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A 3-YEAR POPULATION STUDY OF G*uerlinguetus brasiliensis ingrami* (RODENTIA, SCIURIDAE) AT THE SERRA DA BOCAINA NATIONAL PARK, RIO DE JANEIRO STATE, BRAZIL

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Abstract: The Brazilian Squirrel *Guerlinguetus brasiliensis ingrami* (Rodentia, Sciuridae) is commonly observed in the wild, yet its population parameters are poorly known because this species is rarely captured with traditional live-traps. Here we evaluated the population parameters of *G. b. ingrami* in a 3-year capture-mark-recapture study at the Serra da Bocaina National Park, Rio de Janeiro state, Brazil. Population parameters were evaluated using the Jolly-Seber model POPAN and the Minimum Number Known to be Alive (MNKA). Population size estimates ranged between 3.2 ± 2.4 (mean ± SE) and 51.3 ± 15.0 individuals based on POPAN, and 2 and 10 individuals based on MNKA. Our population density estimates (1.3 to 74.3 individuals/km^2) were similar to those documented in previous studies carried out in the Atlantic Forest. Monthly survival was high (0.94 ± 0.02) and capture probability was low (0.16 ± 0.05), probably reflecting the species trap-shyness. The low capture probability of *G. b. ingrami* evidences the importance of the unique population data presented in this study for increasing basic knowledge on this species.

Keywords: Atlantic Forest; Brazilian squirrel; MNKA; POPAN.

The Brazilian Squirrel *Guerlinguetus brasiliensis ingrami* (Rodentia, Sciuridae) occurs in coastal Brazil from Espírito Santo state to Rio Grande do Sul state, and Misiones in Argentina (De Vivo & Carmignotto 2015). This subspecies is scansorial, and its diet consists mostly of lichens, bryophytes, leaves, fruits, insects, eggs, and coconuts (Ribeiro *et al.* 2010, De Vivo & Carmignotto 2015). *Guerlinguetus b. ingrami* is an important seed disperser because it frequently stores the seeds spread within individuals' home range (Ribeiro *et al.* 2010). A previous study in an area of *Araucaria* forest and a reforested area of *Pinus taeda* in southern Brazil found home range sizes ranging from 2.8 to 6.5 ha for males and 2.1 to 3.5 ha for females of *G. b. ingrami* (Bordignon & Monteiro-

Filho 2000). Mendes & Cândido-Jr. (2014) described several behaviors and foraging techniques for *G. b. ingrami*, including a facial marking behavior that probably has maintenance and territorial functions.

Despite being frequently observed in their diurnal daily activities, individuals of *G. b. ingrami* are rarely captured with traditional live-traps (*e.g.*, Sherman, Tomahawk) and, consequently, appear to be less abundant in mammal inventories when compared to other non-volant small mammal species (*e.g.*, Passamani & Fernandez 2011, Bordignon 2014, Hélder-José *et al.* 2016). Few estimates of population density are available for this species, all of them based on the line-transect distance sampling method, with one exception (Bordignon & Monteiro-Filho 2000). These estimates ranged from 9.3 to 44.0 individuals/km^2 in Atlantic Forest areas in the Espírito Santo state (Chiarello 2000, Ferreguetti *et al.* 2016), and from only 0.2 to 28.7 ind./km^2 in 11 Atlantic Forest areas in southeastern Brazil (Galetti *et al.* 2017). However, density was higher in a secondary *Araucaria* forest in southern Brazil (89 ind./km^2) in the only study based on live-traps (Bordignon & Monteiro-Filho 2000).

Here we evaluated for the first time the population parameters of *Guerlinguetus b. ingrami* in a 3-year capture-mark-recapture study at the Serra da Bocaina National Park, Rio de Janeiro state, Brazil. We sampled non-volant small mammals at four sites along the RJ-165 state highway (Figure 1), which traverses the Serra da Bocaina National Park in the municipality of Paraty, Rio de Janeiro state, Brazil (Site 1: 23°12′19″ S, 44°50′17″W, 1,193 m a.s.l.; Site 2: 23°11′39″ S, 44°50′27″W, 1,122 m a.s.l.; Site 3: 23°11′06″ S, 44°49′47″ W, 800 m a.s.l; Site 4: 23°11′28″ S, 44°50′39″ W, 1,050 m a.s.l.; *Datum* WGS84). The maximum linear (Euclidean) distance between sample sites was 2.3 km (Figure 1).

Twelve trapping sessions were carried out from June 2013 to December 2016. At each site, two 290-m transects were established, each with 30 trap stations. A Tomahawk® trap (30x9x9 cm) was placed on the ground at odd points, and a Sherman® trap (31x8x9 cm) was set in the understory at 1.5–2.0 m above ground at even points. Ten additional Sherman traps were set in the canopy (> 3.5 m above ground) along each transect during the first two trap sessions, and then in the understory, from the third to the last trap session. Tomahawk traps were baited with a mixture of bacon, banana, grinded peanut and oat, and Sherman traps with slices of banana. Live traps remained active for five consecutive nights in each trap session. The total sampling effort was 18,987 trap-nights. Trapping and handling conformed to guidelines sanctioned by the American Society of Mammalogists (Sikes & Animal Care and Use Committee of the American Society of Mammalogists 2016). All captured specimens were marked with a numbered ear-tag at first capture. Specimens that died in the live traps were collected, prepared, and deposited at the Museu Nacional/Universidade Federal do Rio de Janeiro (IBAMA/MMA process no. 02001.003937/2008-18, authorizations no. 248/2013 and 610/2015).

We grouped the capture-history data of individuals from the four sampling sites to carry out the analyses, assuming that the sites sampled the same population. This is reasonable because the total sampled area (see below) was within a home range size found for the species in a previous study (Bordignon & Monteiro-Filho 2000). We did not model males and females separately because of the small sample sizes. Population parameters were estimated using the Jolly-Seber (JS) model POPAN (Schwarz & Arnason 1996, 2018) in Mark program (White & Burnham 1999). We used POPAN formulation to estimate apparent survival (φ), capture probability (p), and population size at each trap session (N_i). The JS models are a type of open population models, as they allow entries from births or immigration and losses from deaths or permanent emigration, even though they cannot distinguish the sources inside each respective group (Schwarz & Arnason 1996). The JS models assume that individual tags are not lost, sampling is instantaneous, the study area is constant, and both survival and capture probabilities are the same for marked and unmarked individuals (Schwarz & Arnason 1996, 2018). Despite we considered *G. b. ingrami* a trap-shy species, we decided to use JS open models and possibly violate the assumption of equal capture probabilities among individuals because we considered the alternative use of closed models inadequate. Even though closed models would account for differences between capture and recapture probabilities, the period of study was sufficiently long (79 months) for the occurrence of breeding and mortality of adults, which would make it inadequate to consider *G. b. ingrami* population closed.

We built models with a combination of φ and p constant or varying with time. The parameter b, which is the probability of entrance in the population, could only vary in time, and not be held constant, because it is restricted to sum to 1 (Schwarz & Arnason 1996). We ranked and selected the POPAN models based on the Akaike's information criterion corrected for small samples (AICc), the AICc difference between each model and the model with the lowest AICc value (ΔAICc), and the Akaike weight (w_i) (Burnham & Anderson 2002).

We also estimated monthly population sizes as the Minimum Number Known to be Alive (MNKA; Krebs 1966), to compare with the results from the probabilistic models. MNKA is an enumeration technique that sums the number of individuals found in a trap session, as well as the number of individuals found before and after that session (Krebs 1966). Although MNKA may be more biased than the probabilistic models as it may underestimate population sizes, MNKA is still used in small mammal studies, especially those with relatively small sample sizes (< 50 individuals; Pacheco *et al.* 2013). Therefore, we used MNKA as a reference, to assess whether JS estimates are indeed above this method, and to provide estimates that can be used for comparison by future studies.

To estimate population density (number of individuals/km^2), we calculated the total area sampled on Google Earth Pro (Google Inc. 2018), using two methods (Figure 1). First, we built a minimum convex polygon (MCP) encompassing the four sampling sites, which returned an estimated area of 1.6 km^2. As the MCP probably overestimated the total area sampled by including non-sampled

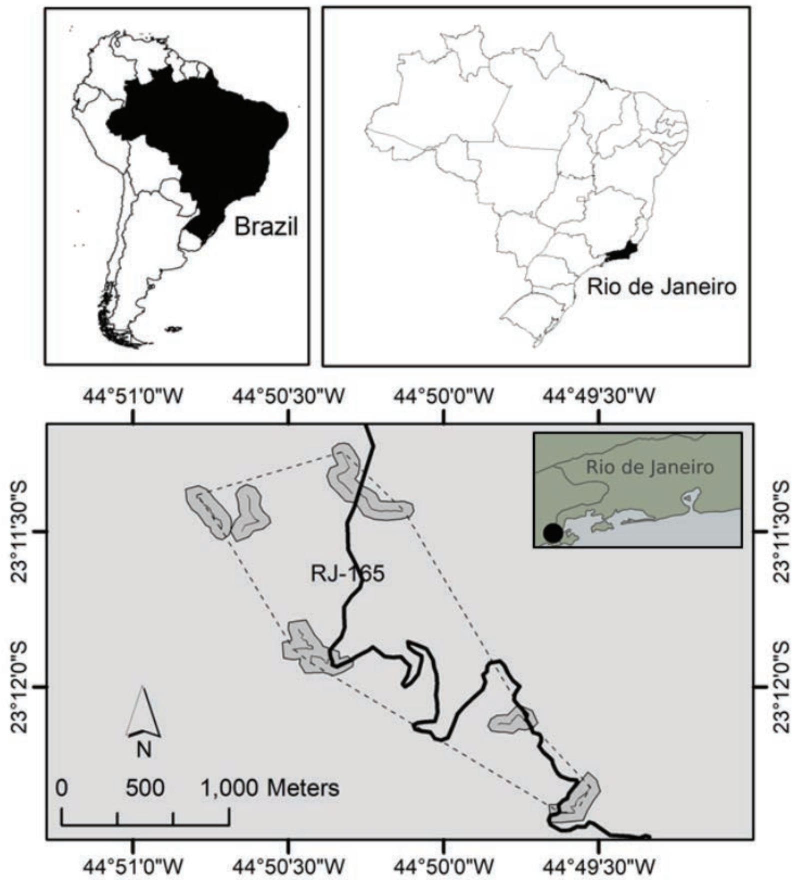

Figure 1. Study site at the Serra da Bocaina National Park (black dot), state of Rio de Janeiro, Brazil. The eight sampling transects (thin lines) were located within the forest in four sites across a state highway (RJ-165). The estimated sampling areas surrounding each transect (gray polygons) were estimated using a boundary strip with a width of 54 m. The dotted line shows the minimum convex polygon encompassing the eight sampling transects.

areas, we also used the classic boundary strip (BS) method (Dice 1938, Eckrich *et al.* 2018). To do so, we built a polygon surrounding each sampled transect, using a boundary strip surrounding each transect with a width of 54 m (Figure 1). This width corresponded to the radius of the home range of *G. b. ingrami*, based on a mean home range size of 3.7 ha (as estimated by Bordignon & Monteiro-Filho 2000) and assuming a circular home range. The few overlapping areas between two close transects were disregarded in the calculations. The final estimate of sampling area by the BS method was 0.69 km^2.

We obtained 35 captures of 28 individuals (14 females and 14 males) of *G. b. ingrami* during the study. Seven captures (20.0%) were obtained with Tomahawk traps on the ground, 27 captures (77.1%) with Sherman traps on the understory, and one capture (2.9%) with a Sherman trap in the canopy. For females mean body mass was 192.6 ± 31.4 g (mean ± SD; N = 14) and mean head-body length 187.5 ± 16.9 mm (N = 14); and for males mean body mass was 193.3 ± 21.8 g (N = 12) and mean head-body length was 186.2 ± 10.8 mm (N = 14). No female with signs of reproduction, such as lactation, was captured during the study.

Table 1. Results of the selection of the POPAN models for the estimation of apparent survival (φ), capture probability (p) and the probability of entrance (b) for *Guerlinguetus brasiliensis ingrami* (Rodentia, Sciuridae) at the Serra da Bocaina National Park, Brazil. K is the number of parameters, AICc is the Akaike's information criterion corrected for small samples, ΔAICc is the difference of AICc value to the best model, w_i is the Akaike weight.

Models	K	AICc	ΔAICc	w_i
φ(.) p(.) b(t)	14	171.14	0.00	1.00
φ(t) p(t) b(t)	33	948.23	777.09	0.00
φ(.) p(t) b(t)	24	951.62	780.48	0.00
φ(t) p(.) b(t)	24	959.10	787.97	0.00

The top-ranked model indicated that both apparent survival and capture probability were constant, with Akaike's weight of 1 (Table 1). Population size of *G. b. ingrami* ranged between 3.2 ± 2.4 (mean ± SE) and 51.3 ± 15.0 individuals, according to the best model using POPAN formulation, and between 2 and 10 individuals using MNKA (Figure 2). Population density estimates ranged from 1.3 (using the MNKA and MCP methods) to 74.3 ind./km^2 (using the POPAN and BS methods; Table 2).

Monthly survival was relatively high (0.94 ± 0.02 (mean ± SE)) and capture probability was relatively low (0.16 ± 0.05 (mean ± SE)). We captured one male (body mass = 200 g; head-body length = 188 mm on first capture) from September 2013 to August 2016 (35 months) and one female (body mass = 217 g; head-body length = 200 mm) from March 2014 to December 2016 (33 months).

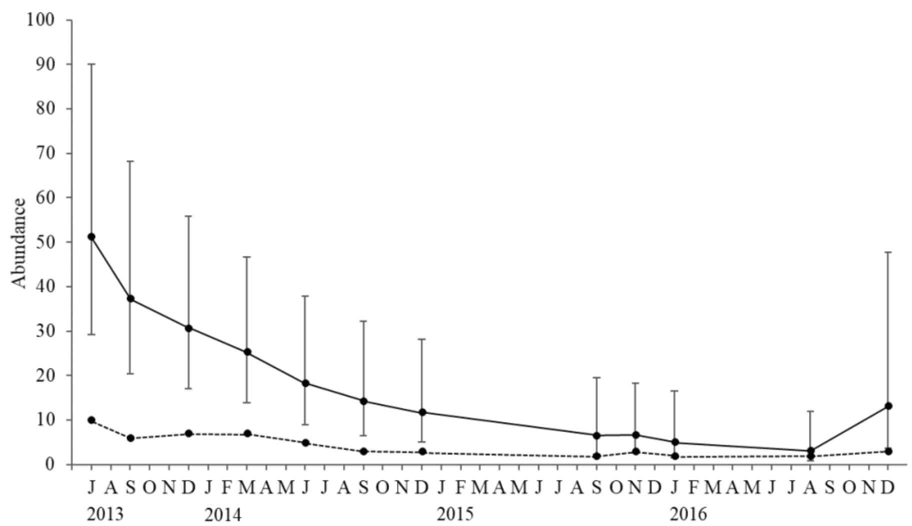

Figure 2. Abundance estimates of *Guerlinguetus brasiliensis ingrami* (Rodentia, Sciuridae) derived from the best POPAN model (solid line) and calculated by the method of Minimum Number Alive (MNKA; dotted line), from June 2013 to December 2016, at the Serra da Bocaina National Park, municipality of Paraty, state of Rio de Janeiro, Brazil.

Table 2. Density estimates (number of individuals per km^2) for *Guerlinguetus brasiliensis ingrami* (Rodentia, Sciuridae) at the Serra da Bocaina National Park, Brazil. Population sizes were estimated with two methods, the Jolly-Seber model POPAN and the Minimum Number Known to be Alive (MNKA). The total sampling area was also estimated using two methods, a minimum convex polygon encompassing all sampling transects and the boundary strip surrounding each individual transect (see Figure 1). Minimum and maximum values are between brackets.

Method to estimate total sampling area	POPAN (mean ± SD)	MNKA (mean ± SD)
Minimum convex polygon (1.6 km^2)	11.7 ± 9.3 (2.0 — 32.1)	2.8 ± 1.6 (1.3 — 6.3)
Boundary strip (0.69 km^2)	27.1 ± 21.5 (4.6 — 74.3)	6.4 ± 3.7 (2.9 — 14.5)

Although the assumption of homogeneity of capture among individuals has probably been violated using POPAN, we believe the estimates from the open model were more accurate than MNKA, which seemed to be negatively biased (Figure 2). *Guerlinguetus b. ingrami* had a low capture probability, and the result was a different pattern between POPAN model and MNKA (Figure 2). This occurred because capture probability and the similarity between MNKA and probabilistic population sizes are positively correlated as demonstrated by Pacheco *et al.* (2013). Also, population sizes of *G. b. ingrami* showed a slight tendency to decrease throughout the study, except for the last month (Figure 2). The intrinsic and extrinsic causes of this potential decrease, such as intra-specific competition or climatic factors, could be a focus of investigation in future studies.

Our estimates of population density were similar to those previously found in studies carried out in other areas of Atlantic Forest (Bordignon & Monteiro-Filho 2000, Chiarello 2000, Ferreguetti *et al.* 2016, Galetti *et al.* 2017). However, differently from the present study, all these previous studies used the line-transect distance sampling method to obtain data on population density (Chiarello 2000, Ferreguetti *et al.* 2016, Galetti *et al.* 2017), except Bordignon & Monteiro-Filho (2000). In the study of Bordignon & Monteiro-Filho (2000), live-traps were used to capture the individuals, but the authors used feeding stations supplied weekly with peanuts to attract individuals, which may have aggregated individuals leading to higher estimates of population density. A similar pattern was found in a previous study with the Balearic lizard *Podarcis lilfordi* (Squamata, Lacertidae) which compared population density estimates using both methods (CMR and line-transect distance sampling) and found comparable estimates, although they slightly differed in magnitude, *i.e.* lower values of population density were found using CMR (Anton *et al.* 2013).

We also found a high monthly survival for *G. b. ingrami* (0.94 ± 0.02). Previous information on longevity and reproduction of *G. b. ingrami* is scarce, but this species has the potential to survive several years in the wild and reproduces once or twice a year (Bordignon & Monteiro-Filho 2000, Alvarenga & Talamoni 2005). We recorded two adult individuals that remained in the study area for at least 33 to 35 months, suggesting longevity longer than three years in the wild. Related species with different body sizes and habitats types frequently live about seven years (Nitikman 1985, Lurz *et al.* 2005, Merrick *et al.* 2012).

Capture probability of *G. b. ingrami* was low (0.16 ± 0.05), but because analysis using POPAN model do not distinguish between marked and unmarked individuals, we can only suppose that this result may be related at least partly to the species trap-shyness. Trap-shyness occurs when the probability of an individual to be recaptured is diminished by previous capture history (Carothers 1979). We noticed that squirrels appeared more stressed inside live traps and with handling than other small mammals during the study, corroborating a previous study (Bordignon 2014). In some cases, death could be considered the ultimate behavioral response to trap (Williams *et al.* 2002). Other possible causes of the observed deaths inside live traps are: 1) hypothermia, as the study region is characterized by periods of high rainfall and lower temperatures, or 2) the diurnal habits of the species, which may prolong the time individuals remain inside traps, compared to the time most nocturnal, non-volant small mammals stay inside traps. Mortality inside traps for this species in particular could be reduced, for example, by carrying out more trap inspections during the day, or by adding hydrophobic cotton and more food inside traps. Also, instead of stress within traps, the low capture probability could also be a consequence of sampling design and intrinsic characteristics of the species. *Guerlinguetus b. ingrami* has considerably large home ranges and probably moves long distances, which may reduce capture probability of individuals in a continuous forest such as the Serra da Bocaina National Park. Moreover, the bait used might not have been sufficiently attractive to squirrels.

Our study is the first to provide estimates of apparent survival and capture probability in *G. b. ingrami*, in addition to population size and density. Future studies should attempt to identify the factors underlying trap-shyness in this species, to provide guidelines for modifying sample designs frequently used for non-volant small mammals in Neotropical forests to increase capture probability of this species. Capturing individuals of this species with live-traps may be more expensive and require more time investment (*i.e.*, more trap sessions or occasions) compared to other methods, such as line-transect distance sampling. However, it is essential to estimate population parameters obtained from individual marking and handling, such as survival and sex ratio. On the other hand, line-transect distance sampling may provide more accurate estimates of effective sampled area and population density than live-trapping if the method premises are fulfilled (Anton *et al.* 2013). However, the use of line-transect distance sampling method can also be challenging for this particular species in Atlantic Forest areas with dense vegetation (Bordignon 2014). Therefore, we suggest that future studies on *G. b. ingrami* use both methods (live traps *vs.* line-transect distance sampling methods) in the same area to provide a more complete understanding of the population ecology of this species.

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