SRAS Final Report

Reproductive ecology of the black caiman (*Melanosuchus niger*) in the Araguaia National Park, Tocantins, Northern Brazil: an initial approach

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Abstract

The black caiman (*Melanosuchus niger*) is a large crocodilian species of significant ecological and conservation importance, with a wide distribution across the Amazon and Tocantins-Araguaia basins. Despite its broad distribution, and considering its occurrence in different forest and savanna formations, studies on its reproductive ecology in ecotonal areas, such as the Amazon–Cerrado transition, remain scarce, particularly in the Araguaia National Park (PARNA), Tocantins, Brazil. This study aimed to generate information on the reproductive ecology of the species in PARNA, contributing to the identification of priority areas for conservation. During three consecutive reproductive seasons (2021–2023), active searches were conducted in 46 water bodies within PARNA, including lakes, channels, and rivers, resulting in the recording of 25 nests of *M. niger*. For each nest, environmental and structural variables were assessed, including nest dimensions, egg characteristics, vegetation cover, distance to water bodies, and incubation microclimate. Clutch size averaged 26.9 ± 4.94 eggs per nest, and mean nest dimensions were 1.73 ± 0.35 m in length, 1.52 ± 0.28 m in width, and 0.45 ± 0.10 m in height. Incubation occurred mainly between September and January, with an average duration of 85.6 days. Nests were found in different vegetation types, including forest and savanna formations, with canopy cover ranging from 5% to 95%. A positive correlation was observed between female size and nest volume, as well as between the number of eggs and clutch mass, indicating reproductive allometric patterns. The average hatching success was 44.41%, with a low predation rate (14.3%). These results provide novel information on the reproduction of *M. niger* in an Amazon–Cerrado ecotone and contribute to the identification of priority areas for the conservation of the species in PARNA.

Introduction

The black caiman (*Melanosuchus niger*) has a wide distribution across the Amazon basin and also occurs in the Tocantins-Araguaia basin. It is the largest crocodilian species in these hydrographic regions, with males exceeding 5.0 m in total length and reaching up to 400 kg (Medem, 1983; Silveira, 2003; Thoisy *et al*., 2006; Thorbjarnarson, 2010; Marioni *et al*., 2013; Costa & Nunes, 2019).

Despite its ecological importance, there are still significant gaps in the knowledge of its reproductive ecology in certain parts of its distribution. The reproductive ecology of crocodilians involves complex strategies related to nest-site selection, nest structure, incubation conditions, and parental behavior (Shine, 1988; Murray, Crother & Doody, 2020). These factors directly influence reproductive success and recruitment of new individuals into the population. In crocodilians, environmental variables such as temperature, humidity, vegetation cover, and hydrological regime can affect both embryonic development and hatchling survival (Villamarín-Jurado *et al*., 2011; Campos & Magnusson, 1995).

The Araguaia National Park (PARNA), located in the northern portion of Bananal Island, lies within the Araguaia-Tocantins basin. This area represents an ecotone between the Amazon and Cerrado biomes and is characterized by high environmental heterogeneity (IBAMA, 2001). The region includes a wide diversity of aquatic and terrestrial environments, such as seasonal forests,

savanna formations, and floodplain areas. The lack of detailed information on the reproduction of *M. niger* in this region limits the development of effective conservation strategies. In this context, this study aimed to monitor and characterize nesting habitats, assess reproductive parameters, and identify priority areas for the conservation of *M. niger* in the Araguaia National Park, contributing to the generation of applied knowledge for the conservation of the species.

Methods

Study area

The study was conducted in the northern portion of Araguaia National Park, located in the state of Tocantins, Brazil (Figure 1). The region is part of the Araguaia-Tocantins basin and is characterized by a hydrological regime with distinct seasonal flooding and dry periods.

During the rainy season, the floodplain known as the Bananal Plain, covering approximately 88,119 km² of floodable area (Irion *et al*., 2016), becomes inundated, with peak flooding occurring between January and May and low-water periods between June and September (Aquino, Latrubesse & Souza Filho, 2008).

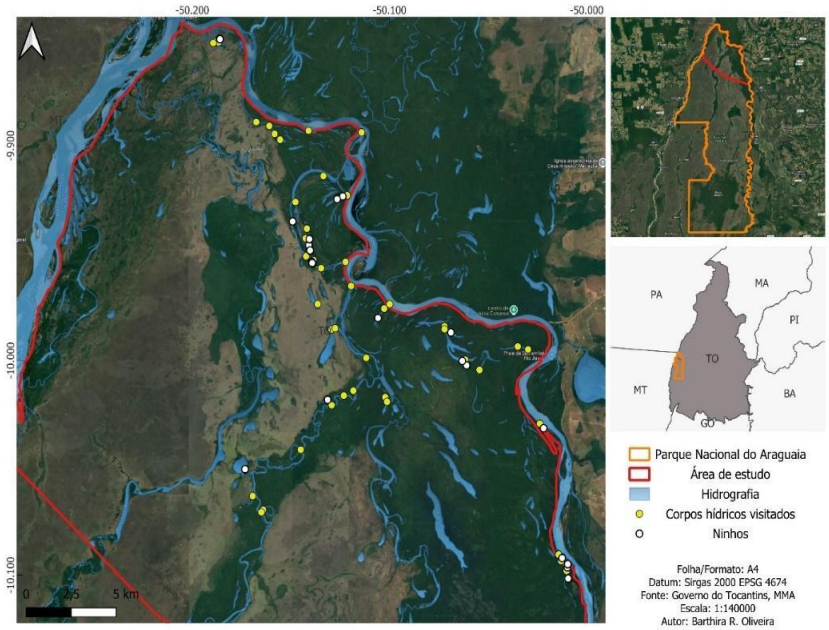


Figure 1. Study area in Araguaia National Park, Tocantins, Brazil highlighting the surveyed water bodies and nesting sites of the black caiman (*Melanosuchus niger*) monitored during the 2021–2023 seasons.

Sampling and nest searching

Field activities were conducted during three consecutive reproductive seasons, between September and January from 2021 to 2023, along the margins of pre-selected water bodies. Initially, water bodies were selected based on the analysis of satellite images available via Google Earth and MapBiomas data (Collection 8), aiming to represent different types of potentially suitable nesting habitats, as described by Campos (2003a), Mendonza (2006), Villamarín-Jurado *et al*. (2011), and Val *et al*. (2024). A total of 46 water bodies were monitored, including lakes, channels, and rivers.

Nest searches were carried out through walking surveys along the margins of water bodies, as well as boat-based surveys using canoes equipped with 15 HP outboard motors. The search area

focused on a strip of up to 20 meters from the water margins towards the vegetation, following ecological criteria described in the literature (Villamarín-Jurado *et al*., 2011; Barão-Nóbrega *et al*., 2014; Val *et al*., 2024). All nests found were georeferenced using GPS and classified according to their status as active, old, or abandoned, based on the presence of eggs and the structural characteristics of the mound (Campos, 2003; Barão-Nóbrega *et al*., 2014).

Monitoring and behavioral records

Each nest was monitored throughout the incubation period, with visits conducted at the beginning of the laying period and at the end of incubation to record embryonic development, predation events, and hatching success.

To document female behavior and events of predation or hatching, four active nests were selected for monitoring using camera traps equipped with infrared sensors and night vision, positioned 2 to 4 meters from the nests and at a height of 50–150 cm above the ground (Torralvo, Botero-Arias & Magnusson, 2017; Merchant *et al*., 2018). In addition, automatic data loggers (Ink Bird, IBS-TH2) were installed in some nests to monitor temperature and humidity throughout the incubation period. These devices were programmed to record data at 30-minute intervals until hatching.

Collection of environmental and structural nest variables

For each nest, environmental and structural variables were recorded, including nest length, width, and height, number of eggs per nest, egg dimensions and mass, distance from the nest to the water body, distance to the nearest tree, and canopy cover.

The distance to the water was measured using a laser rangefinder (up to 100 m range), as this parameter directly influences the risk of flooding and the ability of hatchlings to reach the water after emergence. The distance to the nearest tree was measured with a measuring tape and used as an indicator of the vertical structure of the vegetation surrounding the nest. In tropical environments, proximity to woody vegetation can affect shading conditions, influence nest microclimate, and provide some protection against predation (Campos, 2003a; Villamarín-Jurado & Suárez, 2007). Canopy cover was visually estimated above the center of each nest using a percentage scale (0–100%), based on the degree of canopy obstruction. All estimates were conducted by a single observer to ensure consistency and reduce subjectivity, following the approach described by Jennings, Brow & Sheil (1999) and discussed by Korhonen *et al*. (2007).

Nest morphometric measurements (length, width, and height) were obtained using a measuring tape (±1 cm) (Marioni *et al*., 2021), and nest volume was estimated using an inverted cone geometric model. All nests were carefully opened to count eggs and collect morphometric data (length, width, and mass) using a digital caliper (±0.1 mm) and a precision scale (±1 g) (Barão-Nóbrega *et al*., 2014). During handling, eggs were kept in the same position to avoid damage to the embryo (Webb *et al*., 1987).

The presence or absence of the female at each nest was recorded and, when possible, female size was estimated based on the relationship between total body length and head length (Hall & Portier, 1994; Verdade, 2001; Platt *et al*., 2009; Silva, Botero-Arias & Marmontel, 2011), which was used to assess reproductive allometric relationships.

Monitoring and hatching success

Nests were inspected throughout the incubation period, and hatching was confirmed based on the observation of hatchlings near the nest, as well as evidence such as eggshells and membranes (Villamarín-Jurado & Suárez, 2007; Val *et al*., 2024). Predation events were identified based on signs and disturbances in nest structure, following the procedures described by Torralvo, Botero-Arias & Magnusson (2017), including evidence such as footprints, digging marks, destroyed or

missing eggs, and structural alterations of the mound. Hatching success was estimated as the proportion of hatchlings observed relative to the total number of eggs per nest.

Data analysis

All analyses were performed using R software v.4.3.2 (R Core Team, 2023). Data were initially explored using descriptive statistics (mean ± standard deviation) and tested for normality (Shapiro–Wilk) and homoscedasticity (Levene). When necessary, data were log-transformed (log10). Relationships between reproductive variables were evaluated using simple linear regression, with female size as the independent variable and nest volume, clutch mass, and number of eggs as dependent variables.

The multivariate structure of environmental variables was investigated using Principal Component Analysis (PCA), with standardized data (mean = 0; SD = 1) to ensure equal contribution of variables. Microclimatic variation was analyzed descriptively and graphically to visualize temperature and humidity patterns throughout the incubation period. Relationships between environmental and reproductive variables were assessed using Spearman correlation and non-parametric tests (Kruskal–Wallis and Wilcoxon), while categorical variables were analyzed using Fisher's exact test. Nest distribution among vegetation types was evaluated using Pearson's chi-square test, with Fisher's exact test applied when expected frequencies were low.

Nest volume (m^3) was estimated using an inverted cone model ($V = \frac{1}{3} \cdot \pi \cdot r^2 \cdot h$), based on measured nest dimensions. Reproductive success was assessed using hatching success (%), calculated as the proportion of observed hatchlings relative to the total number of eggs per nest. Of the 25 nests recorded, 21 were classified as active.

To evaluate the effect of vegetation cover on hatching success, a comparison between nests with and without confirmed hatching was conducted using the Wilcoxon–Mann–Whitney test, following normality assessment. Mean and standard deviation were calculated to describe vegetation cover in both groups.

Results

A total of 46 water bodies were monitored in Araguaia National Park (PARNA), where 25 nests of *Melanosuchus niger* were recorded over three reproductive seasons. Egg-laying occurred mainly between September and October. The incubation period ranged from 81 to 92 days, with a mean of 85.6 days. Mean clutch size was 26 eggs, ranging from 18 to 34. Egg length and width ranged from 70.7 to 108 mm (mean = 90.62 mm) and from 44.0 to 74.0 mm (mean = 49.22 mm), respectively. Total clutch mass ranged from 2.19 to 3.89 kg, with a mean of 3.26 kg (Table 1). Nest dimensions varied from 1.15 to 2.20 m in length, 0.92 to 2.04 m in width.

Nests were found across different habitat types, including forest and savanna formations. Canopy cover at nesting sites ranged from 5% to 95%, indicating a wide variation in shading conditions.

Table 1. Descriptive statistics of reproductive and nest variables of *Melanosuchus niger* in Araguaia National Park, Brazil.

Parameter	Number of eggs	Clutch mass (g)	Female size (m)	Nest length (m)	Nest width (m)	Nest height (m)	Volume (m^3)
Mean	26	3.256	2.47	1.73	1.53	0.44	0.29
Min–Max	18–34	2.193–3.978	2.20–2.70	1.14–2.30	0.92–2.04	0.20–0.71	0.09–0.77
SD	4.30	575	0.17	0.32	0.26	0.11	0.15

Analysis of reproductive variables showed a positive correlation between female size and nest volume (Figure 2). In addition, a positive association was observed between the number of eggs and total clutch mass (Table 2).

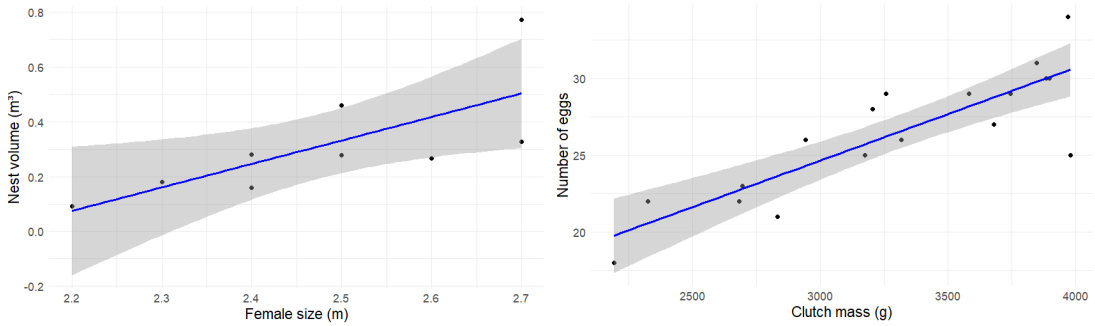


Figure 2. (A) Relationship between female size (m) and nest volume. (B) Relationship between clutch mass (g) and number of eggs in *Melanosuchus niger* nests in Araguaia National Park.

Table 2. Statistical results of simple linear regression analysis between female size (m) and nest characteristics of the black caiman (*Melanosuchus niger*) in Araguaia National Park.

Dependent variable	**Independent variable**	**Coefficient (β)**	**R^2**	**t statistic**	**p-value**
Nest volume (m^3)	Female size (m)	0.857	0.526	2.785	0.0271
Clutch mass (g)	Female size (m)	1413.2	0.169	1.195	0.2714
Number of eggs	Female size (m)	12.783	0.492	2.604	0.0352
Number of eggs	Clutch mass (g)	0.006	0.727	6.522	0.000

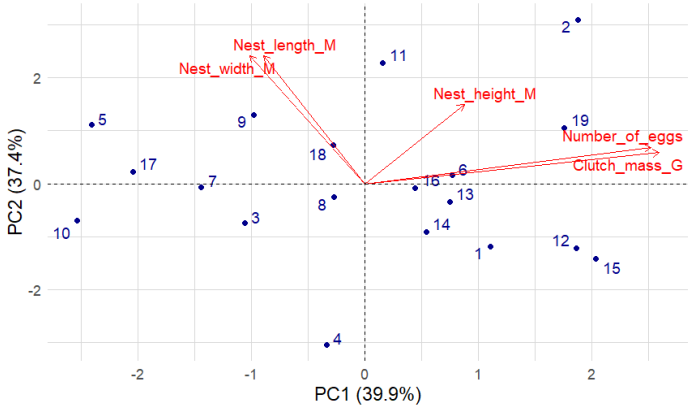
To explore morphometric variation among *M. niger* nests, a Principal Component Analysis (PCA) was performed using structural and reproductive variables. The first two components explained 77.3% of the total variance, with PC1 (39.9%) associated with the number of eggs and clutch mass, and PC2 (37.4%) mainly related to nest dimensions, particularly length and width (Figure 3A).

The PCA of environmental variables showed that the first two components explained 72.2% of the total variance. PC1 (40.1%) was primarily associated with distance to water and nest height, whereas PC2 (32.1%) was related to vegetation cover and distance to the nearest tree, reflecting shading and vegetation structure (Figure 3B).

Reproductive success was estimated using hatching success (%), defined as the proportion of hatchlings observed relative to the total number of eggs per nest (Table 3). Of the 21 active nests, 19 showed evidence of hatching. The mean hatching success, calculated for seven nests with complete data, was 44.41% ± 33.56, indicating high variability among nests.

Based on camera trap observations from four active nests, a total of 74,664 images were obtained, confirming the presence of females near all monitored nests. A total of 22 parental care events were recorded, associated with the presence of female *M. niger* (Figure 4). Most interactions (approximately 82%) corresponded to female presence near the nest, while about 18% involved clearly defensive behaviors against potential predators, such as *Nasua nasua* (coati) and lizards of the family Teiidae (Figure 4).

(A)



(B)

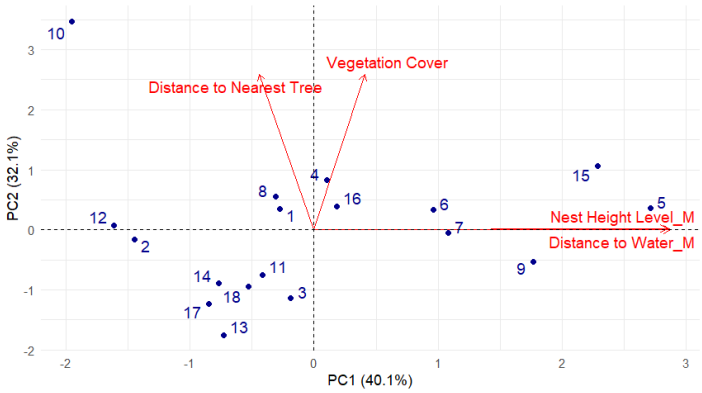


Figure 3. A) Principal Component Analysis (PCA) of nest-related variables of *Melanosuchus niger* (nest length, width, and height, number of eggs, and clutch mass) in Araguaia National Park. B) Principal Component Analysis (PCA) of environmental variables of nest microhabitats of *Melanosuchus niger* (vegetation cover, distance from nest to water, distance to the nearest tree, and nest height) in Araguaia National Park.

Table 3. Hatching success (%) per nest of *Melanosuchus niger* monitored in Araguaia National Park.

Parameter	Number of eggs	Number of hatchlings	Hatching success (%)
Mean	26.28	8.42	44.41
Min–Max	21–30	4–16	0–94.73
SD	4.17	3.88	33.56



Figure 4. Evidence of parental care in *Melanosuchus niger* in Araguaia National Park. A) Female opening the nest to assist hatchlings during emergence; B) Female assisting hatchlings as they leave the nest, with hatchlings observed alongside the female.

Two nests were completely predated by jaguar (*Panthera onca* Linnaeus, 1758) and teiid lizards (*Tupinambis* sp.; *Salvator* sp.). No intact eggshells were found in these nests after predation, indicating complete predation events and resulting in a predation rate of 14.3% (n = 2).

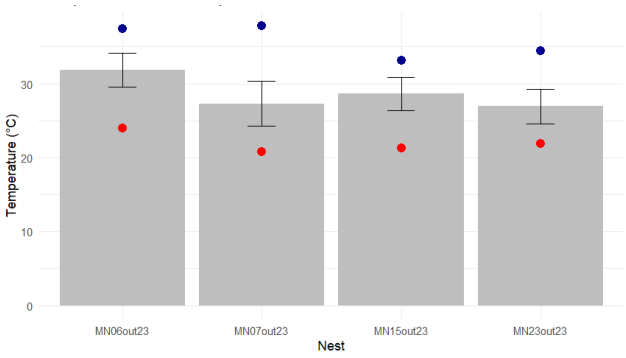
Nests were located in different habitat types, predominantly in forest formations (n = 22), as well as in savanna and floodplain environments (n = 3). Canopy cover ranged from 5% to 95% (mean = 58.4% ± 26.43; n = 23). Nests with hatching showed higher mean canopy cover (66.43% ± 21.92) compared to those without hatching (57.14% ± 30.20), although this difference was not statistically significant (Wilcoxon, p = 0.394), indicating no association between canopy cover and hatching success.

Microclimate analysis of nests monitored with data loggers, revealed variation in temperature and relative humidity during the 2023 monitoring period (Table 4 and Figure 5). Descriptive statistics of microclimatic conditions for each nest are presented below.

Table 4. Incubation microclimate characteristics, vegetation cover, and volume of four *Melanosuchus niger* nests monitored in Araguaia National Park in 2023.

Nest ID	Mean Temp (°C)	Temp SD	Mean Humidity (%)	Humidity SD	Vegetation cover (%)	Volume (m³)
MN06	31.9	2.29	95.6	1.13	60	0.34
MN07	27.3	3.04	81.6	13.3	60	0.28
MN15	28.6	2.20	94.9	2.92	95	0.25
MN23	26.9	2.34	90.0	9.54	90	0.27

(A)



(B)

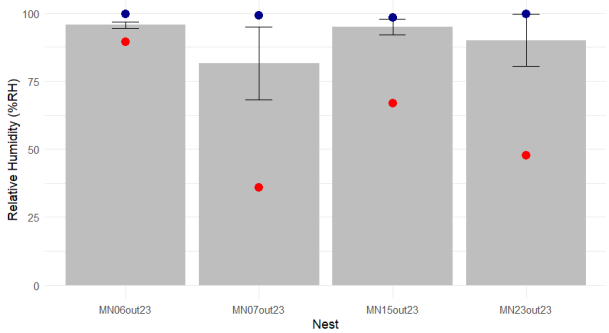


Figure 5. A) Variation in relative humidity (%RH) in *Melanosuchus niger* nests in 2023 in Araguaia National Park. B) Temperature variation (°C) in *Melanosuchus niger* nests in 2023 in Araguaia National Park.

Discussion and Conclusion

The reproductive ecology of *M. niger* in Araguaia National Park is strongly influenced by local environmental conditions, particularly in an ecotonal region characterized by high vegetation heterogeneity and seasonal hydrological dynamics (Shine, 1988; Thorbjarnarson, 1996; Campos, 2003). The occurrence of nests across different vegetation types, under a wide range of canopy cover and distances from water, indicates high plasticity in nest-site selection, a pattern already described for the species in other Amazonian regions (Villamarín-Jurado *et al*., 2011; Murray *et al*., 2020).

The results indicate that environmental variables, particularly vegetation cover and microclimate, play a central role in reproductive success. Nests located in more shaded environments exhibited greater thermal and hydric stability, favoring higher hatching success and reinforcing the importance of microhabitat conditions for embryonic survival (Deeming & Ferguson, 1989; Booth, 2006). Despite the low predation rate observed, factors such as thermal variation, solar exposure, and hydrological dynamics remain important constraints on reproductive success.

The positive relationship between female size, nest volume, and number of eggs reveals a consistent pattern of reproductive allometry, in which larger females exhibit greater reproductive investment (Thorbjarnarson, 1996; Larriera *et al*., 2004; Campos *et al*., 2008). These findings highlight the importance of body size as a key determinant of reproductive strategy, linked to energy allocation and the construction of more robust nests.

Overall, the reproductive success of *M. niger* results from the interaction between female traits, nest structure, and environmental conditions. In this context, the maintenance of heterogeneous habitats with stable microclimates is essential for the persistence of the species in the Araguaia floodplain (Grigg & Kirshner, 2015; Portelinha *et al*., 2019). Considering the historical anthropogenic pressures in the region, these results reinforce the importance of PARNA as a key conservation area and highlight the need for continuous monitoring to support management actions in the face of ongoing environmental changes.

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