An alien rodent on a protected island: estimating the abundance of the rock cavy on Fernando de Noronha, Brazil

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Keywords: *Kerodon rupestris*; capture-resight; exotic species; island conservation.

ABSTRACT – Understanding an alien species' population structure and dynamics is crucial to both assess its potential threat level to native environments and to plan management if needed. This is achieved by estimating population parameters. However, on island environments – especially in developing countries – logistics, cost and certain species traits may hinder data collection, resulting in sparse datasets. The present study aimed at providing preliminary estimation of survival probability and abundance of rock cavy (*Kerodon rupestris*; Caviidae: Rodentia) on the island of Fernando de Noronha using a sparse data. Using a zero-truncated poisson log-normal mixed effects model (ZPNE) we first estimated the number of individuals in one rock cavy colony (i.e., Boldró colony). Using its calculated density (number of individuals divided by colony area) and information on mapped colonies collected using satellite imagery, we calculated the island population size. The ZPNE model presented a mean survival probability of 0.5499 in 185 days, and a mean capture probability of 0.858. The extrapolation of population size estimates from the Boldró colony (21; CI95% 12 – 36 individuals) suggests that the rock cavy population in Fernando de Noronha consists of 5,473 (CI95% 3,114 – 9,622) individuals. Even with limited data and warranted caution, the present preliminary study assessed population parameters for this insular rock cavy population, contributing with valuable information for planning its management for the first time.

Um roedor exótico em uma ilha protegida: estimando a abundância do mocó (*Kerodon rupestris*) em Fernando de Noronha, Brasil

Palavras-chave: *Kerodon rupestris*; captura-observação; espécies exóticas; conservação de ilhas.

RESUMO – Compreender a estrutura e dinâmica populacional de espécies exóticas é fundamental para avaliar seu potencial nível de ameaça aos ambientes nativos e planejar, se necessário, seu manejo. Esse conhecimento é obtido por meio da estimativa dos parâmetros populacionais. No entanto, em ambientes insulares, especialmente em países em desenvolvimento, a logística, o custo e certas características das espécies podem dificultar a coleta de dados, resultando em conjuntos de dados esparsos. O presente estudo teve como objetivo fornecer uma estimativa preliminar da probabilidade de sobrevivência e da abundância do mocó (*Kerodon rupestris*; Caviidae: Rodentia) na ilha de Fernando de Noronha por meio de dados esparsos. Usando um modelo de efeitos mistos log-normais de Poisson truncado em zero (ZPNE), primeiramente estimamos o número de indivíduos em uma colônia de *K. rupestris* (a colônia Boldró). Usando a densidade calculada (número de indivíduos dividido pela área da colônia) e informações sobre colônias mapeadas coletadas por meio de imagens de satélite, calculamos o tamanho da população da ilha. O modelo ZPNE apresentou uma probabilidade média de sobrevivência de 0,5499 em 185 dias e uma probabilidade média de captura de 0,858. A extrapolação das estimativas de tamanho da população da colônia de Boldró (21; IC95% 12 - 36 indivíduos) sugere que a população de mocós em Fernando de Noronha consiste em 5.473 (IC95% 3.114 - 9.622) indivíduos. Mesmo com dados limitados e cautela justificada, o presente estudo preliminar avaliou os parâmetros populacionais dessa população insular de *K. rupestris*, contribuindo com informações valiosas para o planejamento de seu manejo pela primeira vez.

Un roedor exótico en una isla protegida: estimación de la abundancia del mocó en Fernando de Noronha, Brasil

Palabras clave: *Kerodon rupestris*; captura-avistamento; especies exóticas; conservación de islas.

RESUMEN – Comprender la estructura y la dinámica de población de una especie exótica es fundamental para evaluar su nivel de amenaza potencial para los entornos nativos y planificar, en caso necesario, su gestión. Este conocimiento se obtiene mediante la estimación de los parámetros poblacionales. Sin embargo, en islas, especialmente en países en vías de desarrollo, la logística, el costo y ciertas características de las especies pueden dificultar la recogida de datos, dando lugar a conjuntos de datos escasos. El presente estudio tiene como objetivo proporcionar una estimación preliminar de la probabilidad de supervivencia y abundancia del mocó (*Kerodon rupestris*; Caviidae: Rodentia) en la isla de Fernando de Noronha utilizando datos escasos. Utilizando un modelo log-normal de Poisson de efectos mixtos truncado en cero (ZPNE), estimamos primero el número de individuos en una colonia de mocós (la colonia de Boldró). Utilizando la densidad calculada (número de individuos dividido por el área de la colonia) y la información sobre colonias cartografiadas recogida mediante imágenes de satélite, calculamos el tamaño de la población de la isla. El modelo ZPNE mostró una probabilidad media de supervivencia de 0,5499 en 185 días y una probabilidad media de captura de 0,858. La extrapolación de las estimaciones del tamaño poblacional de la colonia de Boldró (21; IC 95% 12 - 36 individuos) sugiere que la población de mocós en Fernando de Noronha consta de 5.473 (IC 95% 3.114 - 9.622) individuos. Aun con datos limitados y una cautela justificada, este estudio preliminar evaluó los parámetros poblacionales de esta población de mocós de la isla, aportando información valiosa para planificar su gestión por primera vez.

Introduction

A species introduced outside of its original distribution range is referred to as an alien (or adventive, exotic, foreign, introduced, non-indigenous, non-native; [1]) species. Although no general consensus exist, an alien species may also be classified as invasive, based on impacts on the new environment [2] or transposed ecological and biogeographical barriers [3][4], depending on the school of thought. In either case, when aiming at protecting natural landscapes and the whole ecosystem thereof, however, it is inadvisable to wait until negative impacts caused by known alien species in a new environment are perceived to act. In fact, when the negative effects of a biological invasion are perceived, eradication of invasive species is considerably more expensive and harder to achieve [5]. To understand to what extent an alien species may threaten a native environment or become invasive, it is first necessary to assess its population structure and dynamics, such as survival rate and abundance [6]. Such population parameters also allow for simulation of management strategies to reduce the risk of eradication failures.

However, in some cases, logistical challenges and high data collection costs may impede effective data gathering. This is especially true for island environments in developing countries due to limited personnel and financial resources. Species that are elusive or cryptic may further halt data acquisition. Under such circumstances, estimating wildlife population parameters can become challenging and the probability of generating a sparse dataset – dataset with limited data points – is increased [7]. Still, when dealing with alien species the importance of generating information for management outweighs the uncertainty that comes with analyzing sparse datasets [8].

The rock cavy (*Kerodon rupestris;* Rodentia, Caviidae) exemplifies the most recent known introduction on the island of Fernando de Noronha (Brazil), intentionally done by the military to be used as eventual food resource [9]. According to Oren [10] and Alves and Leite [11], between 1967 and 1969, four rock cavy specimens (two males and two females) were captured on the continent and released on Fernando de Noronha. Since then, its population grew on the island, benefited by the abundant presence of rocky outcrops, the species' natural *habitat* in the Caatinga, the Brazilian dryland [12]. The island of Fernando de Noronha, located in the state of Pernambuco, belongs to an archipelago with the same name. Since its discovery during the 16th century, it has been colonized by several new species. Despite its potential relevance for this island's conservation, the impacts, colonization stage, and rock cavy population parameters are still largely unknown.

Cost and logistics play an important role on rock cavy data collection on Fernando de Noronha. However, most of the absence of information on this insular rodent population is likely due to considerably low capture rates for capture-recapture studies. In the continent, trapping success has been cited as far less than 1% [13]. Lacher [13] described that the only successful method for capturing wild rock cavies in the continent was by cornering individuals with the help of dogs, and actively constraining them by hand. Zappes, Portella, and Lessa [14] described that using a combination of wires and nets the authors managed to capture one female of *Kerodon acrobata*, which was only recently described as a separate species from the *K. rupestris* [15]. The difficulties of capturing rock cavies reported in the past are still largely corroborated by recent studies [12][16][17][18][19] and inevitably lead to the generation of sparse datasets.

The present study aimed at generating unprecedented information about this insular rock cavy population such as its survival and capture probabilities, colony density and, ultimately, total population size. Such information is highly valuable for alien species management planning to protect this UNESCO World Heritage Natural site [20], even if coming from sparse datasets.

Methods

Study area

The oceanic archipelago of Fernando de Noronha is located on the Northeast of Brazil, approximately 360 km ashore. It is constituted by 21 islands and islets with the biggest one being inhabited (Ilha de Fernando de Noronha), measuring 18.4 km^2. The climate is tropical with dry (August to March) and rainy (March to August) seasons [21]. The original island vegetation was removed when it served as a prison during the 19th century, but recovered to form a xeromorphic, seasonal, deciduous vegetation, with herbaceous, shrub and forest physiognomies [22]. Of the historically registered vascular plant species, 4,2% are endemic (n=14), but it is likely that some of these species have already been extinct while invasive species such as the evergreen leucaena

(*Leucaena leucocephala*) prosper in the archipelago [22]. Not only the climate and the rocky geology of the island, but also the relatively abundant vegetation in comparison to its original *habitat*, are a favorable environment for the rock cavy. We chose a rock cavy colony to calculate species density, as well as survival and capture rates. We define a colony as a rocky outcrop formation with defined size, where a group of rock cavies – a gregarious species – can be found. All rock cavy colonies on Fernando de Noronha compose its insular population. Even on the continent, rock cavies are rarely seen outside of their colony and direct surroundings [12], and have been shown to be displaced by tourist presence [23]. The chosen study colony is locally known as Boldró (03°50'45.23'' S, 32°25'44.80' W, *datum* WGS84), where individuals are less skittish due to the constant tourism presence.

Study species

The medium sized rock cavy, *Kerodon rupestris* (Caviidae), averages 350 mm in body length and weights up to 1,000 g [24]. Although at times reported as crepuscular [25], the rock cavy on the archipelago presents diurnal behavior. The species has a hierarchical familiar organization and relies on running and hiding on rock cracks to avoid predation, with females typically produce 1-2 offspring per litter and breeding potentially multiple times per year, especially during the rainy season [12][24][26][27]. This species has a relatively restricted geographic distribution, occurring from Piauí to northern Minas Gerais state and shows remarkable adaptability to semi-arid conditions, utilizing both terrestrial and arboreal habitats within its range [28]. These areas in northeastern Brazil receive between 400 to 1,200 mm of annual rainfall, with less than 800 mm being most common [29]. Secondary data on the species are scarce. Even regarding the continental populations, there are only 13 behavioral and ecological studies that generated some sort of information about the rock cavy [12][13][17][23][24][26][30][31][32][33][34][35]. Most of the more recent studies citing this species are focused on its morphology, parasites or genetics [15][18][25][36][37][38][39][40][41][42][43][44][45][46][47][48][49][50]1820. There are no scientific studies on this insular population.

Data Collection

Two field trips that lasted 20 days in total were performed in April and October 2014. To estimate survival and capture probabilities, as well as number of individuals in the Boldró colony (i.e., to calculate colony density) we generated two datasets, a capture-mark-recapture by observation (i.e., capture-recapture, detailed in section Capture and marking) and a population survey (i.e., counting, detailed in section Population survey and recapture). This colony was used due to the easier access both for capturing the individuals and for observations. Moreover, the individuals in the colony are more used to humans, which increases the probability of observation, and thus, our dataset for density calculation. We believe, however, that this colony is representative of the other ones observed on the island. The model used to estimate the population parameters from these datasets is described in the section zero-truncated poisson log-normal mixed effects model (ZPNE). We then searched for rock cavy colonies on the island by prospecting transects across the island (Figure 1) and calculated colony area of all those that were detected using satellite imagery. We confirmed the presence of rock cavies on colonies by actively searching for individuals, presence of latrines, and typical cavy herbivory (i.e., leaf and eventual bark consumption). These methods are described in detail in section Identification and measurement of colonies. Using the total area of colonies and the calculated density of rock cavies, we then calculated the total population size (described in the section Calculation of total population size).

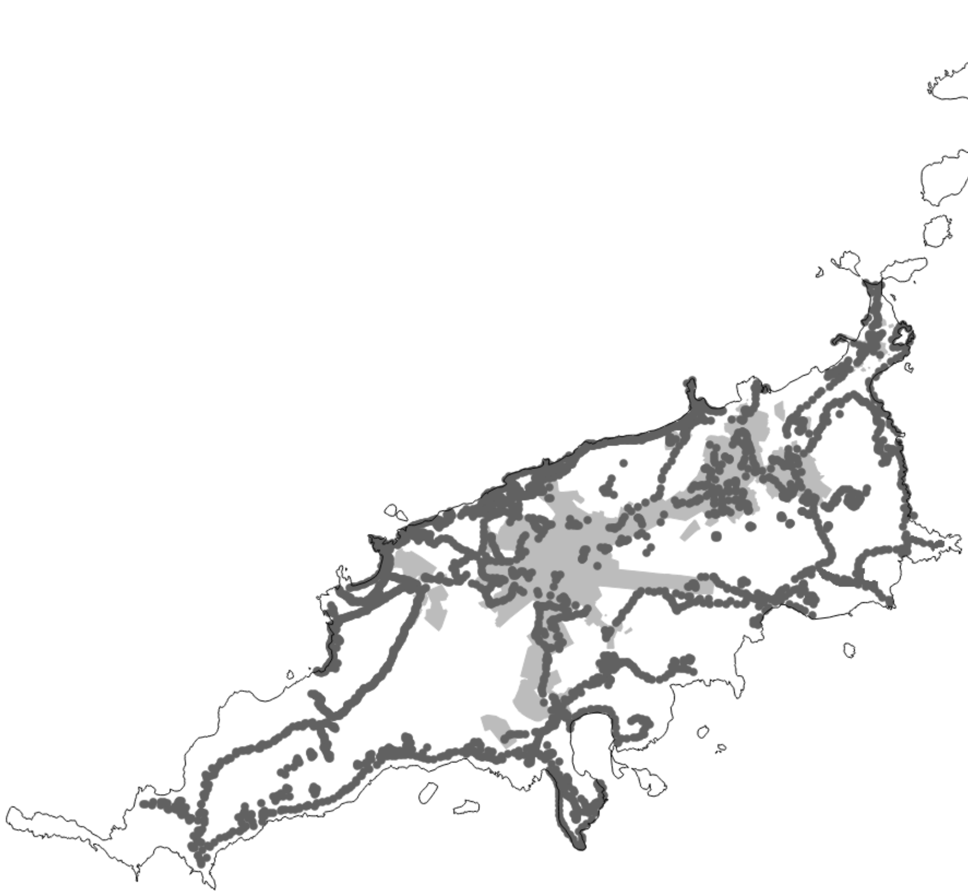

Figure 1 – Map of Fernando de Noronha archipelago, presenting in light grey the island's urbanized area, and in dark grey transects and potential rock cavy (*K. rupestris*) colonies assessed *in situ*. The *in situ* assessment was done to confirm the identification of potential rock cavy colonies in imagery captured by the ©DigitalGlobe Quickbird satellite (65 cm pan-sharpened resolution) as well as to confirm the presence and absence of rock cavies on different *habitat*.

Capture and marking

Capture and marking were performed daily, totaling five occasions on the first field trip, and 15 occasions on the second. Animals were trapped with six Tomahawk (two size 900 x 210 x 210 mm, four size 450 x 210 x 210 mm) and two Sherman (430 x 125 x 145 mm) live traps. The eight traps were baited with local and exotic tree leaves and flowers, and placed on the floor around the colony under tree shadows (to avoid death by insolation) at least 3 m apart from each other. The traps were placed strategically to maximize captures (i.e., near often visited trees). In total, eight individuals were trapped and marked. Their complete capture history can be found in Table 1. Traps were opened in the early morning after population survey observations, and closed in the end of the afternoon, comprehending a total of 1.795 hours of trap effort. Only adult individuals were captured.

Captured individuals were submitted to an anesthetic protocol of ketamine (20 mg/kg), xylazine (2 mg/kg), meperidine (15 mg/kg), midazolam (2 mg/kg) and atropine (0.04 mg/kg) IM in the pelvic member (Dr. Paulo R Mangini, DVM; licenses no. 38804-4 and 38804-5). Under anesthesia, two numbered earrings (one metal and one bright colored) were placed on the right (females) or left ear (males). As ear samples were also collected for genetic analysis (not included in this work), each individual presented a unique set of earmarks, allowing for individual identification. Both sides of marked individuals were photographed to aid posterior individual identification by observation. All marked specimens were individually identifiable throughout the study. The animals were released where captured after recovering from anesthesia. Observation of marked individuals for composing the capture-recapture datasets was performed while counting the population, as detailed below.

Table 1 – Capture-recapture history and daily counting of rock cavies (*Kerodon rupestris*) from a colony located on the island of Fernando de Noronha, Brazil.

Field Trip	Individuals								Daily Counts
	1	2	3	4	5	6	7	8	
1	1	1	0	0	0	0	0	0	11
1	1	1	0	0	0	0	0	0	9
1	0	0	0	0	0	0	0	0	8
1	1	1	0	0	0	0	0	0	16
1	1	0	0	0	0	0	0	0	11
2	0	0	0	0	0	0	0	0	11
2	0	0	1	0	0	0	0	0	7
2	0	0	1	0	0	0	0	0	6
2	0	0	1	0	0	0	0	0	16
2	0	0	1	1	0	0	0	0	10
2	0	0	1	0	1	1	0	0	8
2	0	0	1	0	1	0	0	0	13
2	0	0	1	0	0	0	1	0	13
2	0	0	1	0	0	0	1	0	8
2	0	0	0	0	0	0	0	1	15
2	0	0	0	0	0	0	0	0	3
2	0	0	0	0	0	0	0	0	8
2	0	0	1	0	1	0	0	1	10
2	0	0	1	0	0	0	1	0	11
2	0	0	1	0	1	0	1	0	13

Population survey and recapture

A modified fixed-radius point count method was used as an abundance assessment method [51] any of which can be used to test for differences in community composition among sites, or for differences in the abundance of a given bird species among sites. These indices are (1, where the observed extent was determined by the colony area, which is clearly delimited. Observations were performed once daily, at approximately the same time (between 6:00 h am and 8:30 h am) using photographic equipment (Sony Cyber-Shot DSC-HX100V 30x Zoom) and yielded a total of 7.18 hours of observation (average of 20 minutes per day of activity). For the population survey, all visible animals were counted while individual differentiation was possible to avoid double counting. At the end of each survey day, the maximum number of different non-marked individuals seen was noted as the daily count. Notes and photographs on all observed marked individuals were taken as individual recapture information.

Zero-truncated poisson log-normal mixed effects model (ZPNE)

The chosen model for this work was the zero-truncated poisson log-normal mixed effects model [52], which we used with a sin link function due to data type and structure. The ZPNE allows different types of input data – both capture-resight and population counting datasets – and is a full-likelihood robust design, allowing for a capture 'occasion' within each field trip. This means that each day is considered a different sampling occasion with a closed population within a field trip, and open populations (i.e., death and birth) between field trips. Due to these characteristics, the ZPNE reduces uncertainty in parameters generated by sparse datasets, which is the case of the present study. Outputting survival, capture probability and population size at each sampling occasion, the ZPNE is available off-the-shelf, in the software MARK [53]. Different formulations of the ZPNE were tested and the most appropriate one ZPNE (i.e., smallest AICc) presented constant survival

(φ) probability and varying number of individuals in the colony (*N*) across field trips. Considering the colonies seem to be around carrying capacity (please see discussion regarding carrying capacity on section The rock cavy distribution, population structure, and status on the island) and there are no changes to survival pressures (i.e., stable poaching and predation rates) between the trips, such parameterization choice is easily explained.

Immigration was assumed to be irrelevant due to both the short time between field trips and as studies in captive colonies show that the rock cavy is extremely territorial and do not allow immigration to a colony which is at its carrying capacity [26]. The only study available on *K. rupestris*' social system [54] observed that emigration, and consequently immigration, involve juvenile individuals exclusively. Therefore, the parameter that accounts for 'unavailability' (γ'; or temporary emigration) was fixed to zero. Permanent emigration from the colony was effectively equivalent to mortality, as studies showed that increasing the density by even a small amount (0.09 animals/m2) in a captive experiment resulted in severe territorial disputes, with immigrant individuals typically being violently rejected and killed when attempting to join the established colony [13]. Moreover, the survival of an individual lacking the protection of the colony is also unlikely due to high predation rates of rock cavies by feral cats [55], as well as dogs and poachers. Capture by observation (p^2) and individual heterogeneity (σ) were considered to be constant through time as the landscape did not present significant changes between field trips. All colonies were also assumed to be homogenous with regards to their structure, density, and behaviour. Such assumption is necessary to allow us to calculate the insular population size. Although only available through extrapolation, such information is extremely valuable for management purposes. Considering the complete lack of information on this population, and due to the small island size and the very narrow genetic lineage, we believe it is an acceptable assumption for the time being.

Identification and measurement of colonies

Rock cavy colonies are found in open rocky formations or rocky outcrops (i.e., large stones piled up). We identified 68 colonies through 13 transects walked across all different habitats on the island, totalling ~30 km (Figure 1). We marked the location of the colonies using a GPS device (Garmin eTrex 30® and Garmin Colorado 300®) and overlayed the points on a imagery captured by the ©DigitalGlobe Quickbird satellite (65 cm pan-sharpened resolution) using the QGIS software [56]. All colonies identified on the ground were seen in the satellite imagery except for one small colony (approximately 2 m^2) observed during the transects, where the rocks were completely covered by vegetation. Additionally, we identified 32 'new' colonies in the digital imagery which were not assessable on the ground and could, therefore, only be confirmed in the imagery. All colonies were then manually measured in the imagery. To ensure imagery measurements were accurate for calculating the total colony area, the Boldró Colony was manually measured and compared to its digital measurements.

Calculation of total population size

We calculated the rock cavy density estimates for the Boldró colony by dividing the average number of individuals calculated by the ZPNE by its total area (651 m^2). These calculated densities were then multiplied by the total extent of each identified colony. The sum of all population sizes resulted in the total number of rock cavies on the archipelago. The CI95% for the entire population was calculated using a similar approach, replacing mean estimated population size by the lower and the upper confidence bounds.

Results

Faeces, herbivory and/or rock cavy individuals were observed in 100% of the surveyed colonies. Although this might not be common for the cave-dwelling rodents, all indirect signs of activity observed were recent. Population parameters' estimates generated by the ZPNE for the Boldró rock cavy colony are presented in Table 2. Across both field trips, the population remained relatively stable, while the model estimated survival probability confidence interval at 95% as between 0 and 1. Mean capture probability by observation was estimated at 0.858 (CI95% 0.597 – 0.961). The mean density estimate for the Boldró colony was 0.0316 individuals/m^2. Minimum and maximum densities found on the island were 0.018 individuals/m^2 and 0.0555 individuals/m^2, respectively. The total population size was calculated as 5,473 individuals (CI95% 3,114 – 9,622). Finally, the digital measurement of the Boldró colony presented less than 6% difference in area size (i.e., smaller) in comparison to the manual measurement. Although we only managed to measure one colony,

Table 2 – Estimates, standard error (*Std. Error*), confidence interval at 95% (*CI95%*) of the population size (*N*) for each field trip (FT), probability of observation (p^2), and survival probability in 185 days (φ) calculated by the zero-truncated poisson log-normal mixed effects (ZPNE) model, available in software MARK, for a rock cavy colony in Fernando de Noronha/PE – Brazil.

FT		*Estimates*	*Std. Error*	*CI95%*	Minimum counted
All	φ	0.5499	1,221.236	0.000 – 1.000	–
	p^2	0.858	0.087	0.597 – 0.961	–
1	*N*	19	5.822	11 – 34	16
2		22	6.268	13 – 38	

which could be improved in the future to increase reliability, this result suggests that the digital measure might be considered accurate enough to be used in this study.

Discussion

The present study assessed the distribution and estimated population parameters of the exotic rock cavy on the island of Fernando de Noronha, Brazil, for the first time. We calculated rock cavy colony density per m^2, and the total abundance of individuals for the main island of Fernando de Noronha. We also identified strengths and weaknesses of applying the ZPNE model to our rock cavy sparse dataset. Despite the challenges involved in the calculation of total population size from one to all colonies on the island, our study provides unprecedented information on the insular rock cavy population. Moreover, our results provide a warning case on the establishment of (native) species in new habitats and could support the planning of management actions for this and other exotic species.

The rock cavy distribution and population structure

According to Alves and Leite [11], within 23 years the population of rock cavies was perceived as spread across the whole main island of Fernando de Noronha. This conference abstract is, however, anecdotal; it only presents descriptive data in regards to the species' abundance on different colonies on the island. The present study confirmed rock cavy presence for all of the 68 surveyed colonies, which scientifically supports this anecdote. Neither rock cavies, its latrines, or its presence signs were observed outside a colony's surroundings. This corroborates ecological observations on the species in the continent, where the rock cavy is believed to be very restricted to this type of *habitat* [12][24][26][27].

Despite the availability of few captive studies [13][17][24][30][31][32][33], only three have generated some sort of *in situ* information on this specie's ecology [12][26][35], all in the continent. There is a complete gap of knowledge regarding this alien species on the on Fernando de Noronha. Captive studies, although rarely comparable to *in situ* ones, might improve reliability of estimates by setting maximum thresholds to these. Considering the rock cavy, captive populations to which nests, water and food were provided *ad libitum*, did not endure more than 0.09 individuals per m^2 [13]. In a recent longer-term *in situ* study (i.e., in the continent) mean rock cavy density was found to be 0.0012 (CI95% 0.0007 – 0.0022) individuals/m^2 [12].

The density calculated using the the ZPNE was 35% smaller than the estimated maximum density observed by the captive study and 26 times larger than the mean estimate calculated by the *in situ* study. This demonstrates that the rock cavy density on the island is considerably higher in comparison to the continent, and close, although still lower, than the maximum density tolerated in captivity. The last fact suggests further that the island population might be at carrying capacity. Higher density than in situ studies can be explained, by the marked wet season – which results in abundance of resources for the rock cavy – and decreased poaching and predation pressures on the island than in the continent. On the other hand, lower density than ex situ ones is easily explained by the lack of direct subsidies and existing poaching and predation of individuals *in situ*. Moreover, this demonstrated that our estimates are ecologically sound. It is important, however, to acknowledge that the current effort only used one point of validation for the measurement of the colonies (i.e., in situ versus digital imagery), which could introduce uncertainties in the calculated densities and should be revised by future works.

Extrapolation of results from one colony to the entire island

Extrapolation of estimates and predictions is a considerable challenge to scientists, but it has become a sine qua non in ecological studies in the last decades [60]. Although there are important advantages on extrapolating data from a colony to the whole population, there are also disadvantages. Both are well described by Miller et al. [60]. As a general rule, the more severe the extrapolation, the lower the reliability of the predictions. In a context where precision is of high importance, for example when planning management of highly invasive species in favorable environments, blindly trusting information that presents low uncertainty can lead to failures in accomplishing eradications [61]. Invasive rodent eradication failures, for example, happen at least two times more often on tropical than on temperate islands, in part due to lower certainty of population parameters and their interactions with the tropical island environment [62].

On the other hand, information with high uncertainty is still better than no information and can be used as an abundance index to be monitored by further studies. Even if highly uncertain, an estimate of abundance might provide local managers and decision makers with a comprehensive context of the target species' situation, allowing for initial management feasibility discussions. Invasive species' management, for example, can be planned targeting the upper populations' abundance threshold, instead of its average. This increases the financial burden of a management plan, but is a possible trade-off to improve the chances of success. In the present case, direct scaling up the rock cavy density from a colony to the whole island is believed to be sufficient at this time due to (1) the small sized island and the (2) urgent need of information on population abundance. The information generated by the present work can be considered ecologically sound and, with caution, may be used to simulate management interventions for the rock cavy. Moreover, it may provide managers with enough information about parameters that need improved precision and those that may be sufficient for management decisions.

The ZPNE model used and its application to a sparse dataset

The zero-truncated poisson log-normal mixed effects model (ZPNE) has been extensively used and proven to provide good population estimates. Still, when it comes to using it with sparse datasets for developing management plans, generated estimates should be used cautiously. Our model, although the best option for a sparse dataset available off-the-shelf, presented two main weaknesses: (1) an uninformative confidence interval for the survival probability, and (2) a lower estimate for population size than the minimum number of individuals known to be present. Regarding the first weakness, although it is not possible directly assessing bias for real data, extreme values on standard errors of parameter's estimates might provide information regarding its accuracy. The ZPNE presented an uninformative confidence interval for survival (Table 2), due to its considerably large standard deviation. Still, even though uninformative confidence interval might indicate that some model assumptions were violated [63][64] a large standard error not necessarily mean that estimates are biased. Regarding the second weakness, the ZPNE estimated a lower confidence bound than the minimum number of individuals known to be alive, which is the known number of marked individuals summed by the total non-marked individuals counted. On the other hand, recapture probability's uncertainty was calculated to be within a reasonable interval, especially for a sparse dataset. This parameter suggested that recapture by observation is highly efficient for this species. Moreover, as previously noted, our estimates seem to be ecologically sound. However, even though we were able to estimate urgently needed population parameters of the Fernando de Noronha's rock cavy, we advise caution when using these parameter estimates for planning rock cavy management due to its high level of uncertainty.

Rock cavy management considerations

While the precautionary principle is valuable for managing known invasive species, especially during early establishment, addressing well-established populations such as the rock cavy require substantial resources and comprehensive management plans [57] prevention of its spread to non-affected areas (e.g., sites, regions, and cross-continent. While the rock cavy population has established itself beyond geographical barriers [3][4], it is critical to note that there have not been any formal impact assessments for the species.

Biological studies should, for example, confirm the specie's potential impact on native flora and facilitation of invasive plant species. Concerns about landscape modification through rock erosion [11][58] also warrant scrutiny. Health impact assessments, including investigation of potential Chagas disease transmission [59], would also provide valuable data for informed management decisions. The priority moving forward should be a comprehensive, scientific assessment of the rock cavy's ecological impact on the main island of the archipelago. This evaluation would enable evidence-based allocation of conservation resources, ensuring that management efforts target the most significant threats to the archipelago's ecosystem.

Conclusion

Our observations show that the rock cavy is distributed across the entire island, though confined to rocky outcrops and their surroundings, similar to its habitat on the mainland. We estimated survival probability and density within one colony and used this information to calculate the total abundance of individuals on Fernando de Noronha. Future studies could enhance abundance and survival estimates, as well as recruitment rates, by developing tailored models for this species – models that can better accommodate sparse data. As demonstrated here, observational recapture is highly effective and could serve as a cornerstone for such customized models, especially for species that are difficult to trap. Although the information on population abundance could help managers understand the potential implications of this species on the archipelago, the ecological impacts of the rock cavy on the island require scientific assessment, as the population seems well established and has an important colonization potential. Importantly, we generated unprecedented information on the rock cavy population on Fernando de Noronha. While this data should be interpreted with caution due to the high uncertainty, it may nonetheless provide local managers with a foundation for initial management feasibility discussions.

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