using ArcGIS Survey123 and analyzed in RStudio. A total of 603 individuals (including possible repeats) were counted in the 32 surveys. The region with the highest observed density was along El Paseo Del Morro with 34 iguana/hectare during one survey occasion. Of the weather variables collected, wind speed (m/s) was the only one found to be a significant predictor of observed green iguana density. Using N-mixture modeling and choosing the most ecologically reasonable model with the lowest AIC score, we obtained park-wide abundance estimate of 491 iguanas (range: 352–688) across 30.351 ha, and an estimated density of 16.18 iguana/hectare (estimated density range of 11.59, 22.67 individuals/hectare). These results are imperative to inform the green iguana management plan and to protect the cultural and natural resources of SJNHS.

Keywords (optional): Invasive species management, Green Iguana (*Iguana iguana*), natural resource management, cultural resource protection, Visual Encounter Surveys, N-Mixture Modeling

List of Terms or Acronyms

SJNHS: San Juan National Historic Site

VES: Visual Encounter Survey

IQR: Interquartile range

AIC: Akaike Information Criterion

ZIP: Zero-inflated Poisson



Resumen

La iguana verde (*Iguana iguana*) es una especie invasora de reptil en Puerto Rico cuya población ha crecido exponencialmente desde los 1970s a 1990s y se ha observado ocupando muchas áreas del SJNHS en Viejo San Juan, Puerto Rico. Su presencia posa numerables riesgos a la salud pública y ambiental y a los recursos culturales de SJNHS. Actualmente, no existen estudios sobre la historia natural de *I. iguana* o sobre la demografía de sus poblaciones en el Viajo San Juan o SJNHS. Por tanto, quienes están a cargo del manejo de recursos naturales en SJNHS tienen un conocimiento incompleto de información crucial con respecto a las dinámicas de población y los impactos de esta especie en el parque. Para mitigar esta brecha de conocimiento y para ayudar a prevenir y evaluar los riesgos que presenta la *I. iguana*, SJNHS completó un conteo visual inicial March 2026–April 2026. Durante este período de muestreo se llevaron a cabo 32 Visual Encounter Surveys (estudio de encuentros visuales) en conjunto con la recolección de datos de clima y estos fueron conducidos a través de cuatro regiones diferentes dentro de SJNHS para informar decisiones de manejo a futuro, hacer estimados de abundancia y determinar qué variables pudiesen afectar las dinámicas de población en SJNHS. La región con la mayor densidad observada fue a lo largo del Paseo del Morro, con 34 iguanas/hectárea durante un día de muestreo. De las variables de clima documentadas la velocidad del viento (m/s) fue la única que se encontró ser un indicador significativo de densidad observada de iguanas verdes. Utilizando un modelo de N-mixture y escogiendo el modelo más ecológicamente razonable con el marcador más bajo de AIC, obtuvimos estimados de abundancia de todo el parque y con este modelo encontramos una densidad estimada de 16.18 iguanas/hectárea a través de SJNHS (rango de densidad estimado de 11.59, 22.67 individuos/hectárea). Estos resultados son imperativos para informar el plan de manejo de la iguana verde y proteger los recursos naturales y culturales de SJNHS.

Introduction

The San Juan National Historic Site (SJNHS) is the only National Park Service unit in Puerto Rico and contains the oldest European-designed fortifications in the United States dating back to the 16th century (NPS, 2025). Located in the historic city of Old San Juan, an islet off San Juan, Puerto Rico, this historic site contains many unique ecological conditions, with a variety of microhabitats. The green iguana (*Iguana iguana*), an invasive reptile species in Puerto Rico whose population has increased exponentially since the 1990s, has been seen occupying many areas of the park (López-Ortiz, 2012; NPS, 2025). This arboreal and burrowing, herbivorous lizard is native to Central and South America, and their presence and behaviors pose numerous risks to SJNHS; including damage to flora and fauna, public health concerns, economic concerns, and the potential to weaken and damage the historic structures and landscaping that characterize SJNHS (López-Ortiz, 2012; NPS, 2025).

Due to these risks, SJNHS aims to implement a management and mitigation plan to reduce the number of *I. iguana* in an effort to protect the cultural and natural resources of the park (NPS, 2025). Prior to starting mitigation of an invasive species, an initial population count is essential to assess population response to mitigation and be able to see how changes in the abundance may influence ecosystem properties and processes (Mehta, 2007; Moon, 2015; Rivera-Milán, 2020). SJNHS recognizes that harvest mortality could have unforeseen outcomes due to the release from density dependence which could lead to *I. iguana* overcompensation through high survival and fecundity rates (Rivera-Milán et al., 2020). Therefore, it is necessary to document the initial population to proactively determine any outcomes of mitigation and prevent further and future population spread (Mehta, 2007; Darrigran, 2015). Natural history and demographic studies of *I. iguana* are limited in Puerto Rico (López-Torres et al., 2012; Arce-Nazario & Carlo, 2012). There are currently no studies regarding *I. iguana* natural history or population demographics in Old San Juan, PR or across SJNHS; therefore, natural resource managers at SJNHS have an incomplete understanding of crucial information regarding the invasive green iguana's population dynamics and impacts across the historical park (NPS, 2025).

To fill these information gaps, SJNHS conducted Visual Encounter Surveys (VES) and collected climate data across the park to conduct an initial population study of the *I. iguana*, acting as the first step of the NPS Management of the Green Iguana in San Juan National Historic Site Plan (NPS, 2025). Multiple statistical analyses from these data were performed, including regression and Pearson non-parametric correlation tests, Kruskal-Wallis rank sum tests and pairwise comparisons using Wilcoxon rank sum tests with continuity correction, and the pcount() N-mixture model of Royle (2004) used with the zero-inflated Poisson (ZIP) N-mixture model variant. The information of *I. iguana* collected from this study was crucial to (1) estimate densities and abundances prior to mitigation deployment, (2) to inform management and mitigation strategy, (3) to inform a preliminary impact report, and (4) to inform any other future wildlife and natural resource studies.

Methods

Study Sites

Iguana iguana populations were monitored throughout 4 pre-determined study zones (i.e, Zone Cristobal (18.46657, -66.11089), Zone Morro (18.46839, -66.12325), Zone Paseo (18.46498, -66.11948), and Zone Isla de Cabra (18.46619, -66.13637); Fig. 1) in the boundaries of SAJU, NPS (Fig. 1). The location and size of the zones were determined by (i) presence of species or the expected distribution of *I. iguana* based on observation, (ii) SJNHS park boundaries, (iii) accessibility, and (iv) sufficient distance between zones to prevent overlap. All of these study zones are characterized by a variety of microhabitats including coastal bluffs with dense tree coverage, large grass plots, anthropologic coastal paths with large shore break rocks, historic fortifications, and areas with sandy, rocky soil (NPS, 2025).



Fig. 1: Map of the San Juan National Historic Site, San Juan, PR; showing locations of study zones and boundaries of SJNHS where VES surveys took place to estimate green iguana abundance from 3/21/2026 to 4/23/2026.

Climate data at SJNHS

Old San Juan, Puerto Rico is characterized by warm temperatures, with extreme heat events, especially in the summer months (Range: 24 °C to 32 °C; Méndez, et. al., 2015). The mean annual precipitation in Old San Juan and outlying areas, during the period from 1971 to 2000, is between 1,256 and 1,630 millimeters (Gómez, 2014). The urban landscape greatly influences local microclimates, contributing to higher temperatures compared to rural areas, with a recorded increase of 0.41 °C per decade in metropolitan areas (González-Cruz, 2004). Daily climate data was collected

prior to the start of each survey using the *Extech Environmental Meter EN510*. The climate parameters collected at the start of each survey were: Temperature (°F), dew point (°F), relative humidity (%rH), wind speed (m/s), and climate category (rainy, cloudy, foggy, clear, windy, dry) (Harris, 1982; López-Torres et al., 2012).

Population Counts

Visual Encounter Surveys (VES) ($N=32$) were conducted (March 2026–April 2026) across ~130m transects separated by a minimum of 10m in the predetermined zones (Fig. 1) to estimate density (i.e., $\hat{D}$ = number of individuals/ha) and make abundance estimates for the entire San Juan National Historic Site (i.e., $\hat{N}$ = number of individuals in 30.351 hectares; Fig. 1). VES were conducted two times daily (i.e., AM survey between 9:30 am-11 am, and PM between 2:30 pm-4 pm), eight times per week (i.e., Monday through Thursday, two per day) for 5 weeks (March 2026–April 2026). Each zone was repeated two times weekly, once in the AM and once in the PM, resulting in 8 survey occasions per zone for the study period. The total number of individual *I. iguana* observed along each predetermined transect was recorded by groups of 2-4 observers. Each *I. iguana* observed was categorized by age class (hatchling, juvenile, adult), sex (undetermined, female, male), and status (alive, dead, dying). Age and sex class were determined by identifying key physical traits (body size, coloration, dewlap, dorsal crest, femoral pores) as described in Hatfield, 1945. All hatchlings and juveniles were not assigned a sex. Anthropologic disturbance level (low, medium, and high) was recorded for each transect. All information collected and geolocations of each individual iguana was recorded using ArcGIS Survey123. Each survey took an average of 1:02 hours to complete, and only one member of the team assigned age and sex for standardization purposes.

Data Analysis

All statistical tests were performed using RStudio version 4.5.2 from posit. Since various climatic variables were previously found to be significant predictors of *I. iguana* activity (Harris, 1982; López-Torres et al., 2012), multiple regression and Pearson non-parametric correlation analyses were performed to predict their effect on green iguana density (all age classes and sexes considered), representative of activity and detection.

To further determine activity and detection predictors a Wilcoxon rank sum test with continuity correction was conducted to test for a difference in green iguana density between AM/PM survey times. Kruskal-Wallis rank sum tests and pairwise comparisons using Wilcoxon rank sum tests with continuity correction were performed to determine differences in iguana density between survey sites and categorical weather conditions. Pairwise significantly differed at the 0.05 confidence level.

N-Mixture hierarchical modeling was used to obtain iguana abundance estimates and detection probabilities. This regression method uses spatially and temporally replicated count data to model abundance and detection error simultaneously and takes into account imperfect detection, repeated site visits, and zero inflated data (Royle 2004; Joseph, 2009). The R package, unmarked, was used to run this analysis. The pcount() N-mixture model of Royle (2004) was used with the zero-inflated Poisson (ZIP) N-mixture model variant, chosen based on its ecologically sensible mechanisms and low Akaike information criteria (AIC) scores compared to other variants (Joseph, 2009).

Results

From 3/21/2026 to 4/23/2026 a total of 32 *I. iguana* population count surveys were conducted across 4 different study zones at San Juan National Historic Site (Fig. 1). Of the 603 *I. iguana* counted across the 32 surveys (including potential repeats), 208 (34.49%) were female adults, 208 (34.49%) were male adults, 157 (26.04%) were undetermined juveniles, and 30 (4.98%) were undetermined adults; 584 (96.85%) were alive, and 19 (3.15%) were dead or dying. These data represent a closed population and include potential repeat individuals counted (Fig. 2).



Fig. 2: Map of the San Juan National Historic Site, San Juan, PR; showing locations of all green iguana individuals counted during 32 VES surveys that took place to estimate green iguana abundance from 3/21/2026 to 4/23/2026. The red points determine each individual green iguana counted, including potential repeats across the 32 surveys occasional.

Weather Analysis

After running regression analyses, wind speed was the only weather variable of the ones collected that was found to be significant and negatively related to the total number of *Iguana iguana* hectares -1 per survey when using density data from all zones (Fig. 3; Table 1). Relative humidity was found to be significantly and positively related to the total number of *Iguana iguana* density per survey only at Zone Paseo and Zone Cristobal (Table 1).

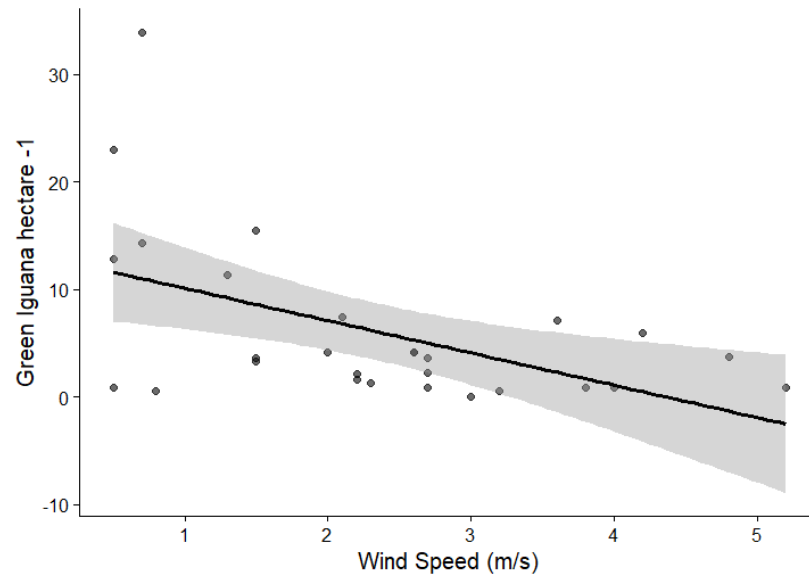


Fig. 3: Plot showing the negative linear relationship between the number of green iguanas counted per hectare across all zones in SJNHS (representative of green iguana observed density in SJNHS; y axis) to the wind speed (m/s; x-axis) recorded. The dark gray line represents the linear regression line (Adj. $R^2 = -0.51$), and the shaded region represents the standard error. The scattered grey points represent individual data observations (n=28).



Table 1: Regression analyses of *Iguana iguana* density (number of individuals/ha) as a function of climatic variables. Predictor variables are as follows: Temperature (°F), Dew Point (°F), %RH percent relative humidity (%), and wind speed (m/s). The (*) symbol delineates significance.

Predictor	Linear Regression analyses			Spearman's rank correlation	
	Coefficient	P-value	R ²	ρ	df
<i>Zone Morro</i>					
Temperature	23.022279	0.997	3.252e-06	0.001803245	6
Dew Point	-190.913	0.144	0.3203	0.5659441	6
%RH	12.5951	0.794	0.01226	0.1107204	6
Wind Speed	12.982	0.248	0.2545	0.5044429	5
<i>Zone Paseo</i>					
Temperature	204.960	0.489	0.08289	-0.2879112	6
Dew Point	-51.597	0.812	0.01024	0.1011994	6
%RH	-104.9050	0.0497 *	0.5005	0.7074657 *	6
Wind Speed	59.745	0.19366	0.3106	-0.5573361	5
<i>Zone Cristobal</i>					
Temperature	26.1476	0.751	0.01813	-0.1346358	6
Dew Point	-69.7402	0.279	0.1912	0.4372517	6
%RH	-41.2216	0.0259 *	0.5903	0.7683065 *	6
Wind Speed	6.2444	0.6171	0.06824	-0.2612215	4
<i>Zone Isla</i>					
Temperature	-0.17076	0.891	0.003392	0.05823814	6
Dew Point	62.2557	0.0810	0.4225	-0.6499782	6
%RH	35.7599	0.222	0.2359	-0.4856514	6
Wind Speed	7.7988	0.0749	0.4357	-0.6600411	6
<i>All Zones</i>					
Temperature	-42.2898	0.111	0.08242	0.2870895	30
Dew Point	-29.1632	0.416	0.0222	0.1489831	30
%RH	20.7150	0.303	0.03527	-0.1878141	30
Wind Speed	13.126	0.005582 *	0.162	-0.5098204 *	26

Group Comparisons

The total number of iguanas counted per hectare did not differ significantly ($W = 123$, $N = 32$, $P = 0.8797$) between AM and PM survey visits. It also did not differ significantly ($X^2 = 1.7592$, $df = 3$, $N = 32$, $P = 0.6239$) between weather conditions (clear, cloudy, sunny, windy). Green iguana density differed significantly ($X^2 = 22.634$, $df = 3$, $N = 32$, $P = 4.814e-05$; Fig. 4) between the four zones (Zone Morro, Zone Isla, Zone Paseo, Zone Cristobal). The density of iguanas counted at Zone Paseo ($M = 15.9 \pm 3.09$, Range: 34-7.17 iguana/hectare -1) was significantly different than Zone Cristobal ($M = 0.923 \pm 0.273$, Range: 2.6-0 iguana/hectare -1), Zone Isla ($M = 2.89 \pm 0.826$, Range: 7.44-0.826 iguana/hectare -1), and Zone Morro ($M = 3.50 \pm 0.447$, Range: 5.99-2.10 iguana/hectare -1) ($P = 0.0054$, 0.0078, 0.0056, respectively). The pairwise comparison indicated that Zone Morro ($M = 3.50 \pm 0.447$, Range: 5.99-2.10 iguana/hectare -1; Fig. 4) was also significantly different than Zone Cristobal ($M = 0.923 \pm 0.273$, Range: 2.6-0 iguana/hectare -1; Fig. 4) ($P = 0.0159$).

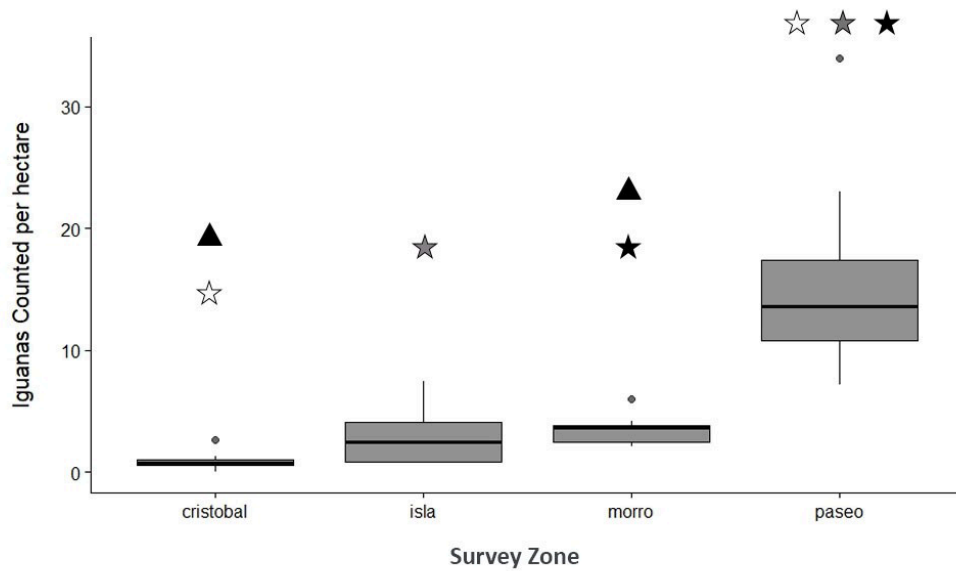


Fig. 4: Boxplot of *Iguana iguana* density at the SJNHS (y-axis) across different survey zones: cristobal, isla, morro, and paseo (x-axis; Fig 1). The horizontal black lines within the boxes indicate the medians. The shaded grey region indicates the interquartile range (IQR), while the whiskers extend to the smallest and largest values within 1.5 times the IQR. Black points beyond the whiskers denote outliers. The different shaded stars and triangles represent the significant differences in *I. iguana* density between zones.

N-Mixture Modeling for Abundance and Detection Probability

The y variable count data was the total number of green iguanas counted per survey (8) in each site (29 transects). The site covariates, variables linked to abundance (λ) that reflect structural or spatial differences between sites over the sampling period, used were visibility score (1-low visibility: high density of trees, structures, or other obstructions; 2-intermediate visibility: intermediate amount of obstructions; 3-high visibility: nearly no obstructions) and elevation (taken in meters at the center of each site). The observational covariates, variables linked biologically to detectability (p) that tend to influence behavior, activity, and visibility during survey periods, used were temperature ($^{\circ}\text{F}$), relative humidity (%rH), dew point ($^{\circ}\text{F}$), wind speed (m/s), and anthropological disturbance score (1 being low, 2 intermediate, and 3 high).

Numerous biologically reasonable ZIP *N*-mixture models were run with various scaled covariate combinations based on ecological relevance and low Akaike Information Criterion (AIC) scores ($\sim$ observation covariate(s) $\sim$ site covariate(s); Table 2). A null model without covariates was also conducted ($\sim 1 \sim 1$; Table 2). For statistical purposes it was necessary to assume that the populations of each site were closed (i. e., no birth, death, immigration, or emigration) during the survey period. After running these models, the model with the lowest AIC score was the “Ecological model” (Table 2) with the visibility and elevation site covariates, and the wind speed, dew point, and anthropologic disturbance observation covariates (AIC: 1033.941; Table 2). This model gave a predicted abundance estimate of 491 individual green iguanas across the SJNHS, with an upper prediction of 688



estimated individuals, and a lower prediction of 352 estimated individuals. The average detection probability of green iguanas across all zones of the SJNHS was predicted to be 16.4% with an upper estimate of 21.5% and a lower estimate of 12.4%.

Table 2: *N*-mixture model results for *Iguana iguana* of the San Juan National Historic site using zero-inflated Poisson (ZIP) distributions. The values in parenthesis represent lower and upper estimates of predicted abundance (λ) and detection probability (p), respectively.

Model Name	Site Covariates Used	Observation Covariates Used	AIC	Abundance, λ	Average Probability of detection, p
Null Model	~1	~1	1401.992	359 (292, 436)	21.3 % (18.1, 24.8)
Full Model	visibility, elevation	wind speed, dew point, anthropologic dist., temperature, humidity	1036.291	527 (369, 757)	15.5 % (11.2, 21.1)
Ecological Model	visibility, elevation	wind speed, dew point, anthropologic dist.	1033.941	491 (352, 688)	16.4 % (12.4, 21.5)
Parsimonious Model	~1	wind speed	1163.803	357 (277, 460.)	21.7% (17.9, 26.2)_

Discussion

The findings from the initial VES-based population census of the green iguana across the San Juan National Historic Site suggests that this species is abundant across most areas of the park, and control efforts should be enforced to proactively mitigate the effects of this invasive species on environmental health, historic park structures, and human health. Further studies should focus on population dynamics and behaviors in response to management control efforts to inform future studies and natural resource management action.

Climate Considerations

Wind speed was the only weather variable of the ones collected that was found to be a significant predictor of iguana density when using density data from all zones. As wind speed increased it was significantly correlated to a decrease in iguana density across all zones (Fig. 3). This result suggests that green iguanas at SJNHS are less active or less detectable at times of higher wind speed. This result is congruent with previous studies, as wind speed affects the heat exchange between animals and the environment, and can also cool the substrate, effectively impacting thermoregulatory behaviors and activity in ectothermic organisms (Ortega et al., 2017; Maia-Carneiro et al., 2012; Logan et al., 2015). Further research is needed to determine if *I. iguana* body thermoregulation effectiveness decreases with increased wind speed causing a reduction in activity and detection rates as has been seen in other lizards (Ortega et al., 2017). It is interesting to note that the other weather variables collected at the time of survey, temperature (°F), relative humidity (%), and dew point (°F) were not significant predictors of iguana density, representative of activity or detection. In previous studies, mean monthly temperatures were seen to be significant predictors of iguana activity and density (López-Torres et al., 2012). The difference in findings could be due to the study methods; weather measurements were taken at the beginning of each survey and correlated to each survey, rather than looking at mean monthly temperatures or even mean daily temperatures. It has been shown that seasonal and daily activity is more crucial in determining ectotherm body temperature, which could explain the lack of correlation of survey weather variables correlated to observed density (Stevenson, 1985; López-Torres et al., 2012). Diurnal lizards including the green iguana are well known to thermoregulate during their daily activity period, despite fluctuating ambient temperatures further explaining why daily temperature collection may not have had a strong effect on observed density (van Marken Lichtenbelt, 1997). There could also be threshold temperatures that never occurred in our study time that could have had a stronger impact on observed density, as our minimum temperature reached was 74.2°F and a maximum of 91.7°F, while iguanas have been known to bask at 100°F and fall into sleep when temp drops below 40°F (López-Ortiz, 2012). Air temperature only captures a fraction of the thermal experience of an ectotherm, and solar radiation has the ability to further impact ectotherm behavior and physiology; which was not measured in this study (Gardner et al., 2024). It would be important to perform monthly population counts to determine if there is a stronger relationship with mean monthly weather measurements and mean monthly population densities, as was found to occur in previous studies (López-Torres et al., 2012). There are likely multiple variables affecting observed density of the green iguana that must be taken into confounding consideration.



Density Estimates

The Visual Encounter population surveys of *I. iguana* at SJNHS suggest that this species is present and varies in density across the study zones. The highest density of green iguana recorded at the park was determined to be along the Paseo del Morro Trail with a maximum of 34 iguanas per hectare observed, a mean of 15.9 +/- 3.09 individuals per hectare, and a minimum density observed of 7.17 iguana hectare; compared to the mean densities of 0.923, 2.89, and 3.5 iguanas per hectare found at zones Cristobal, Isla, and Morro respectively. Differences in observed maximum iguana density may be due to differing environmental characteristics (tree coverage, resource availability, nesting site availability, species interactions etc.) and/or anthropogenic effects (tourist activity, construction activity, site accessibility, previous third-party trapping efforts etc.) that may affect both iguana behavior, population size, and detection probability all able to impact observed density.

Anthropogenic disturbance was recorded for each survey and was found to not have a significant impact on the number of iguanas counted per transect, this suggests that tourist or construction activity is unlikely to explain the differences in iguana density observed at the different zones. Zone Paseo borders the San Juan Bay and has large shore break boulders that have been seen to be occupied by the green iguana and act as potential nesting sites or basking sites, a large cliffside with soft exposed soil for burrowing, and ample coastal vegetation directly below the San Felipe del Morro fortifications that may provide further shelter and warmth; all leading to potentially ideal iguana habitat and may explain part of the variation in site densities. However, other sites do have similar resources available. There were efforts of intense iguana trapping that are known to have occurred at zone Cristobal, however they are not recorded at zone Paseo which may further explain part of the reason for the differences in observed density. More research should be done on the population dynamics and behavioral changes of the green iguana in relation to the zone sites and trapping activity to further determine the explanation for the differences in site densities. The mean density of the green iguana observed at the Paseo zone in SJNHS was found to be slightly higher than the estimated density in areas of its native range (Central and South America, [López-Ortiz, 2012](#)) where the species was overexploited for food (Columbia, 13.7 iguanas/hectare; [Muñoz et al., 2003](#)) and lower than in the range where the species was protected (Panama 36-50 adults/hectare; [Dugan, 1982](#)). Our maximum density of iguana/hectare observed was found to be much lower than the maximum density observed elsewhere in Puerto Rico (119 and 223 individuals per hectare at the peak of the breeding season in Parque Lineal and Canal Blasina respectively; [López-Torres et al., 2012](#)). This difference could be due to a variety of environmental variables and may be partially explained by seasonality differences, as this density was observed at the peak of the breeding season in January, and our data was collected just at the end of the breeding season in late march, early April ([López-Torres et al. 2012](#)). However, this difference in densities should not appease management efforts, given the capability of exponential growth of this species (estimated wild population of 1 million in 2010 and 4 million by 2012 in all of Puerto Rico, [López-Ortiz \(2012\)](#)) (estimated 12.96 iguana per hectare in 2014, and by 2018 without harvest management, estimated to be 67.34 iguana per hectare, [Rivera-Milán \(2020\)](#)). Therefore, it is necessary to continue to monitor this population and take necessary control measures to ensure this invasive species does not exponentially grow in density and risk.

Population Abundance Estimates

N-Mixture hierarchical modeling from VES count data and environmental data collected was used to obtain iguana abundance estimates and detection probabilities to better inform natural resource managers at the SJNHS. To obtain ecologically realistic estimates of abundance, the sources of variation in the data were considered to choose appropriate error distributions and models ([Joseph, 2009](#)). The model with the lowest AIC score and highest ecological relevance gave an estimated abundance of 491 individuals with an estimated range of 352-688 individuals across the 30.351 hectares of the park land considering all sex and age classes. This gives an estimated total density of 16.18 individuals per hectare (estimated minimum: 11.59 individuals/hectare; estimated maximum: 22.67 individuals/hectare) across the park. This model is ecological and reasonable to use, as it had the lowest AIC score of the ones tested and considers weather variables, disturbance, and environmental variables that are likely to affect observed abundance ([López-Torres et al., 2012](#); [Ortega et al., 2017](#)). Of the other models tested the lowest estimated minimum abundance was 277 individuals (9.13 iguana/hectare; Parsimonious model, Table 2) and the highest estimated maximum was 757 individuals (24.94 iguana/hectare; Full Model, Table 2). Based on all models, the estimated abundance of iguanas across the SJNHS does indicate a potential need for management and mitigation control operations. Green iguanas have a very rapid growth rate of hatchlings, early maturity, and high fecundity rate of females, and without management, are expected to grow rapidly from low abundance ([Meshaka et al., 2007](#)). As previously mentioned, the estimated densities obtained across the park are similar to iguana densities obtained in other regions that have seen drastic population increases, and therefore it is recommended to dedicate resources to control efforts at the SJNHS ([Rivera-Milán, 2020](#)).

The models used assume an approximately closed population during the sampling period and given the geographic uniqueness of the study area (a peninsula surrounded by ocean and urban area), this assumption was reasonably appeased, as large-scale immigration and emigration were likely limited during the sampling period. However, there were findings of third-party iguana trapping efforts in the park, which could have had an impact on iguana behavioral changes over time and/or population size, potentially affecting observed abundance and skewing results in certain areas of the park compared to others. While age class and sex were not considered in the N-mixture model for detection/abundance, it is likely they play an important role in detectability relating to the natural history of the green iguana (juveniles are more cryptic, adults have different activity levels based on seasonality or mating presentations [López-Torres et al., 2012](#); [Rivera-Milán, 2020](#)). Cluster size was also not considered and is known to be an important detection covariate, as larger clusters are more detectable ([Rivera-Milán, 2020](#)).

Many factors may influence observed population abundance estimates and models, as what we observe does not necessarily represent the actual population structure, size, and age classes. Therefore, the abundance estimates should be used only as an initial population mark for future modeling and suggestive of population response to management and mitigation efforts due to the uncertainties from the estimation process.



Management Suggestions

The total abundance estimate presented should be accepted with caution, as the true value of the iguana population at the park is likely different and variable to the seasonality (López-Torres et al., 2012; Rivera-Milán, 2020). Our survey window (9:30-11:00 AM and 2:30-4:00 PM) may only be accounting for times when individuals are still relatively visible, explaining the lack of a strong AM/PM effect. This is relevant information to take into account from a management perspective to consider encounter rates, trapping efficiency, and human interactions. Future research on daily temporal iguana activity and seasonality effects on observed density should be conducted to gain further information on timing efficiency for trapping and management operations.

In the Grand Cayman harvest efforts try to maintain iguana density below 2.55 iguanas per hectare (Rivera-Milán, 2020). Our estimated iguana/hectare across the park is 16.18, incentivizing the need to implement control efforts across the park. The highest density of iguanas found at the park was in the Paseo zone, and it could be recommended to focus more effort and resources in this area. If weather conditions were to be considered when planning control schedules, our results suggest that days with lower wind speeds may result in an increased observed density of iguanas and could potentially lead to higher success. However, future research is necessary to confirm that a higher density of iguanas means a higher success in trapping. As variables concerned with strategic trap deployment and trapping methods may find to be more critical in trapping success than environmental variables (wind speed) or density and abundance of iguanas (Nafus et al., 2025).

It should be considered that when intense management control efforts take place, it could result in overcompensation and increased rates of survival and fecundity due to a release from density dependence (more foraging and nesting resources available; Zipkin et al., 2009). Maintaining iguana densities under a certain abundance is not necessarily a management objective, and instead efforts should aim to reduce economic losses, health and safety risks, protection of historic fortifications, improve tourist experience, and minimize risks of iguanas to native flora and fauna (Rivera-Milán, 2020). Reducing fecundity rates may prove to be more important when attempting to control r-selected species such as the green iguana (Meshaka et al., 2007). And therefore, other methods such as artificial nest implementation (Krysko et al., 2007), removal of optimal habitats/vegetation (Krysko et al., 2007) in addition to trapping methods may find to be more cost effective and efficient rather than just aiming to maintain the population under a particular abundance. Therefore, it is also suggested to continue monitoring efforts while performing management control efforts to determine reasonings for potential changes to density (density dependence effects, seasonality effects, harvest management efforts) that may influence the population abundance and dynamics and in result shape management control efforts. It is also recommended to put efforts into further vegetation and ecological studies, as there is limited info on green iguana threats to native species of flora and fauna in Puerto Rico, which could provide important information to further manage this invasive species at the SJNHS.

There is an incomplete understanding of the green iguana population dynamics at the SJNHS, and it is essential to continue monitoring and modeling efforts to further assess population response and guide natural resource management decisions. The information from this initial study should be

referenced for the implementation of specific management and conservation actions. This is essential to effectively promote public health, protect the cultural landscape, and conserve the natural resources across the San Juan National Historic Site.



Acknowledgements

I would like to thank the entire SAJU Wildlife team for all of their guidance and support, especially Miguel A. Naveira-Guzmán, Mariela J. Gomez-Ortíz, Stephanie Malavé-Hernández, Adriana Sepúlveda-Mangual, Keishla Rondón, Kelly Altenhofen, Felix J. López. I would also like to thank Dr. Ricardo López-Ortíz and Dr. Adolfo Rodríguez-Velázquez for guidance and ideas on statistical methods and considerations. Thank you again to Mariela J. Gómez-Ortiz for the translation of the Resumen and Camila Marie-Rain foster puppy for emotional support.

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