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Population estimate, spatial distribution, social organization and daily activity pattern of the red-billed curassow (*Crax blumenbachii* Spix, 1825) reintroduced in Minas Gerais state

João Eduardo Vardiero Carvalho
Magister Scientiae

VIÇOSA - MINAS GERAIS
2025

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In memoriam de Elvira Maria Vardiero Soares, minha avó materna e quem mais instigou minha curiosidade sobre as Ciências da Vida.

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“Não inveje os outros cantos
Outras plumas e outras cores
Que de todos és o primeiro
Urubu tu és tão negro” (Rogério Skylab)

ABSTRACT

CARVALHO, João Eduardo Vardiero, M.Sc., Universidade Federal de Viçosa, February, 2025. **Population estimate, spatial distribution, social organization and daily activity pattern of the red-billed curassow (*Crax blumenbachii* Spix, 1825) reintroduced in Minas Gerais state**. Adviser: Fabiano Rodrigues de Melo.

One of the main challenges in planning management strategies for endangered species target on reintroduction projects is the difficulty in obtaining ecological data on reintroduced populations. Threatened species often have systematic data gaps in literature due to their rarity. The red-billed curassow (*Crax blumenbachii* Spix, 1825) is an endangered species endemic to the Atlantic Forest, whose bibliography on ecological aspects is scarce and sometimes conflicting. Thus, the present study aims to contribute to management strategies by collecting information on a reintroduced population of *Crax blumenbachii*, through camera traps and linear transects. Between 2021 and 2022, ten camera traps were installed in forested areas managed by Cenibra to collect data on spatial distribution, social organization, and daily activity patterns. From 2021 to 2024, a total of 311.62 km of line transects were covered to generate population estimates and complement the data on spatial distribution and social organization. The population exhibited a sex ratio of 1.12 males per female and a diurnal activity pattern, results consistent with the literature. The spatial distribution of *C. blumenbachii* was restricted to parts of the RPPN Fazenda Macedônia and its surroundings, resulting in a density of 5.23 individuals/km² and a population estimate of 33 individuals. These findings contribute to databases for action plans and viability analyses, providing valuable insights for developing long-term conservation strategies for the reintroduced population.

Keywords: curassow; threatened species; conservation

RESUMO

CARVALHO, João Eduardo Vardiero, M.Sc., Universidade Federal de Viçosa, fevereiro de 2025. **Estimativa populacional, distribuição espacial, organização social e padrão da atividade diária do mutum-do-sudeste (*Crax blumenbachii* Spix, 1825) reintroduzido no estado de Minas Gerais**. Orientador: Fabiano Rodrigues de Melo.

Um dos grandes desafios para o planejamento do manejo de espécies ameaçadas incluídas em projetos reintrodução é a dificuldade para a obtenção de dados sobre a ecologia das populações reintroduzidas. Além disso, espécies ameaçadas podem possuir lacunas de dados sistematizados na literatura de acordo com sua raridade. O mutum do sudeste (*Crax blumenbachii* Spix, 1825) é uma espécie ameaçada e endêmica da Mata Atlântica, cuja bibliografia sobre aspectos ecológicos é escassa e, por vezes, conflitante. Dessa forma, o presente estudo objetiva contribuir para estratégias de manejo a partir da coleta de informações sobre uma população reintroduzida de *Crax blumenbachii*, por meio de armadilhas fotográficas e transecção linear. Entre os anos de 2021 e 2022, dez armadilhas foram instaladas em regiões florestais pertencentes à Cenibra para a coleta de dados sobre distribuição espacial, organização social e padrão diário de atividades. Entre os anos de 2021 e 2024, 311,62 km foram percorridos durante as transecções para a coleta de dados utilizados em estimativas populacionais, além de complementarem as informações sobre a distribuição espacial e a organização social. A população apresentou uma razão sexual de 1,12 machos por fêmea e um padrão de atividades diurno, resultados similares aos encontrados na literatura. A distribuição espacial de *C. blumenbachii* se restringiu a porções da RPPN Fazenda Macedônia e adjacências, o que resultou em uma densidade de 5,23 indivíduos/km² e uma estimativa populacional de 33 indivíduos. Estes resultados podem contribuir para bancos de dados de planos de ação e análises de viabilidade, sendo importantes para o estabelecimento de estratégias de manejo que visem a conservação da população reintroduzida a longo prazo.

Palavras-chave: mutum; espécie ameaçada; conservação

LIST OF FIGURES

LIST OF GRAPHICS

LIST OF TABLES

SUMMARY

1. INTRODUCTION

1.1 General Introduction

The Atlantic Forest biome originally covered approximately 1.3 million km² along Brazil, Paraguay and Argentina (de Lima Palidon, 2005). Since the arrival of non-american in South America territory, about 87,6% of the biome was modified by extractive deforestation, agriculture, livestock and urban expansion (Ribeiro et al., 2009). This led to an estimate of nearly 250 species of terrestrial vertebrates extinct in the least 400 years, what shows the impact of the antropization on this forest (Leal, 2003).

This biome has approximately 2,000 species of vertebrates described (Myers et al., 2000), including an avifauna with 832 species (Hasui et al., 2018). Among these birds, 233 are threatened, mostly by habitat loss, fragmentation and hunting (Hasui et al., 2018).

To address the preservation of biodiversity impacted by anthropogenic disturbance, Conservation Biology has emerged as a multidisciplinary science focused on understanding, maintaining, and restoring biological diversity, grounded in ecological, evolutionary, and social principles (Soulé, 1985). The field arose in response to the escalating environmental crisis and the rapid extinction of species, proposing both *in situ* and *ex situ* conservation strategies (Meine, Soulé & Noss, 2006).

The *ex situ* conservation has a key role on preservation strategies of high threatened species and involves maintaining organisms outside their natural habitats, allowing the genetic preservation of endangered species, the study of their reproductive biology and the development of techniques for their reproduction and management (Heywood, 2017). Furthermore, *ex situ* may be the only conservation methodology to prevent extinction in critical situations where wild threatened populations are decreasing, in addition to enabling scientific researches and future reintroduction projects (Conde et al., 2011).

The animal reintroduction projects evolve the return of specimens bred in captivity or translocated from isolated populations to areas where the target species was extinct (Seddon et al., 2014). To reach success on these projects, the IUCN recommendation is the identification and action against the causes of the local extinction, the monitoring of the reintroduced population and the execution of viability studies (Kleiman et al., 1994). According to IUCN/SSC (2013), other factors, including disease transmission, interspecies competition, and community acceptance, may influence the viability of the reintroduction, highlighting the need for integration between science, environmental management, and public engagement.

Most animal reintroduction projects target vertebrates. The most well-represented group is mammals, followed by birds (Fischer & Lindenmayer, 2000). Notable successes of bird

reintroductions include the Spix's Macaw (*Cyanopsitta spixii*) in Brazil (Purchase et al., 2024), the California Condor (*Gymnogyps californianus*) in North America (Walters et al., 2010), and the Mauritius Kestrel (*Falco punctatus*) on Mauritius Island (Jones et al., 1995).

Bird reintroduction initiatives have historically prioritized certain avian groups based on ecological function, degree of threat, and feasibility of captive management (Seddon et al., 2005; Armstrong & Seddon, 2008). Notably, the order Galliformes have one of the most global and Brazilian reintroduction efforts (Snyder et al., 2000). Within Galliformes, the family Cracidae includes large-bodied frugivores crucial for seed dispersal in Neotropical forests (Collar & Butchart, 2014). Their sensitivity to habitat fragmentation and hunting pressure has made them target for conservation translocations, especially in the Atlantic Forest regions (Pereira & Wajntal, 1999; Araujo, 2015).

The selection of bird species for reintroduction projects is based on a combination of ecological, practical, and socio-political criteria aimed at maximizing conservation outcomes and program feasibility. Ecologically, species that play key functional roles are often prioritized due to their potential to restore disrupted ecosystem processes (Seddon et al., 2014). Practical considerations include the availability of individuals for release, often from captive breeding programs, and the presence of suitable and secure habitats for reintroduction (Armstrong & Seddon, 2008). Additionally, species with high public appeal are frequently chosen due to their potential to attract funding, media attention, and local community support, thereby enhancing project sustainability (Purchase et al., 2024; Wang et al, 2023). According to Griffith (1998), 90% of the analyzed reintroduced species was important for hunting activities, that also have public interest. On the other hand, the threat status does not have much influence on the choice of species, as shown by Seddon et al., 2005, where almost half of the species analyzed were not on the IUCN threat list.

On the American continent, Cracidae is the most threatened family of birds, mainly by hunting and habitat loss (Brooks & Fuller, 2006). On Brazilian territory, several species are included in some threat level: *Crax blumenbachii* Spix, 1825 (EN), *Crax pinima* (Pelzeln, 1870) (CR), *Mitu mitu (Linnaeus, 1766)* (EW), *Aburria jacutinga* Spix, 1825 (EN), *Penelope ochrogaster* (Pelzeln, 1870) (EN), *Penelope jacucaca* (Spix, 1825) (VU), *Penelope pileata* (Wagler, 1830) (VU), and *Crax globulosa* (Spix, 1825) (EN) (IUCN Red List, 2023).

These conditions contributed to the interest in developing *ex-situ* reintroduction projects with this family. Therefore, some Cracidae species have been the target of these projects:

Crax blumenbachii, Crax fasciolata, *Aburria jacutinga*, *Mitu mitu, Penelope superciliaris* Temminck, 1815 e *Penelope obscura* Temminck, 1815 (Araujo, 2015).

1.2 *Crax blumenbachii*

The red-billed curassow (*Crax blumenbachii*) is an endangered cracid endemic to the Atlantic Forest (IUCN, 2023). This species is also classified as EN (endangered) by the Official List of Threatened Species of Brazilian Fauna (MMA 148, 2022) and as CR (critically endangered) by the list of threatened species of the state of Minas Gerais (COPAM nº 147, 2010). The threatened condition of this avian species results from three main factors: i) reduction of the diversity and quantity of resources used by these birds, through habitat loss leading to forest remnants of lower quality, ii) an increase in populations of nest predators, including cats and dogs, and iii) hunting (IBAMA, 2004). According to Griffith (1989),

The life cycle of the species is relatively long, which can make it difficult to reestablish affected populations. Estimates show that the generation time of the species is approximately 7 years, with the reproductive period of females beginning at around 2.5 to 3 years and ending at 10 years. Females produce an average of two offspring per clutch, and the reproductive period may vary depending on environmental factors (IBAMA, 2004).

Due to its critical conservation status, the red-billed curassow has been targeted for reintroduction programs combined with captive breeding (Azeredo & Simpson, 2004). To date, the reintroduction of this species has been carried out in the states of Minas Gerais (Araujo, 2015) and Rio de Janeiro (Bernardo, 2012).

During the 1990s in Minas Gerais, Celulose Nipo-Brasileira S.A. (Cenibra) partnered with the Society for Research and Management on the Reproduction of Wildlife (CRAX) and initiated the “Mutum Project”, aiming to reintroduce endangered wild birds into their natural habitat. Since its implementation, the project has enabled the release of the red-billed curassow (*Crax blumenbachii*), the solitary tinamou (*Tinamus solitarius*), the spot-winged wood-quail (*Odontophorus capueira*), the southern jaó (*Crypturellus noctivagus*), the brown tinamou (*Crypturellus obsoletus*), the dusky-legged guan (*Penelope obscura*) and the black-fronted piping-guan (*Aburria jacutinga*) (CENIBRA, unpublished data).

By 2019, the Mutum project reintroduced 219 individuals (118 males and 101 females) of red-billed curassows in Fazenda Macedônia project, located in the municipality of Ipaba, Minas Gerais. For this, the captive animals were first kept in an acclimatization aviary built inside the area for adaptation prior to release in the wild. Since then, the reintroduced population has been the target of studies concerning the diet, seed dispersal, and population density estimates

(Rufino et al., 2022; Araujo, 2015). The *in situ* reproduction of the reintroduced population has also been monitored in a non-systematic manner, with 181 offspring recorded to date (CENIBRA, unpublished data). These data highlight the reproductive success of the species in the wild, but the lack of information about its spatial occupation and social organization prevents future decision-making about the management of the species.

Besides the Fazenda Macedônia project, Cenibra has other four areas in the middle Rio Doce region: Rio Branco project (adjacent to the Fazenda Macedônia project), Lagoa Perdida project, Lagoa do Piau project and Lagoa do Jacinto project. These last three areas border with the Rio Doce State Park, leading to the possibility of migration of reintroduced curassows to this fragment. This reinforces the need for systematic monitoring to obtain data on the spatial distribution and activity patterns of the species.

Therefore, in this work we aimed to obtain data on the natural history, density and abundance of the threatened, red-billed curassow *Crax blumenbachii* in the region of the middle Rio Doce. We focused on aspects of population dynamics and compared our data with other populations of the species. With this, we generated unprecedented information that can be used for delineating new conservation strategies to guarantee a successful establishment of curassows in the region.

2. METHODS

2.1. Study area

For the present study, five sample areas belonging to Cenibra were defined: Fazenda Macedônia, Rio Branco, Lagoa Perdida, Lagoa do Piau and Lagoa do Jacinto, all projects belonging to Cenibra S.A. (CENIBRA, unpublished data)

These areas are characterized by mosaics where eucalyptus plantations and secondary Semideciduous Seasonal Forest fragments predominate. The region is located in the Atlantic Forest domain and belongs to the middle Rio Doce valley (Oliveira-Filho & Fontes 2000; França & Stehmann, 2013). The sample region that includes the Fazenda Macedônia project has a Private Natural Heritage Reserve (PNHR) within it with an area of 560 hectares (Amaral et al., 2009), where the management and reintroduction of the cracid *Crax blumenbachii* have been carried out for over 20 years (Araujo, 2015).

2.2. Camera trap

Camera trapping was conducted from April 2021 to October 2022, using 10 cameras

(Bushnell Trophy Cam HD) in Atlantic Forest fragments within the five sampling areas, without the use of bait. The location of the camera traps was chosen based on the following criteria: possibility of access, greater sampling dispersion in the study area, and minimum distance of 800 meters from another point. The camera traps were attached to trees approximately 0.15 cm DBH (Diameter at Breast Height) and 50 cm above the ground.

The cameras operated 24 hours a day, with a setting for a photo trigger followed by a 15-second to 20-second video, and with the trigger sensors in automatic mode. The camera traps were inspected, on average, every 45 days to replace the memory cards, identify possible damage and check the battery level.

The number of camera traps and the sampling period varied in the locations according to the limited availability of access within the sampling areas and number of cameras. The sampling effort (camera-days) of each area was calculated by multiplying the number of cameras by the number of sampling days. Capture success was calculated by dividing the number of records by the sampling effort and the result was expressed as a percentage (Srbek-Araujo et al., 2012).

Each photograph taken by the camera traps was considered a record. In cases where two or more photographs containing records of indistinguishable specimens were captured in the same camera trap within a one-hour interval, only the first was considered a record (Sollmann, 2018). When two or more distinguishable individuals were captured at intervals of up to five minutes, the photographs were counted as records of pairs or groups. Captures were classified as: individual (male or female), pair (male and female) or group (two or more individuals, except pairs). Males and females were differentiated by plumage dimorphism (Sick, 1997).

2.3. Line transects

To conduct the population survey of the red-billed curassow in the release areas and to detect whether the species has dispersed into neighboring areas, transects were made along forest fragments within the sampling units from 2021 to 2024.

The forests in the sampled area have a high density of undergrowth, which prevented the transects from being built without opening trails. Since the opening of new trails was not permitted, and, consequently, the randomization of sampling in the area, we chose to use the trails that had already been built, with no connection between them. Given the large home range of curassows, estimated at approximately 125 ha (Bernardo et al., 2011), and the low availability of transects, we chose to use all available transects that were not connected to each other, which may violate the principle of independence of records (Buckland et al., 1993).

The transects were covered by two observers, walking at an average speed of 1 km/h (Buckland et al., 2015). During the demographic census, the following data were recorded: animal species, date/time of the record, location, sex and perpendicular distance between the animal and the transect before any movement in response to the observer's approach (Thomas et al., 2010).

2.4. Data analysis

Given the difficulty in obtaining records, as the red-billed curassow is a threatened species with elusive behavior and naturally low density, we opted to model the detection function using data from curassows, black-fronted piping guans (*Aburria jacutinga*), and solitary tinamous (*Tinamus solitarius*). These species have similar detection probabilities, which makes such grouping feasible, according to Buckland et al. (2009). We also calculated the encounter rates of the curassows to compare the relative abundance with other linear transects studies with this species.

Subsequently, we performed analyses using various combinations of data truncation, detection functions, and adjustment terms to select the best detection model, following Buckland et al. (1993), using the software Distance 7.5. The model's fit to the obtained data was evaluated based on the corrected Akaike Information Criterion for small samples (AICc), the coefficient of variation (CV), chi-square tests, quantile-quantile (Q-Q) plots, and the models' fit to the detection curve. (Graphic 3, Graphic 4, Table 4)

Thus, we obtained the ESW value (Effective Strip Width) as a result of the analysis using the three species in the software Distance 7.5. Using this ESW value, we estimated the population size and specific density of *Crax blumenbachii* following the equations described in Buckland et al. (1993), through the R software version 4.3.3.

In active search methodologies, males of the species *Crax blumenbachii* may exhibit a higher detection probability than females due to behavioral differences, particularly during singing and fleeing (Alves et al., 2015). Therefore, based on the data obtained during the line transect survey, we used a chi-square test to assess the significance of the deviation from the sex ratio observed in monitoring through camera traps. Since the capture probability in camera trapping is the same for males and females (Alves et al., 2015), it more accurately reflects the sex ratio of the studied population. From this analysis, we identified the need for a correction in the population estimates based on a revised proportion between males and females.

Based on previous information collected at our study site, initially we only considered Fazenda Macedônia regions for the line transects analysis. The area encompasses two fragments

with a total of 631ha - a Private Natural Heritage Reserve (PNHR) with 560ha and a 71ha forest corridor. During our study, 7 transects were surveyed in this region, resulting in a sampling effort of 260.32 km.

We also noticed the need to consider other areas with potential for the distribution of *Crax blumenbachii* at the Fazenda Macedônia area and its surroundings. Further analyses were conducted using three potential distribution areas: the first, considering only the northern portion of the RPPN and the fragment that connects it to the southern portion, the only areas during the line transects where *C. blumenbachii* records were made; the second, considering the RPPN and other native forest regions that belong to the Fazenda Macedônia project; and the third, considering the area from the second analysis plus the native forest regions of the Rio Branco project.

For the alternative one, the total distribution area of curassows considered was 365 ha. Transects in the southern portion were excluded, resulting in a total of 215.42 km of trails surveyed. For the alternative two, the total distribution area considered was 806.07 ha. The total distance surveyed during the transects were the same as in the main analysis. For the alternative three, the total area considered was 1,683.37 ha. The surveyed distance also included the transects conducted in the Rio Branco region, totaling 311.62 km.

3. RESULTS

The sampling effort of the camera traps varied across the sampling areas, as follows: Fazenda Macedônia, 1,152 trap-days; Rio Branco, 605 trap-days; Lagoa do Piau, 1,043 trap-days; Lagoa Perdida, 575 trap-days; and Lagoa do Jacinto, 590 trap-days. Of the 10 cameras used in this study, one was stolen, and another was damaged during data collection.

We obtained 57 independent records of the red-billed curassow from two localities: Macedônia (56 records, 98%) and Rio Branco (1 record, 2%). In Macedônia, we recorded the red-billed curassow at four of the six installed camera traps, and in Rio Branco, the species was recorded at one of the four camera traps. No records were obtained from Lagoa do Piau, Lagoa Perdida, or Lagoa do Jacinto (Figure 1,

Table *1*).

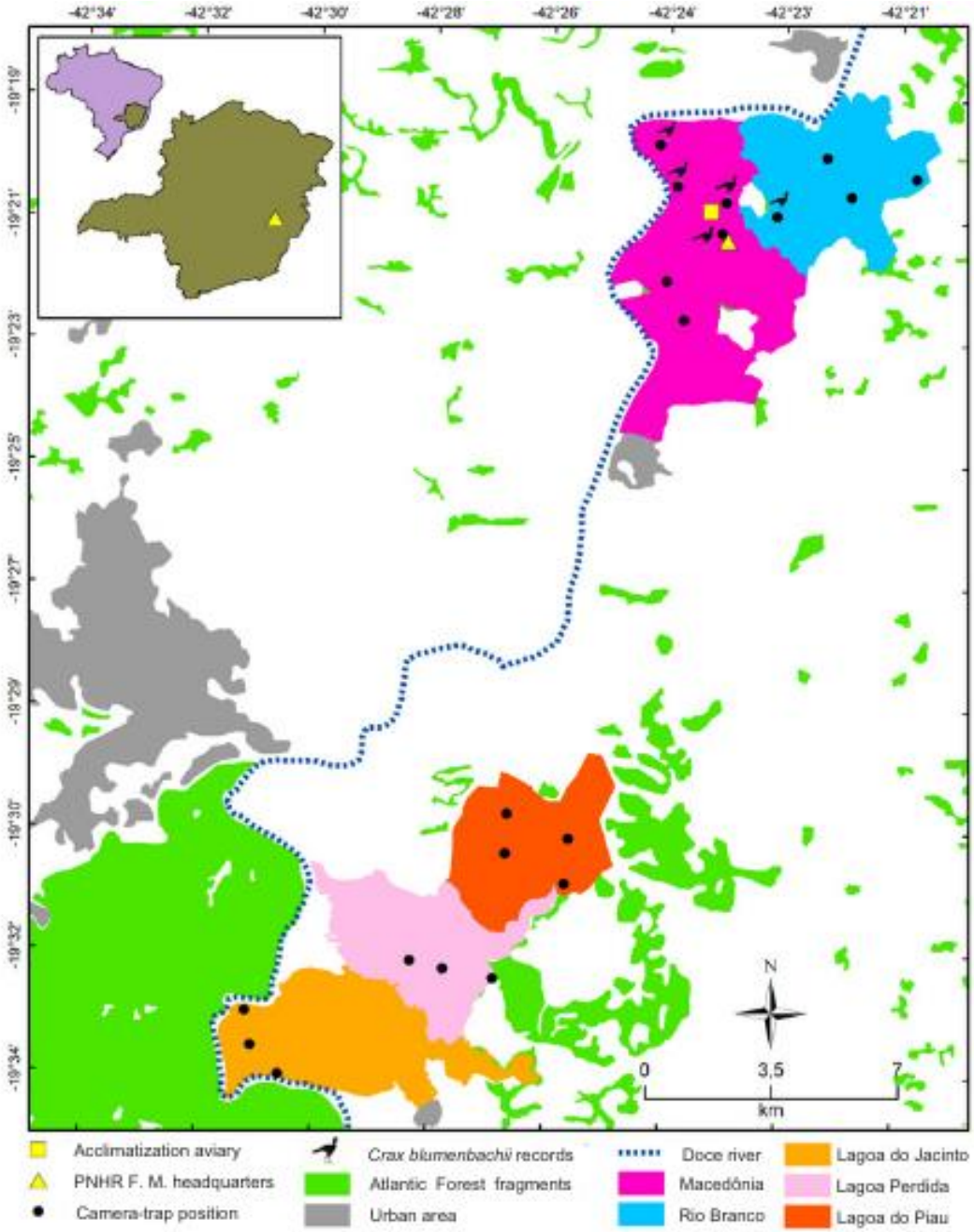


Figure 1: Position of the camera-traps and records of *Crax blumenbachii* obtained during camera trapping in the Cenibra areas, Minas Gerais, Brazil, from April 2021 to October 2022.

Table 1: Number of records, sampling effort, and capture success of the red-billed curassow in the Cenibra areas, Minas Gerais, Brazil, using camera traps from April 2021 to October 2022.

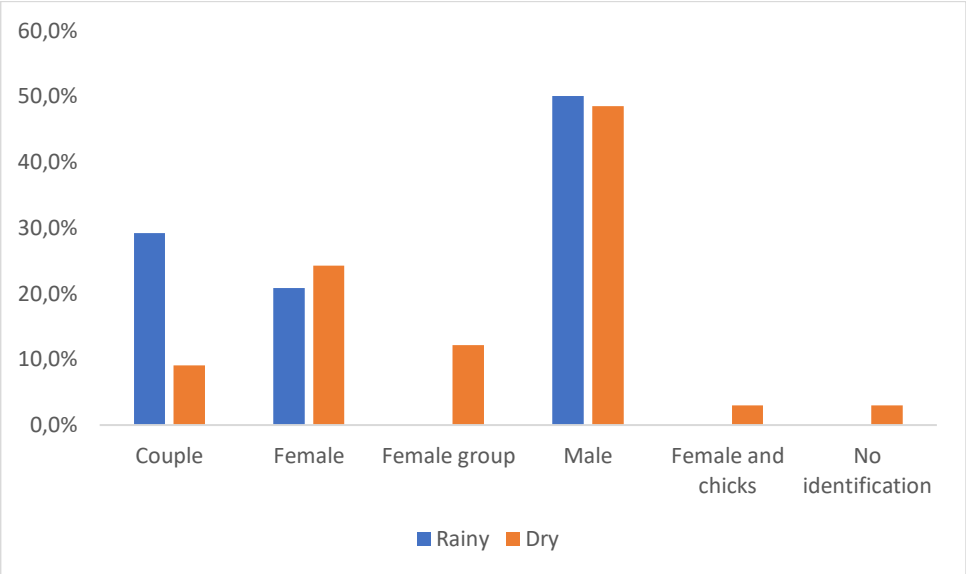
		Season	
Variables	**Total**	**Dry**	**Rainy**
Fazenda Macedônia			

Number of records	56	33	23
Sampling effort (trap-days)	1.152	742	410
Capture success	4,86	4,44	5,60
Rio Branco			
Number of records	1	0	1
Sampling effort (trap-days)	605	359	246
Capture success	0,16	0	0,4
Lagoa do Piau			
Number of records	0	0	0
Sampling effort (trap-days)	1.043	548	495
Capture success	0	0	0
Lagoa Perdida			
Number of records	0	0	0
Sampling effort (trap-days)	575	394	181
Capture success	0	0	0
Lagoa do Jacinto			
Number of records	0	0	0
Sampling effort (trap-days)	590	327	263
Capture success	0	0	0

In the camera trapping data, solitary individuals were recorded more frequently (74%, n = 42) than pairs or groups (36%, n = 19). Solitary males were the most frequently recorded (41%, n = 23), followed by solitary females (23%, n = 13), pairs (21%, n = 12), groups (12.5%, n = 7), and unidentified individuals (2%, n = 1). Six of the seven recorded groups consisted of two females, and one group consisted of a female and a chick. Solitary males composed the most of records in both season (50% on the rainy and 48,5% on the dry), showing similar values ($X^2 = 0.35$; df = 1; $P > 0.5$). Solitary females composed 20,8% of the records on rainy season and 24,2% on dry, showing the same pattern ($X^2 = 0.35$; df = 1; $P > 0.5$). However, the couples were recorded mostly on wet (29,2%) than dry season (9,1%) ($X^2 = 0.35$; df = 1; $P < 0.5$). Groups with two females or more were recorded only on the dry season (4 groups, 12,1%) and, despite the low number or records, may represent a different pattern between the seasons (X^2 =

0.35; df = 1; P < 0.5). Only one group with a female with individuals identified as chicks was recorded, occurred on the dry season (3%). (Graphic 1).

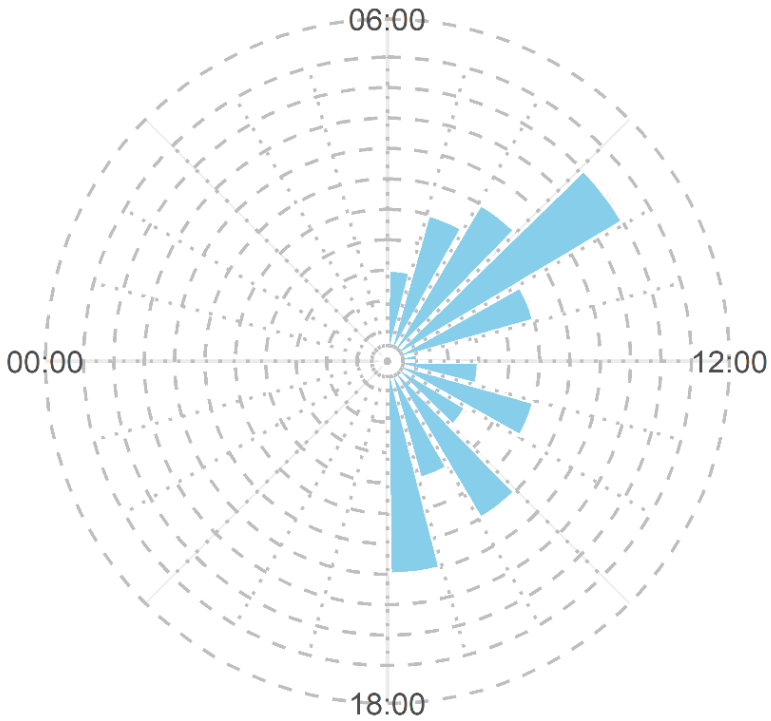
Graphic 1: Percentages of records showing males, females, pairs, and groups in relation to the total number of records of the red-billed curassow obtained at each season during the study in the Atlantic Forest fragments of Cenibra.



In the present study, *Crax blumenbachii* exhibited a diurnal activity pattern. Capture rates were similar when comparing the activity periods during the dry season (April to September) and the rainy season (October to March) ($X^2 = 0.35$; df = 1; P > 0.5). Red-billed curassows were recorded over a 12-hour period, with the first record at 06:03 h and the last at 17:37 h. Captures showed a bimodal distribution, with the first peak occurring between 09:00 h and 10:00 h, and the second between 17:00 h and 18:00 h. (Graphic 2).

Graphic 2: Daily activity pattern of the red-billed curassow in the Atlantic Forest areas of Cenibra, Brazil. The bars represent one-hour intervals in which records were obtained. The

circles indicate the number of records, while the lines represent the hours.



During the transects, we obtained 17 sightings. Of these, 12 were of curassows, totaling 16 individuals, one was of a black-fronted piping guan, with one individual, and four were of solitary tinamous, with five individuals. This resulted in an encounter rate of 0,46 curassows per 10 km (Table 2).

Table 2: Compilation of available encounter rates (records/10 km), population and density estimate of the red-billed curassow (*Crax blumenbachii*) populations detected during line transects. NA = not available or not applicable due to lack of data.

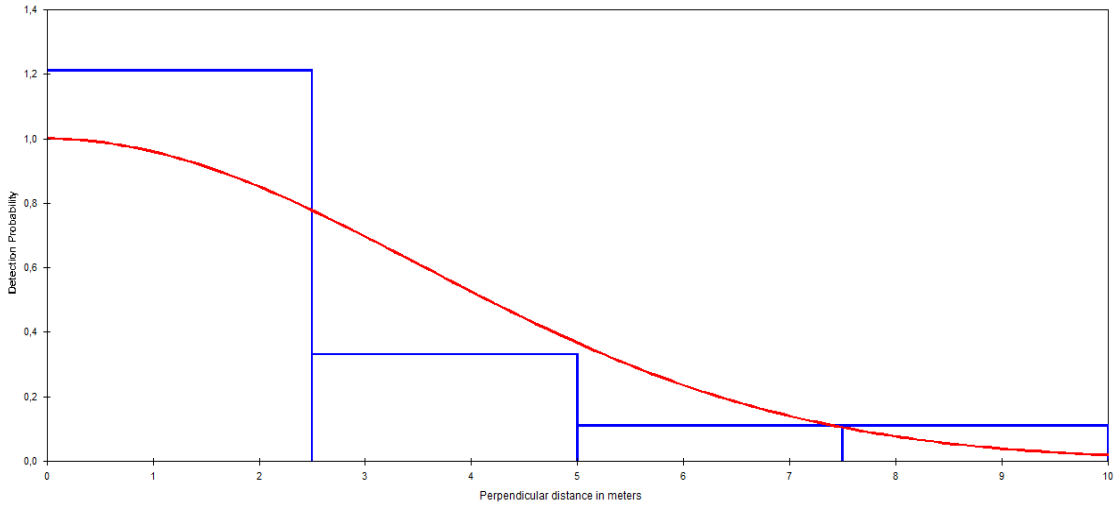
Patch	**Reference**	**Sampling effort (km)**	**Patch size (ha)**	**Encounter rate**	**Population estimate (n)**	**Density estimate (n/km²)**
Fazenda Macedônia	This study	260.32	361	0,46	33	5,23
Fazenda Macedônia	Araujo (2015)	280	1420	0,36	34	2,36
Capitão Reserve	Gatto et al. (2007)	22.2	6258	0,45	NA	NA

Vale Natural Reserve	Alves et al. (2017)	868.6	23000	0,48	325	1,6
N. Serra do Conduru State Park	Rocha et al. (2019)	205,5	9688	0,29	NA	NA
Una Biological Reserve	Rocha et al. (2019)	307,5	11967	0,13	NA	NA
	Rocha et al. (2019)	300,6	18715	0,20	NA	NA
Descobrimento National Park	Rocha et al. (2019)	328,8	24084	0,27	NA	NA

Among the curassow records, seven were of solitary males, three of solitary females, one of a pair, and one of a female with three juvenile individuals. This sex ratio (1.6 M/F) did not show a significant deviation from that observed in the data collected through camera trapping between April and December 2021 (1,12 M/F) ($X^2 = 0.039746$; GL = 1, $p > 0,1$).

Our analysis using Distance software with data from curassows, black-fronted piping guans, and solitary tinamous resulted in an estimated effective strip width (ESW) of 4,4047m (CV 11,93%, IC 95% = 3,4189m – 5,6746m). This led to a population estimate of 33 individuals (95% CI: 14 to 52) for *Crax blumenbachii* with a density of 5.2327 (95% CI: 2.2720 to 8.1933) individuals/km². The most suitable detection function was the Half-normal with simple polynomial, using data truncation at the 5% largest distances (Graphic 3, Graphic 4).

Graphic 3: Detection histogram of the most suitable detection function. The curve represents the Half-Normal function with no simple polynomial. The X-axis represents the distance of encounters, and the Y-axis represents the detection probability along the distances.



Additionally, to the presented data, during the path between transects and camera trap points, occasional records of the species were made outside the regions where systematic data collection occurred (Figure 2).

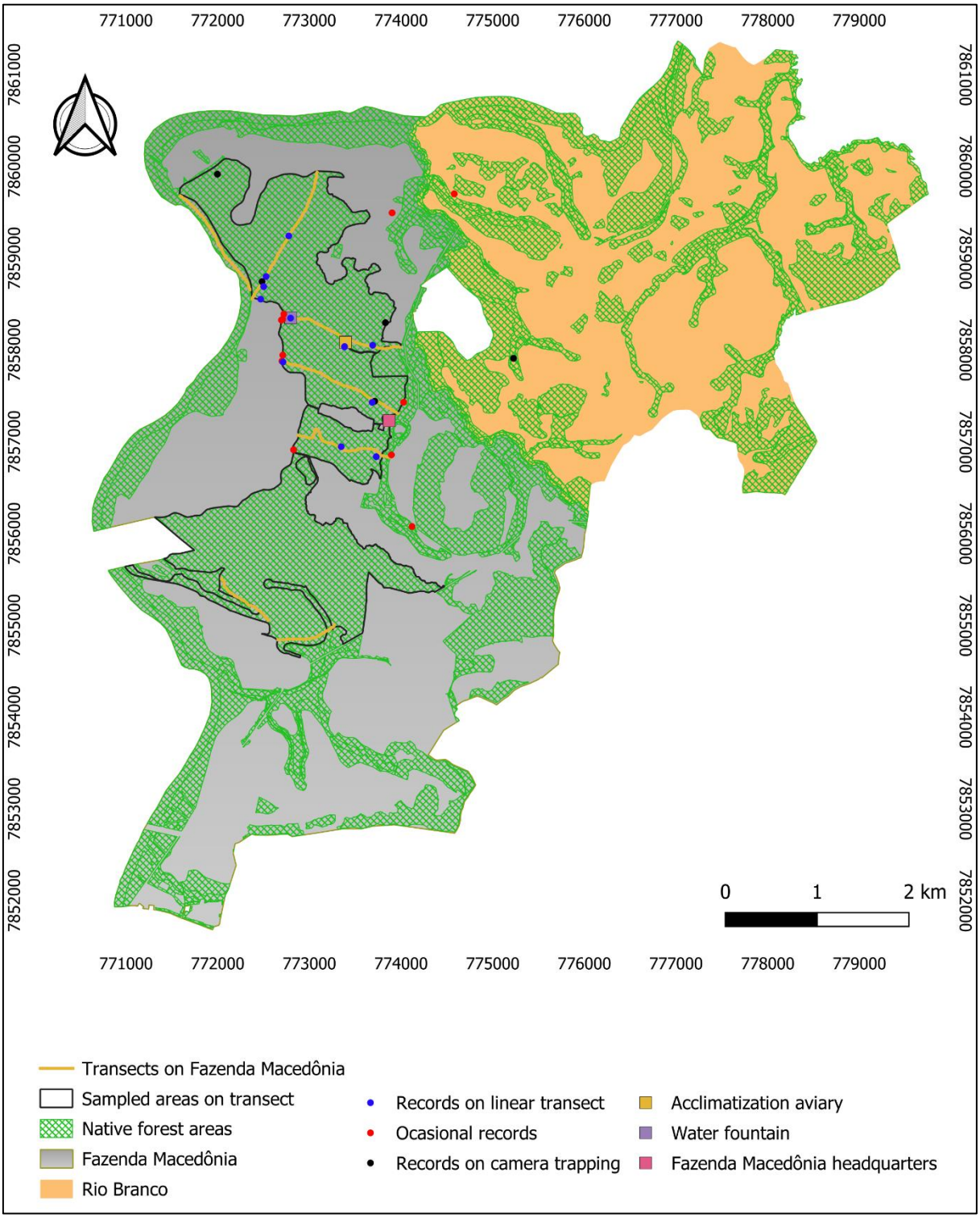


Figure 2: Occasional and systematic records of *Crax blumenbachii* during the line transect and camera trapping surveys.

The occasional records do not include encounters with the species within and around the headquarters of Fazenda Macedônia. These encounters occurred on most of the sampling days and commonly involved groups of 5 to 6 individuals (Figure 3), with numbers reaching up to

12 individuals. These curassows displayed behaviors resembling those of domesticated animals, such feeding, calling and no running on the presence of humans.

Figure 3: Group of curassows recorded near the headquarters of Fazenda Macedônia.

Some occasional records occurred outside the distribution area considered, while, in contrast, the most systematic records of this study and Araujo (2015) occurred only at the northern portion of the RPPN Fazenda Macedônia. These data lead us to consider three alternative potential distribution areas.

For the alternative one, a distribution area of 365 ha was considered. On this area, 16 sightings were recorded: 12 of curassows, one of a black-fronted piping guan, and three of solitary tinamous. For the alternative two, a distribution area of 1453,89 ha was considered, and the sightings during the transects were the same as in the effective area. For the alternative three, a distribution area of 2159,69 ha was considered, and the sightings used were the same as in the effective area, as no encounters with the project's target species were recorded in the Rio Branco region.

The results of all analyses are shown on Table *3*.

Table 3: Population estimates of *Crax blumenbachii* considering different distribution areas in Cenibra regions. Legend: DA = distribution area (ha); DI = distance surveyed during transects (km); ESW = effective strip width (m); PE = population estimate (n); CI = 95% confidence interval for PE; DE = density (n/km²).

Distribution areas	**DA**	**DI**	**ESW**	**PE**	**CI**	**DE**
Effective area	631	260,32	4,4047	33	14 to 52	5,2327
Alternative one	365	215,42	3,2653	31	14 to 49	8,5176
Alternative two	1453,89	260,32	4,4047	76	33 to 119	5,2327
Alternative three	2159,69	311,62	4,4047	94	41 to 148	4,3712

4. DISCUSSION

Studies report the difficulty of obtaining sufficient encounters to generate robust population estimates for the species (Rocha et al., 2017), with a minimum of 40 samples recommended. However, robust estimates can still be achieved with smaller sample sizes if the obtained data is carefully analyzed and the fit to the detection curve is satisfactory (Peres & Cunha, 2011). The encounters with *Crax blumenbachii* during the transects were scarce, as expected given the elusive behavior and natural low density of this species registered before. In this study, we found an encounter rate that was similar to the Vale Natural Reserve and Capitão reserve populations, and considerably higher than the populations evaluated by Rocha et al. (2019) (Table 2).

Our results indicate a populational stability for the red-billed curassow in the RPPN Fazenda Macedônia. Despite the lower population estimate compared to Araujo (2015), the 95% confidence interval (CI) of the estimate obtained in the present study, ranging from 14 to 52 individuals, is contained within the 95% CI from the previously mentioned work, ranged from 10 to 111 individuals, which means that they are statistically indifferentiable.

Between the periods of these estimates, from 2015 to 2018, 141 individuals were released, along with several records of births of free-living curassows (CENIBRA, unpublished data). Based on this information, it is possible to infer that the carrying capacity of the area has been reached, as the population remained constant despite the additions of individuals. However,

these findings should be interpreted with caution, as the total distribution area considered by Araujo (2015) differs from that used in the present study.

The sampled density is high when compared to other populations on *Crax blumenbachii* (Alves et al., 2017; Araujo, 2015), but consistent with the abundance of resources around the Fazenda Macedônia headquarters and the limited distribution area identified through camera trap and transect monitoring. In the areas surrounding the headquarters and orchard, which contain a variety of fruit trees, large groups of curassows were frequently observed, reaching up to 12 individuals. Besides the availability of water and food resources, the area experiences significant human activity. Feeding wildlife is a common practice in environments with frequent human presence and, when sustained over long periods, can influence the natural behavior of species (Orams, 2002). Therefore, the availability of fruit trees used as food by curassows, combined with the potential practice of wildlife feeding, may explain the high density observed for the *Crax blumenbachii* population in this region.

According to Araujo (2015), the main factors that may influence the probability of detection along the Fazenda Macedônia are the density of understory and the proximity with water sources, forest edges and release points. On our linear transects, 4 encounters occurred on the dependences of forest edges areas, 1 on the proximities of an artificial water source and 2 on the perimeter of release, that also have an artificial water source, what suggest a similar pattern.

The fauna of the Fazenda Macedônia RPPN includes potential terrestrial bird predators such as the puma (*Puma concolor*) and the ocelot (*Leopardus pardalis*), both recorded during camera-trap monitoring. According to Massara et al. (2015), the ocelot population from Fazenda Macedonia have the highest density of individuals compared to other 5 Atlantic Forest reserves, mostly attributed to the abundance of reintroduced birds as potential food sources. These predators may help regulate the curassow population, contributing to its stability in the area.

In addition to predation, the dispersion of curassows to other areas is also possible, once the Fazenda Macedônia is connected by forest corridors leading to various fragments and the Rio Doce State Park (PERD). Because of the large home range of the species, the PERD has the potential to shelter a higher number of individuals, representing a good chance to the long-term conservation of one red-billed-curassow's population.

The daily activity pattern of the red-billed curassow population reintroduced at Fazenda Macedônia, based on our study, can be classified as diurnal. The results are similar to those of Srbek-Araujo et al. (2012), showing a peak in activity near 6:00 PM and reduced activity during

the hottest hours of the day. However, our study identified the highest activity peak between 9:00 AM and 10:00 AM, whereas Srbek-Araujo et al. (2012) reported a broader peak between 8:00 AM and 10:00 AM. These authors also observed an earlier beginning of the activity period between 3:00 AM and 4:00 AM, and a later ending, between 6:00 PM and 7:00 PM. This results in a broader activity range than that observed in the present study, which began between 6:00 AM and 7:00 AM and ended between 5:00 PM and 6:00 PM.

The discrepancy in the amplitude of daily activity periods recorded in both studies may be influenced by the difference in sampling effort. Srbek-Araujo et al. (2012) had a sampling effort of 9,534 camera-trap hours, while our study recorded 1,757 camera-trap hours in regions with curassow detections. The larger number of records obtained by Srbek-Araujo et al. (2012) (197 records) may have allowed for the detection of activity at other times, even if these periods featured fewer capture events.

The sex ratio obtained with camera-trapping showed values close to those expected for the species, with the number of males recorded being similar to the number of females (Alves et al., 2017). Sick (1970) reported a higher proportion of females compared to males for this species; however, this is likely due to anthropogenic hunting pressure on the analyzed population (Araujo, 2015).

The red-billed curassow is considered a monogamous species, with records of polygyny under the influence of skewed sex ratios and other anthropogenic factors (IBAMA, 2004). The systematic records of curassows in this study align with the expected pattern for the species, including solitary males and females, pairs, female duos, and females with chicks. Couples were observed mostly on the wet season, what corroborates the Bernardo & Locke (2014) results about the months with breeding records. However, large groups, comprising varying numbers of males and females, were observed near the headquarters of Fazenda Macedônia and its surroundings. None of the observed individuals were banded, indicating they were not the same individuals released by Cenibra's reintroduction program.

Araujo (2015) reported that individuals released at Fazenda Macedônia, even five years post-release, continued to exhibit typical behaviors of captive animals, such as group formation and docility toward humans. In our study, which included data collection up to ten years after Araujo (2015) observations, the same behavior was recorded. This suggests that the environmental conditions provided by Fazenda Macedônia support the persistence of these behaviors across generations.

5. CONCLUSIONS

Monitoring reintroduced populations can provide valuable insights into species ecology and is essential for evaluating the success of reintroduction programs. Data on the breeding season, population estimates, and sex ratios can inform population management strategies, particularly in programs involving periodic releases.

To better understand the dispersion of *Crax blumenbachii* individuals reintroduced at Fazenda Macedônia, we propose three monitoring approaches: continuity of camera-trap monitoring, with additional traps installed in areas near Fazenda Macedônia that have been minimally or not sampled; passive listening surveys, whose data analysis methodologies have been improved in recent years and may contribute to this purpose; tracking individuals via radiotelemetry, that may elucidate if the curassows dispersion stays or go beyond the Cenibra areas.

From the high number of released individuals and birth records at Fazenda Macedônia and the proportional low estimated number of individuals in both populational studies, we conclude that the releases have been ineffective on increase the population size on this area. For the effectivity of this reintroduction program, we suggest three effort investments: the maintenance of the habitat quality of the RPPN areas, which includes the removal of possible illegal hunters and loggers and the preservation of surrounding areas that have influence on the quality of natural water sources of the reserve; the reforestation of surrounding areas, increasing the potential habitat of this population; the reintroduction of individuals on the Cenibra areas near the PERD, an area with the potential to support a large population of curassows.

The population estimate and sex ratio data obtained in this study can enable a Population Viability Analyses (PVA), which, together with niche modeling, provide projections on population growth and long-term sustainability. Combined with periodic monitoring, these efforts are crucial for establishing a conservation status for the curassow population in the middle Rio Doce region.

Furthermore, this study contributes to important data on the red-billed-curassow that may corroborate some threat classification criteria from IUCN: the estimated population size (criterion A, C, D); the estimative of mature individuals by our estimated population (criterion A, B, C, D); the viability of PVA by our population estimate and sex ratio data (criterion E) (IUCN, 2001).

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7. SUPPLEMENTARY MATERIAL

Table 4: List of distance sampling models applied to this study and their respective AICc, Effective Strip Width (ESW) and the Coefficient of Variation (CV) of the population estimative. E = Distance program presented error in the analyses. *Combination between detection function and adjustment term presented parameters very highly correlated, parameters constrained to obtain monotonicity and/or parameter at a lower bound.

Detection function	**Adjustment terms**	**AICc**	**ESW (95% CI)**	**CV**
Uniform	Cosine *	64.553	4.1219	30,37
	Simple polynomial*	73.682724	4.2207	32.49
	Hermite polynomial*	68.562057	5.2661	35.81
Half normal	Cosine*	65.073	3.1859	28,49
	Simple polynomial	65.073	4,4047	25,65
	Hermite polynomial*	65.073	4,4047	25,65
Hazard rate	Cosine*	31.000	0.36891	40.15
	Simple polynomial*	31.000	0.36891	40.15
	Hermite polynomial	E	E	E

Graphic 4: Detection histogram of the discarded detection probabilities. The curve represents the Half-Normal function with simple polynomial. The X-axis represents the distance of encounters, and the Y-axis represents the detection probability along the distances.