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Original Article

Ecological patterns of *Lissachatina fulica* in a seasonally dry biome: implications for control

Padrões ecológicos de *Lissachatina fulica* em um bioma sazonalmente seco: implicações para o controle

A. Patiño-Montoya[a] and R. Tidon[a,b]*

[a]Universidade de Brasília – UnB, Instituto de Ciências Biológicas, Programa de Pós-Graduação em Ecologia, Brasília, DF, Brasil
[b]Universidade de Brasília – UnB, Instituto de Ciências Biológicas, Departamento de Genética e Morfologia, Brasília, DF, Brasil

Abstract

The giant African snail (*Lissachatina fulica*), one of the world's most harmful invasive species, has spread across all Brazilian states. However, population-level studies in some biomes, like the Cerrado, remain scarce. This study provides the first comprehensive assessment of the distribution, density, shell morphometry, and reproductive characteristics of *L. fulica* in the Brazilian Federal District. Between 2021 and 2022, 25 field expeditions were conducted, resulting in the capture of 5,242 individuals. The species was predominantly found in moderately disturbed urban areas with vegetation and organic debris, while it was absent from highly urbanized zones, possibly due to climatic limitations or lack of suitable microhabitats. Population densities were generally low (<0.33 ind/m^2), with nearly half of the individuals concentrated at three sites. Shell length ranged from 13 to 163 mm, showing a bimodal distribution. Morphometric analysis indicated negative allometry and earlier elongation compared to other regions, possibly reflecting earlier onset of reproductive maturity. Gravid individuals, mostly 50–103 mm long, were recorded in 80% of the sites. The reproductive cycle appears to be strongly influenced by seasonality, with over 85% of annual rainfall occurring from November to April, which coincides with post-estivation activity and egg-laying. The maximum number of eggs per individual (246) was lower than in other studies, likely due to a shorter reproductive window. These findings suggest that targeted control strategies in the Federal District are still feasible and should prioritize early rainy-season collection in moderately urbanized areas, focusing on individuals exceeding 50 mm in shell length.

Keywords: *Lissachatina fulica*, Cerrado biome, invasive species, land mollusk, population ecology.

Resumo

O caracol gigante africano (*Lissachatina fulica*), uma das espécies invasoras mais prejudiciais do mundo, já se espalhou por todos os estados brasileiros. No entanto, estudos populacionais em alguns biomas, como o Cerrado, ainda são escassos. Este estudo apresenta a primeira avaliação abrangente da distribuição, densidade, morfometria da concha e características reprodutivas de *L. fulica* no Distrito Federal. Entre 2021 e 2022, foram realizadas 25 expedições de campo, que resultaram na coleta de 5.242 indivíduos. A espécie foi encontrada predominantemente em áreas urbanas moderadamente perturbadas, com vegetação e acúmulo de matéria orgânica, estando ausente em zonas altamente urbanizadas, possivelmente devido às limitações climáticas ou à ausência de micro-hábitats adequados. As densidades populacionais foram geralmente baixas (<0,33 ind/m^2), com quase metade dos indivíduos concentrados em três locais. O comprimento das conchas variou de 13 a 163 mm, com distribuição bimodal. A análise morfométrica revelou alometria negativa e alongamento precoce em comparação com outras regiões, sugerindo maturidade reprodutiva antecipada. Indivíduos grávidos, em sua maioria com 50–103 mm, foram registrados em 80% dos locais amostrados. O ciclo reprodutivo parece ser fortemente influenciado pela sazonalidade, com mais de 85% da precipitação anual ocorrendo entre novembro e abril — período que coincide com a retomada da atividade após a estivação. O número máximo de ovos por indivíduo (246) foi inferior ao relatado em outras regiões, possivelmente devido à janela reprodutiva mais curta. Esses resultados indicam que estratégias de controle direcionadas ainda são viáveis no Distrito Federal, com ênfase na coleta precoce, durante a estação chuvosa, e em áreas urbanas medianamente construídas.

Palavras-chave: *Lissachatina fulica*, bioma Cerrado, espécie invasora, molusco terrestre, ecologia populacional.

*e-mail: rotidon@unb.br
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1. Introduction

The giant African snail *Lissachatina fulica* poses significant threats to the environment, public health, and agriculture (Thiengo et al., 2007). From an ecological perspective, this invasive species endangers native snails both through direct predation and broader ecosystem impacts. It has been reported feeding on native mollusks (Meyer 3rd et al., 2008), and control measures targeting *L. fulica* may inadvertently result in the mortality of *Megalobulimus paranaguensis*, as the two species share morphological similarities and are easily misidentified (Miranda and Pecora, 2017). From a public health perspective, the snail serves as a vector for up to 36 different pathogens, some of which are harmful to humans, underscoring its significance as a public health hazard (Vázquez et al., 2018; Silva and Morassutti, 2020; Gippet et al., 2023; Rangel et al., 2023). In agriculture, it damages a variety of commercially valuable crops, including papaya, stored grains, ornamental plants, and small-scale home gardens, resulting in considerable economic losses (Kant and Diarra, 2016). The International Union for Conservation of Nature (IUCN) has classified this species, named as *Lissachatina fulica* (Bowdich, 1822), as one of the 100 worst invasive alien species worldwide (Lowe et al., 2000). It is worth noting, however, that the species was initially described as *Achatina fulica* Bowdich, 1822, and both names are still found in the literature. Regardless of the taxonomic debate, effective management and control strategies are urgently needed to mitigate the ecological, health-related, and economic impacts of the giant African snail in invaded areas.

In non-native areas, the giant African snail populations exhibit remarkable variation in several biological traits. Population densities can range widely, from less than 1 ind/m^2 (Vázquez and Sanchez, 2014) to over 100 ind/m^2 (Gutiérrez-Gregoric et al., 2011), depending on environmental conditions. Morphometric traits also vary widely, with adult shell lengths reaching up to 200 mm (Barçante et al., 2005). Its high reproductive capacity contributes to its invasiveness; individuals can lay up to 460 eggs at a time (Roda et al., 2016), enabling rapid population growth under favorable conditions. These traits are influenced by environmental factors such as climate, habitat type, and food availability (Albuquerque et al., 2008, 2009). Urban areas, in particular, may provide conditions that favor the proliferation of this species (Miranda et al., 2015; Gołdyn et al., 2016, 2017).

The first record of *Lissachatina fulica* in Brazil occurred in 1997 (Santana-Teles et al., 1997). In 2001, the Brazilian Society of Malacology issued recommendations for controlling this invasive species. In 2002, the Brazilian Institute of Heliciculture launched the National Program for Environmental Sanitation to address the invasion. The following year, the Ministry of the Environment, in partnership with the Brazilian Institute of the Environment and Renewable Natural Resources (IBAMA) and the Ministry of Agriculture, banned the sale of the mollusk. In 2004, IBAMA initiated a pilot management plan, called "C-Day", followed in 2005 by the "1st National Symposium on Invasive Alien Species" (Thiengo et al., 2007). In 2009, Brazil established the National Strategy for Invasive Alien Species.

In the Federal District of Brazil, *L. fulica* was first recorded in 2006 (Cazarin-Oliveira et al., 2021). Since then, its rapid spread and harmful effects have raised serious ecological and agricultural concerns. By 2018, it was officially designated as one of the five invasive species prioritized for management by the Brasília Ambiental Institute (IBRAM), reflecting its status as a significant threat to local biodiversity and ecosystems.

This study aimed to investigate the population attributes of *Lissachatina fulica* in the Federal District of Brazil. Specifically, we described its spatial distribution, population density, weight, shell characteristics, and reproductive potential. This characterization is intended to provide environmental authorities with useful data for developing target management plans.

2. Materials and Methods

2.1. Study area and sampling

The Federal District, located in Brazil´s Central-West Region, is the smallest of the country´s 27 federal units, with an area of 5,760.78 km^2. Its estimated population of three million inhabitants is concentrated in the more urbanized areas (IBGE, 2025). The region has a tropical climate, with an average temperature of 22 ± 10 °C and rainfall primarily occurring between October and April. Drought conditions may persist for over 160 days in some areas, as observed in 2024.

Snails were collected from 25 sites: 13 between February 4 and May 13, 2021, and 12 between January 24 and April 6, 2022 (Figure 1). Sites were selected based on occurrence records compiled by IBRAM, the agency responsible for monitoring and controlling invasive species in the Federal District. At each site, a 50 m × 50 m quadrat was established, centered on the georeferenced location. Two to three people actively searched for snails within each quadrat, collecting live and dead individuals as well as empty shells. Search efforts continued until no more individuals could be found. Snails were placed in 25 L plastic containers and transported to the Evolutionary Biology Laboratory at the University of Brasília.

2.2. Laboratory procedures

In the laboratory, specimens were counted, classified as alive or dead, measured, weighed, and dissected. Shell length, shell width, and peristome thickness, were measured using a digital caliper (±0.01 mm), and live individuals were weighed with an analytical balance (±0.001 g). Reproductive potential was assessed in individuals with shell lengths greater than 30 mm through dissection and egg counting (Patiño-Montoya et al., 2024). After analysis, specimens were euthanized, immersed in 10% bleach for one week, autoclaved, and discarded as biological waste. Due to restricted laboratory access during the COVID-19 pandemic, a subsampling strategy was employed. At sites with less than 100 individuals, total shell length and width were measured in all individuals except for those from site S16. For sites with more than 100 individuals, measurements were taken from at least 25% of the individuals, ensuring representation across the full size range (see Supplementary Material).

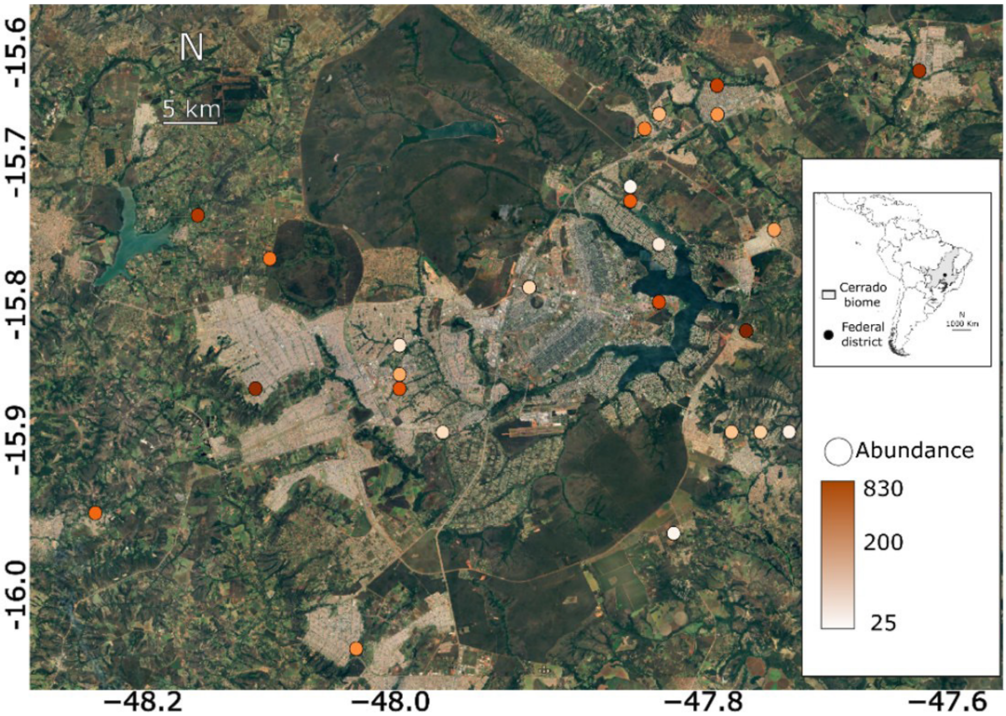

Figure 1. Sites where the giant African snail (*Lissachatina fulica*) was recorded and collected in the Federal District. On the right, the map of South America with the location of the Cerrado biome and the Federal District.

2.3. Statistical analysis

Geographic distribution was mapped, and population density was calculated per site as the number of individuals divided by 2,500 m^2 (quadrat area). Frequency histograms were used to explore the distribution of shell length, width, and weight. Allometric relationships were examined by associating shell length with width (linear model) and weight (power model). For the power model, we tested whether the allometric coefficient (b) differed significantly from the isometric expectation (b = 3), using the sma function from the R package smatr (Warton et al., 2012). Reproductive potential was evaluated by determining the percentage of gravid individuals by shell length interval, the total number of eggs per site, and the number of eggs per individual (minimum, maximum, mean, and standard deviation). As shell length and peristome thickness have been used to indicate the reproductive period in *L. fulica* (Tomiyama and Miyashita, 1992; Tomiyama, 1993), Pearson correlation analyses were used to assess associations between these variables with the number of eggs. The analyses were conducted using the base packages of R 4.2.0.

3. Results

The giant African snail is widely distributed across the Federal District (Figure 1). Most occurrences were recorded near vegetation or water bodies in the vicinity of Brasília. No individuals were found in densely urbanized areas dominated by built, impervious surfaces. A total of 5,242 individuals of *L. fulica* were collected (3,701 alive and 1,541 dead): 2,027 in 2021 and 3,215 in 2022. The abundance of individuals per site ranged from 25 to 830, corresponding to population densities from 0.01 ind/m^2 to 0.33 ind/m^2. Notably, three sites (S3, S22, and S23) accounted for 42% of all individuals collected (Table 1).

The population showed a marked variation in size and weight. Shell lengths ranged from 4.17 mm to 114.5 mm, with one atypical shell measuring 163 mm. The frequency distribution of shell length showed two peaks: one between 15-30 mm (17.83%) and another between 55-70 mm (35.89%). Intermediate sizes (35-50 mm) were less common (13.22%) (Figure 2A). Shell width ranged from 3.07 mm to 50.70 mm, with an outlier at 60 mm. The width distribution was also slightly bimodal (data not shown). Width increased 0.43 times with length, indicating that larger individuals were relatively more elongated (Figure 2B). Snail weight ranged from 0.04g to 131.66g, with most individuals weighing under 50g (Figure 2C). A relationship was observed between length and weight (b = 2.64; slope test r=-0.76; d.f.=2,385; p<0.01), indicating negative allometry (Figure 2D).

Regarding reproduction, 11.2% of the individuals examined were gravid, collectively containing 14,893 eggs. Gravid individuals had shell lengths between 50.05 mm and 103.14 mm, and egg counts ranged from 3 to 246 per individual (mean ± SD: 86.58 ± 40.80) (Figure 3A). Egg number showed a moderate positive correlation with shell length (r=0.44, $t_{(170)}$=6.43, p<0.01), with increased variability from 80 mm onward (Figure 3B). Peristome thickness ranged from 0.8 mm to 7 mm (mean ± SD: 2.54 ± 0.66 mm; median: 2.49 mm) but was not correlated with egg number (Figure 3C).

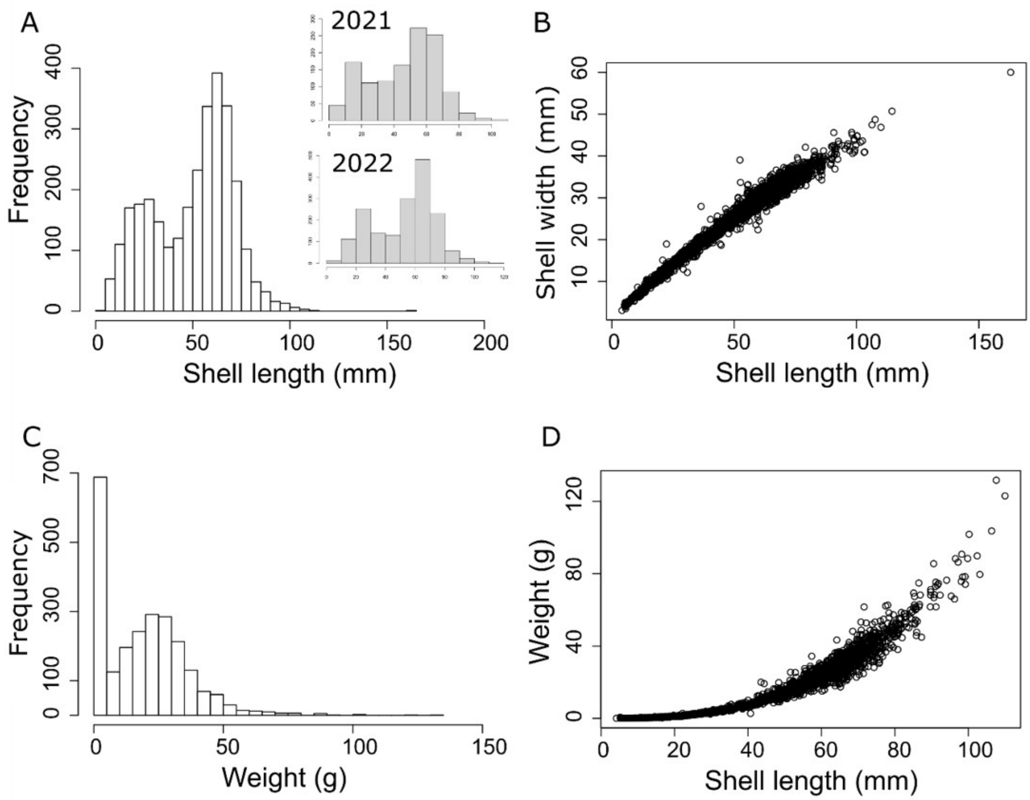

Figure 2. Characterization of the giant African snail *Lissachatina fulica* in the Federal District of Brazil. A. Frequency distribution of total shell length (mm) (n=2,997), and the distribution of total shell length in 2021 (n=1,252) and 2022 (n=1,744) collection years without outliers. B. Relationship between width (mm) and length (mm) (n=2,972, equation y=0.43x+3.46; R^2=0.98). C. Frequency distribution of weight (g) in individuals (n=2,382). D. Relationship between weight (g) and length (mm) (n=2,387, equation $y=0.0005x^{2.6437}$; R^2=0.98).

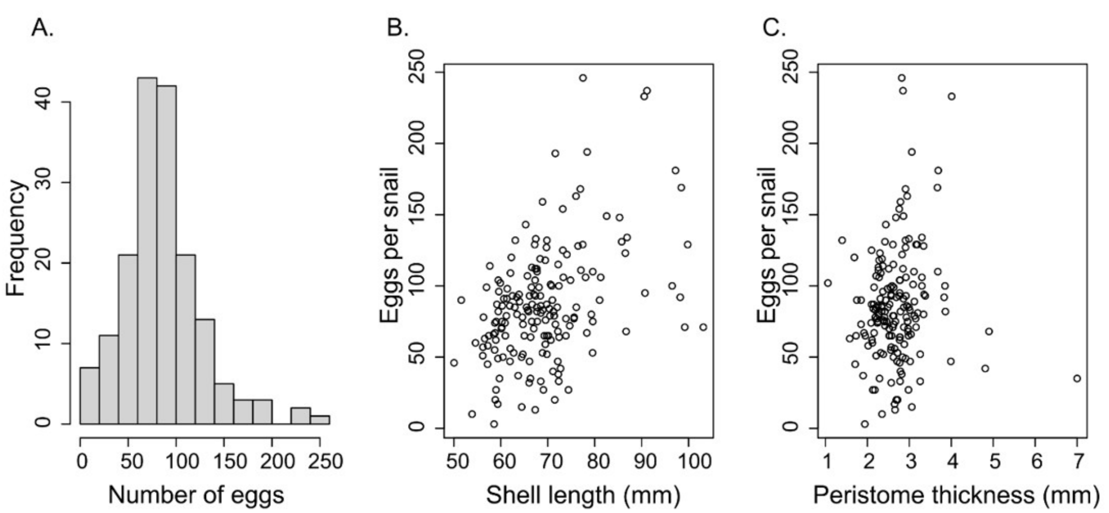

Figure 3. Reproductive attributes of the giant African snail (*Lissachatina fulica*) in the Federal District. A. Frequency of number of eggs per individual (n=172). B. Number of eggs per individual associated with snail shell length (n=172). C. Number of eggs per individual associated with the thickness of the peristome (n=169).

Table 1. Sites of occurrence of the giant African snail in the Federal District, showing the date of collection, geographical coordinates, administrative region, abundance and population density.

Site	Date	Latitude (S)	Longitude (W)	Administrative Region	Abundance	ind/m²
S1	04/02/2021	-15.88	-47.77	Jardim Botânico	83	0.033
S2	12/02/2021	-15.88	-47.75	Jardim Botânico	33	0.013
S3	17/02/2021	-15.81	-47.78	Paranoá	830	0.332
S4	24/02/2021	-15.71	-47.86	Lago Norte	25	0.01
S5	02/03/2021	-15.88	-47.99	Riacho Fundo 1	44	0.018
S6	03/03/2021	-15.75	-47.84	Lago Norte	36	0.014
S7	12/03/2021	-15.72	-47.86	Lago Norte	194	0.078
S8	17/03/2021	-15.66	-47.84	Sobradinho	94	0.038
S9	19/03/2021	-15.67	-47.85	Sobradinho	158	0.063
S10	30/04/2021	-15.95	-47.83	Jardim Botânico	25	0.01
S11	03/05/2021	-15.84	-48.02	Águas Claras	113	0.045
S12	07/05/2021	-15.78	-47.93	Cruzeiro velho	47	0.019
S13	13/05/2021	-15.64	-47.80	Sobradinho	345	0.138
S14	24/01/2022	-15.79	-47.84	Vila Planalto	281	0.112
S15	28/01/2022	-15.82	-48.02	Águas Claras	40	0.016
S16	01/02/2022	-15.88	-47.79	São Sebastião	87	0.035
S17	01/02/2022	-15.85	-48.02	Arniqueira	242	0.097
S18	07/02/2022	-15.73	-48.16	Brazlândia	463	0.185
S19	09/02/2022	-15.74	-47.76	Itapoã	114	0.046
S20	14/02/2022	-15.66	-47.80	Sobradinho	117	0.047
S21	16/02/2022	-16.03	-48.05	Gama	132	0.053
S22	21/02/2022	-15.85	-48.12	Ceilândia	702	0.281
S23	21/03/2022	-15.63	-47.66	Planaltina	669	0.268
S24	28/03/2022	-15.76	-48.11	Brazlândia	183	0.073
S25	06/04/2022	-15.93	-48.23	Recanto das Emas	185	0.074

4. Discussion

Throughout the Brazilian Federal District, the giant African snail was primarily recorded in areas where vegetation and accumulated garbage provide food, shelter, and suitable places for oviposition, supporting previous findings (Thiengo et al., 2007; Cazarin-Oliveira et al., 2021). The absence of records in highly urbanized areas and conservation units may reflect both ecological and observational factors. In the case of densely populated urban areas, such as Brasília, the lack of reports is unlikely to result from underreporting, as residents have easy access to communication tools and are likely to notice conspicuous invasive species. It is more plausible that these urban environments are too dry or resource-scarce to support viable populations. In contrast, the absence of records in conservation units may be due to a lack of residents who could detect and report the species. Since *L. fulica* has been recorded in other protected areas in Brazil (Instituto Hórus, 2024), and no targeted surveys have been conducted in natural areas of the DF, we cannot rule out its presence in these environments. Altogether, our findings suggest that the giant African snail prefers moderately disturbed areas in the DF, but continued monitoring in conservation units remains important.

Snail densities varied across sites but were generally low (<0.33 ind/m²), much lower than those reported in Argentina (>100 ind/m²; Gutiérrez-Gregoric et al., 2011), Colombia (>18 ind/m²; Cano Garzón, 2018), or northern Brazil (6.15 ind/m²; Oliveira et al., 2013) (see also Patiño-Montoya et al., 2022). In our study, nearly half of the individuals were concentrated in three sites across the Federal District, indicating potential infestation hotspots. These areas were characterized by the presence of organic matter and debris, although we did not quantify these resources. Thus, while densities are currently low, the invasive potential of *L. fulica* should not be underestimated, as its populations may increase under favorable conditions.

Shell length measurements support previous records of the species in Brazil. The largest individual (163 mm) approached the species' maximum recorded length (200 mm; Barçante et al., 2005), while the majority of individuals were smaller than 115 mm, a pattern also observed in other regions (e.g., 150 mm in Rio de Janeiro: Vasconcellos and Pile, 2001; 102 mm in Bahia: Albuquerque et al., 2009). The distribution of shell lengths showed two distinct peaks at 15-30 mm and 55-70 mm. The lower frequency of intermediate-sized shells (30–50 mm) may reflect seasonal environmental pressures in the study area. During the dry season, juvenile snails experience higher mortality due to desiccation stress while aestivating (Raut and Barker, 2002). In addition, older snails display greater dietary plasticity during the rainy season, outcompeting younger conspecifics for resources (Raut and Ghose, 1983). Consequently, by the onset of the rainy season, most surviving individuals are likely to exceed 50 mm in shell length, contributing to the second size-class peak. A similar distribution pattern was observed in India, where the giant African snail reproduces during the monsoon months (July–October) and estivates during the dry season (Raut and Ghara, 1990). Therefore, the first peak likely represents recruits from the current reproductive season, whereas the second peak corresponds to individuals that survived the preceding estivation period.

The allometric relationships observed in this study revealed negative allometry in weight-length ratios (WLR; b<3), which could indicate either more elongated adult forms or that smaller individuals are in relatively better nutritional condition. Although WLR has been used to infer body condition or shape changes in groups such as fish (Froese, 2006) and crustaceans (Carvalho-Souza et al., 2023), its application in gastropods remains uncommon (Miranda and Fontenelle, 2015). Additionally, shell width increased less in DF specimens (0.43 times the length) than in specimens from Colombia (0.46; Avendaño and Linares, 2015), Ecuador (0.48; Villavicencio-Abril et al., 2020), and the Brazilian Amazon (0.49; Santos et al., 2020). These differences in shell morphology may result from environmental factors (Goodfriend, 1986) or reproductive stage (Patiño-Montoya et al., 2024). It is possible that DF individuals elongate earlier in their development, potentially reaching hermaphroditic maturity faster than those in other regions.

Evidence of recruitment during the collection period further supports seasonal reproductive dynamics. The concentration of individuals in the 50–103 mm size range aligns with the size of gravid individuals, as reported by Roda et al. (2016) and observed in laboratory studies by Tomiyama (1993). A second, smaller size class likely corresponds to juveniles or non-reproductive males. The presence of gravid individuals at 20 of the 25 sampling sites indicates active reproduction during the rainy season. Although the maximum number of eggs observed per individual (246) was below the record of 460 eggs (Roda et al., 2016), reproductive activity was widespread. In the DF, 85–90% of the annual rainfall occurs between November and April (INMET, 2021), a period that reactivates snail behavior and promotes reproductive activity (Silva and Omena, 2014). Rainfall not only ends estivation (Rahman and Raut, 2010) but also stimulates plant growth, providing essential food and shelter. Thus, the reproductive window in the DF appears to be limited to approximately five months, after which dry conditions lead snails to resume estivation—burrowing into the soil to avoid desiccation, as observed by the authors. This pronounced seasonality strongly regulates the reproductive cycle of *L. fulica* in this region.

Given the relatively low population densities and localized reproductive activity, the management of *L. fulica* in the DF appears feasible. Control efforts should prioritize moderately urbanized and peri-urban regions, where suitable habitats and reproductive individuals are more common. These actions should begin early in the rainy season and target individuals larger than 5 cm, which are likely hermaphroditic and capable of reproduction. Finally, the data presented here may help inform control strategies in other Brazilian regions with similar climate conditions, as the likelihood of reproduction by individuals exceeding 50 mm is high in such environments.

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Data Availability Statement

The entire data set that supports the results of this study was published in the article as supplementary material.

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Supplementary Material

Supplementary material accompanies this paper.

Appendix 1. Number of snails collected per sampling site, with length and width measurements, weight, number of eggs per snail, and peristome thickness. Abundance: Total number of snails collected per site, Live: Total number of snails alive, Size: Number of snails with length and width measured, Weight: Number of snails weighed, Eggs Total: Number of snails that were opened to look for eggs, Snails with eggs: Number of snails with egg occurrence. Peristome: Number of snails with peristome thickness measured.

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