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Population dynamics and reproductive biology of *Achatina fulica* Bowdich, 1822 (Mollusca, Gastropoda) in Salvador - Bahia

Eder Carvalho da Silva[1,3] *& Elianne Pessoa Omena*[2]

[1]*Núcleo Integrado de Estudos em Zoologia – NIEZ, Instituto de Ciência Biológicas da Universidade Católica do Salvador – UCSal, Av. Prof. Pinto de Aguiar, 2589, 41.740-090, Salvador, BA, Brasil.*
[2]*Departamento de Biologia Marinha, Instituto de Biologia da Universidade Federal do Rio de Janeiro – UFRJ, Avenida Carlos Chagas Filho, 373, Bloco G, Cidade Universitária, 21.941-902, Rio de Janeiro, RJ, Brasil.*
[3]*Corresponding author: Eder Carvalho da Silva, e-mail: edercarvalho514@oi.com.br*

SILVA, E.C., OMENA, E.P. **Population dynamics and reproductive biology of *Achatina fulica* Bowdich, 1822 (Mollusca, Gastropoda) in Salvador - Bahia.** Biota Neotropica. 14(3): e20140004. http://dx.doi.org/10.1590/1676-0603000414

Abstract: The risks following introduction of invasive species are enormous and incalculable. *Achatina fulica* is considered one of the 100 species of greatest invasive potential, stands out among the land pulmonate snails, mostly for its high reproductive potential that accelerates the process of dispersion, increasing the damages related to health (disease transmission), to economy (crops destruction) and to environment (biodiversity loss). In order to investigate the relationship of the African snail with the environment, trying to relate sexual activity with climatic variables (temperature, rainfall and humidity), a study was conducted on aspects of population dynamics and reproductive biology in Salvador city. The snails were collected by hand, monthly. Morphometric data were obtained in the field and dissections to analyze the reproductive system at laboratory. To test if there was a greater sexual activity in wet periods was performed first a Principal Component Analysis (PCA) with climatic variables, followed by a regression between precipitation (the most influential environmental variable) and the variable of interest (sexual activity). The results showed that there is an apparent annual cycle for *A. fulica*, with a recruitment period covering the end of rainy season and the dry season (August to December 2006 and February 2007). Increase of shell size (height) and of sexual activity were observed during the rainy season, although snails were found in full sexual activity during the whole period of study. The von Bertalanffy curve showed that the oldest specimen collected would have three years and eleven months. The regression between precipitation and sexual activity was significant ($P = 0.002$) showing that the higher rainfall increased sexual activity. In addition, it was observed that there is an increase in the thickness of peristome as the specimens reaches sexual maturity however this relationship isn't precise (it were found individuals with sexual structures not consistent with the reproductive stage given by the thickness of peristome) and should be set for each region studied. As the eradication becomes impossible because of high level of invasion found in Salvador, it is recommended to control the population of African snails by continuously removing specimens, especially in the rainy periods.
Keywords: *bioinvasion, invasive species, reproductive cycle, growth, giant African snail.*

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Resumo: Os riscos com a introdução de espécies invasoras são enormes e incalculáveis. Constando como uma das 100 espécies de maior potencial invasor, *Achatina fulica* se destaca dos demais gastrópodes pulmonados terrestres, principalmente, pelo seu elevado potencial reprodutivo que acelera o processo de dispersão, aumentando os danos relacionados à saúde (transmissão de doenças), à economia (destruição de cultivos) e ao meio ambiente (perda da biodiversidade). Com o intuito de investigar as relações do caramujo africano com o ambiente, tentando relacionar atividade sexual com variáveis climáticas (temperatura, precipitação e umidade), foi realizado um estudo sobre aspectos da sua dinâmica populacional e biologia reprodutiva na cidade de Salvador. Os caramujos foram coletados manualmente, mensalmente. Dados morfométricos foram obtidos em campo e dissecações para estudo do sistema reprodutivo em laboratório. Para testar se havia uma maior atividade sexual em períodos úmidos foi realizada, inicialmente, uma Análise de Componentes Principais (PCA) com as variáveis climáticas, seguida de uma regressão entre a precipitação (variável ambiental com maior influencia) e a variável de interesse (atividade sexual). Os resultados mostraram que há um aparente ciclo anual para *A. fulica*, com um período de recrutamento abrangendo o

final da estação chuvosa e a estação seca (agosto a dezembro de 2006 e fevereiro de 2007). O aumento do tamanho da concha (altura) e da atividade sexual foi observado durante a estação chuvosa, embora tenham sido encontrados caramujos em plena atividade sexual em todo o período de estudo. A curva de von Bertalanffy mostrou que o exemplar mais velho teria três anos e onze meses. A regressão entre a precipitação e a atividade sexual foi significativa (P = 0,002) mostrando que precipitações mais elevadas aumentam a atividade sexual. Além disso, observou-se que a espessura do perístoma aumenta à medida que o individuo atinge a maturidade sexual, porém esta relação não é precisa (havia indivíduos com estruturas sexuais não consistentes com o estagio reprodutivo dado pela espessura do perístoma) e deve ser ajustada para cada região estudada. Como a erradicação se torna impossível pelos níveis de invasão encontrados em Salvador, é recomendada, para controlar a população de caramujos africanos, a remoção continua de espécimes, especialmente nos períodos de chuva.
Palavras-chave: *bioinvasão, espécies invasoras, ciclo reprodutivo, crescimento, caramujo gigante africano.*

Introduction

The introduction of species in a new habitat represents environmental and economic risks; free of predators, parasites and natural competing, in positive environmental conditions, these organisms can reach high population densities. Once established, they are rarely eliminated resulting generally in losses of local biodiversity (Carlton 1996, Dajoz 2005, Towsend et al. 2006). The introduction of invasive species is considered the second greatest cause of biological diversity loss in many ecosystems, also, can cause a change in its structure and function, increasing the homogenization of biota (USC 2001, Alowe et al. 2004, Fischer & Colley 2004).

Known as giant African snail, the land pulmonate mollusc *Achatina fulica* Bowdich, 1822, reaches considerable dimensions, nearly 20 cm shell length and weigh up 200 g (Teles et al. 1997, Vasconcellos & Pile 2001), but in Brazil the maximum average records vary in about 11 cm and little over 100 g (Vasconcellos & Pile 2001, Carvalho et al. 2003, Simião & Fischer 2004, Fischer & Colley 2005, Fischer et al. 2006).

The species is distinguished from other pulmonate molluscs due the high invasion potential (Teles et al. 2004). The characteristics that makes it one of the 100 species of greatest invasive potential at the List of the International Union for Conservation of Nature (IUCN) (Alowe et al. 2004) are: high reproductive capability, being a protandric hermaphrodite species with reciprocal copulation (Tomiyama 1993), the ability to stock sperm for long periods (Raut & Barker 2002), and a high annual eggs postures (5 to 6) and eggs per posture (Tomiyama & Miyashita 1992). These aspects of African snail reproductive biology is an increment to the growth and population explosion process, affecting the environment (potential predator and competitor of native mollusks leading to extinction of species), economy (agricultural pests) and local health (a possible intermediate host for nematodes that cause eosinophilic, meningoencephalitis and abdominal angiostrongyliasis in humans and other zoonosis in domestic animals) (Cowie 1998, 2001, Fischer & Colley 2005, Thiengo et al. 2008, Caldeira et al. 2007, Graeff-Teixeira 2007, Neuhauss et al. 2007).

Studies in the state of Paraná conducted by Fisher & Colley (2005) led the supposition that *A. fulica* has a seasonal cycle of one or two generations per year with copulas occurring mainly in spring and autumn. The evidence of seasonality of *A. fulica* was also registered by several authors (Berry & Chan 1968, Lai et al. 1982, Raut & Barker 2002, Fisher & Colley 2005) which showed that there are high sexual activity points in favorable environmental conditions such as high humidity, moderate temperatures and abundant rainfall.

Studies show that the economic losses caused by the introduction of invasive species are estimated at US$ 42.6 billion per year, the environmental costs, US$ 6.7 billion per year and the costs with human health, despite more hard to estimate, are also huge (Pimentel et al. 2001). Although the trend described by Simberloff & Gibbons (2004) of population collapse after some time of invasion, researches about population dynamics and reproductive biology of *A. fulica* is extremely important to be able to understand their ecological relationships and the search for better handling and control strategy, reducing the problems caused by the species.

Therefore, this study intend to present data about population dynamics of *A. fulica* in Salvador, describing aspects of life cycle of the species such as growth rate, size, recruitment season, age (life time) and reproductive season, as well as characterize the reproductive biology, evaluating the existing relationship between the thickness of peristome and stage of sexual maturity, and among weather effects, such as rainfall, temperature and humidity with sexual activity periods.

Considering the explained data, our hypothesis of interest is that exists a relation between sexual activity and weather variables studied (temperature, rainfall and humidity), being waited a largest sexual activity in humid periods in Salvador - Bahia.

Material and methods

1. *Study site*

The studied site is located at Salvador metropolitan area, which is situated at 12°57'13''S and 38°27'24''W (between the Tropic of Capricorn and the Ecuador line); its climate is hot and humid - sunny, with an average temperature of 25.5°C with low variation during the year. The annual rainfall rate of the city is around 2000 mm, the average humidity is 81% (maximum 83% in May and minimum 79% in February). It has historically been a wet season which is usually April to September and a dry season from October to March. (INMET 2008). These characteristics make Salvador propitious to the establishment and expansion of invasive gastropod *Achatina fulica*.

2. *Sampling & experimental design*

According to previous studies (Silva 2005), there are 15 districts infested by *A. fulica* in Salvador (Amaralina, Barra, Barris, Caminho das Árvores, Costa Azul, Itaigara, Itapuã, Jardim Encantamento, Ondina, Piatã, Pituba, Praia do Flamengo, Rio Vermelho, Stella Maris and STIEP). From this data, three districts were randomly chosen for each monthly

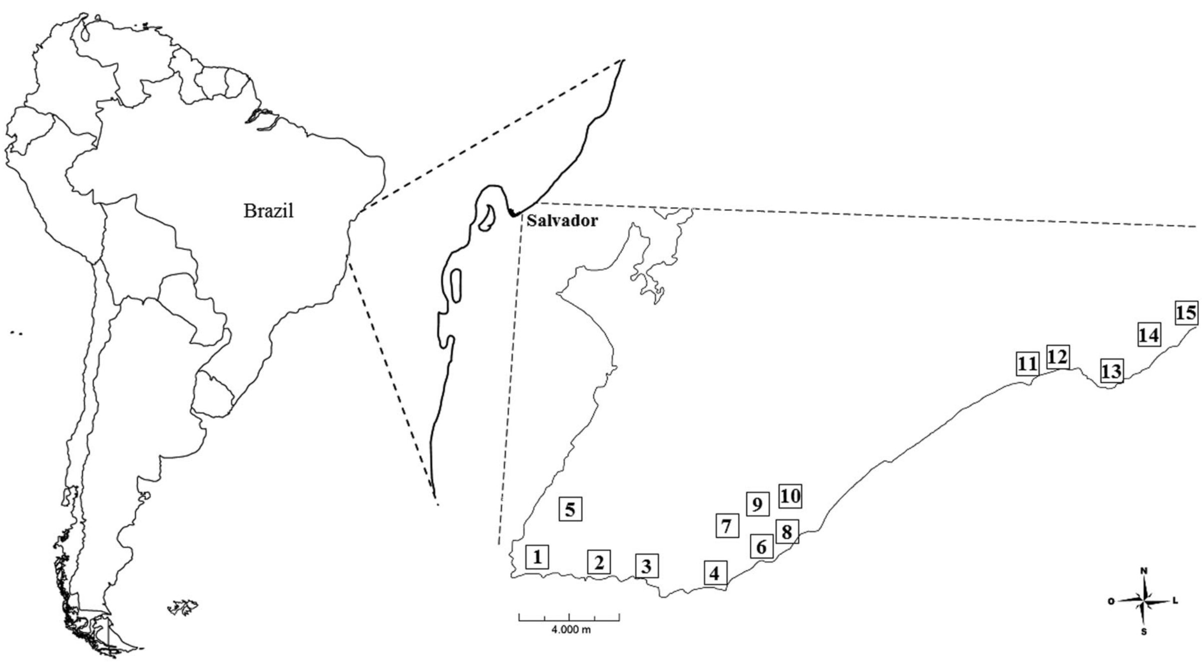

Figure 1. Map of localization of the city of Salvador, Bahia, showing the sites of the sampling areas visited during the study period. Areas (visits). 1. Barra (2); 2. Ondina (1); 3. Rio Vermelho (3); 4. Amaralina (1); 5. Barris (3); 6. Pituba (3); 7. Itaigara (3); 8. Costa Azul (2); 9. Caminho das Árvores (2); 10. Stiep (2); 11. Piatã (3); 12. Itapuã (3); 13. Jardim Encantamento (3); 14. Stella Maris (2); 15. Pr. do Flamengo (3).

sampling campaign. In each district a 1 km^2 area was demarcated (Figure 1). Some districts were chosen more than once, for a maximum of three times, when it happened, the limited 1 km^2 areas were moved to new areas that could be visited, but remaining inside the chosen districts. The collects were designed to sample, representatively, the study area, avoiding the spatial variability as a confounding variable affecting the temporal variation that was searched in the present study. Maps with the delimited sample areas were used, as well as the route to be followed during the gathering, with the intent to assist the moving of collectors.

The gathering procedure consisted on hand capture of specimens at streets, squares, gardens and some other public places. All gathering were made by two collectors, early in the morning, activity time of snails end (Tomiyama 1993, Raut & Barker 2002, Albuquerque 2003), and lasted about one hour. Collectors wore surgical gloves to protect them against snails' and/or possible environmental pathogens where they were found.

Gathering were made monthly from September 2006 to August 2007, in the areas of sampling. All the specimens of *A. fulica* found in one hour were gathered, within each sampling area (a total of 884 in 12 months). All then were submitted to morphologic analysis in the field to population dynamic data. Of the total collected, 45 snails per campaign (540 in total) were taken, in plastic containers to Universidade Católica do Salvador's laboratory, to macro-anatomical analysis of reproductive system.

The monthly amounts of accumulated rainfall (mm), temperature average (°C) and humidity (%) were collected from the Center of Weather Forecasting and Climatic Studies – National Institute for Space Research (CPTEC/INPE), through the database available on the World Wide Web at the site: http://www.cptec.inpe.br/. The amounts corresponded to 30 days preceding gathering.

3. *Morphometric analysis*

The animals collected in September 2006 were measured with the assistance of a pachymeter (0.05 to 150 mm) and weighed with Titan's field digital weighing-machine with accuracy of 0.1 g. The measured dimensions were: large diameter (ld), opening height (oh), opening width (ow), spire height (sh), shell height (h), thickness of peristome (pe), number of whorls (Figure 2) and weight (p). After found the best measure that represents the growth of the animal, to enhance the sampling, only the shell height (h) and total weight (p) were measured in remaining collects.

4. *Laboratorial analysis*

To examine the anatomical characteristics of reproductive system, specimens of different sizes were sacrificed by heating

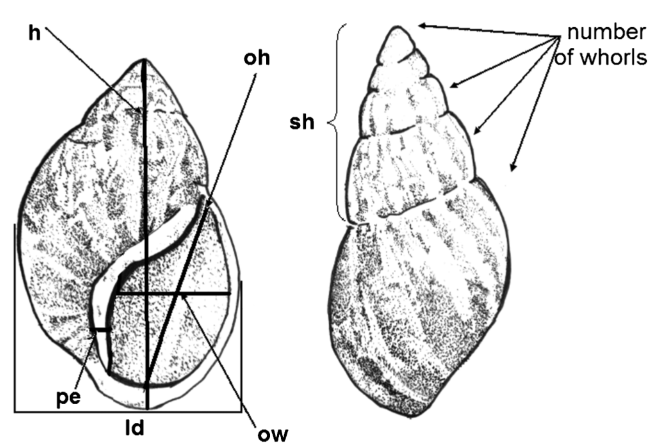

Figure 2. Shell scheme of *A. fulica* Bowdich, 1822 indicating the morphometrical measurements (ld, large diameter; h, shell height; oh, opening height; sh, spire height; ow, opening width; pe = thickness of peristome). Illustration from Fischer (2005).

(100°C for a minute) and dissected under stereo-microscope. The structures of reproductive system were observed following the illustrations and descriptions by Tomiyama (1993, 2002), Caetano (2005), Fisher & Colley (2005) and Teixeira et al. (2008), to *A. fulica*.

The weight of protein gland was obtained using a digital analytical weight-machine with accuracy of 10mg (0.01g) to verify if the snail was sexually active or not.

The number of eggs inside the uterus of the snails was also quantified.

5. *Statistical analysis*

Initially it was applied a Principal Components Analysis (PCA) using MVSP (Multi-Variate Statistical Package) version 3.13l for Windows, with the purpose of extract the first two axis of variation (PC1 e PC2). Subsequently PC1 x PC2 were plotted to observe the clustering.

Because of small variation in temperature, humidity and, consequently, small influence on sexual activity, also correlated to the species biology, just the rainfall was used in the regression with the variable of interest (sexual activity). The regression was done using SPSS (Statistical Package for the Social Sciences) 13.0 for Windows, being 0.05 the deemed value to α. The variable of interest (sexual activity) represented the proportion between number of sexually active individuals (protein gland > 650 mg) and the sexually inactive (gland < 650 mg).

To establish the morphometric measurement that best represents the growth of the snail, it was made Pearson correlations among morphometric variables (h, dm, ha, la, he, number of turns) and the weight of each individual using SPSS 13.0 for Windows (Statistical Package for the Social Sciences). From this determination was possible to create a linear equation and define, more accurately, the frequency distribution of the population of *A. fulica*. It was stipulated that the value of α would be 0.05, however, this value was fixed by Bonferroni correction (α/n, where $\alpha = 0.05$ and n is the number of hypothesis testing). This procedure was adopted because they were conducted several hypothesis testing for the same data set. 0.008 is the deemed value of α in this present study.

The growth curve was obtained using the von Bertalanffy model, which is:

$$L_t = L_\infty [1-\exp(-k(t-t_0))]$$

where:

L_t = length at age t;
L_∞ = maximum asymptotic length;
k = constant of growth;
t_0 = "age" in zero length ($L_t = 0$)

The growth parameters, as the growth curve were obtained using Microsoft Excel 2002.

The value of the constant of growth (k) was estimated from three pairs of known literature values of length and age or found in this study. Initially it was estimated the asymptotic length (L_∞) from the biggest taken specimen (Lmax), being: $L_\infty = Lmax/0.95$ (Pauly 1983). The average longevity to *A. fulica* found in literature is three to five years, being able to live until nine years in favorable conditions (laboratory for instance) (Tomiyama 1993; Raut & Barker 2002). Thus, with the value of asymptotic length (L_∞) found, the snail would have, nearly, six years.

Another characteristic found in literature is the period since fecundation until the birth (egg hatching), that varies around 13 days (0.036 years) (Raut & Barker 2002, Rao & Singh 2000). As it is improbable that a species grows following this equation since the moment of birth until it reaches the senility, the curve frequently cuts the x-axis, that refers to the age, on a point less than zero (King 1996). Knowing that with length zero ($L_t = 0$ mm) the snail has -0.036 years (-13 days) and that at birth (t = 0 years) presents nearly 3 mm shell length (E.C. Silva, unpublished data) it was able to estimate the steady growth (k). From that, it was just replace the value of t to get the Lt.

The longevity to the present study, established as how long the specimen takes to reach 95% of asymptotic length, was estimated based on formula proposed by Taylor (1958): $t_{max} = t_o + 2.996/k$.

Results

1. *Aspects of population dynamics of* Achatina fulica

The shell of *A. fulica* is reddish brown with strips of variable colors, from slightly brown until slightly purplish. The number of turns ranges between 5 and 8 and increase in diameter quick and progressively. The general form is bulimuloid (h/dm=1.58), with an elongated spire (he/h=0.41) and opening oval slant (ha/la=1.63; ha/dm=0.87; la/dm=0.54).

A total of 884 snails were collected in 12 sample campaign. The average of all gathering period was 50.17 mm height and 17.20 g weight. The remaining variables measured are described in tables 1 and 2.

All values of correlation among morphometric measurements and total weight found were positive and significative. The shell height was the best descriptor of size, presenting higher values of correlation with weight. (Table 3).

Table 1. Descriptive statistics of morphometric variable of 60 snails *Achatina fulica* Bowdich, 1822 collected in the city of Salvador, Bahia in September 2006. h = Shell height (mm); ld = large diameter (mm); oh = opening height (mm); ow = opening width (mm); sh = spire height (mm); Perist. = thickness of peristome (mm).

	Weight (g)	H	Ld	ow	ow	Sh	Turns	Perist.
Average	14.96	47.70	30.27	26.37	16.21	19.68	6.25	1.01
Median	14.60	50.50	32.45	27.75	16.90	20.45	6.00	0.95
Modal	23.0	54.6	30.7	33.6	20.8	25.7	6.0	1.9
Standard dev.	9.748	14.403	7.666	7.052	4.245	6.772	0.875	0.637
Standard err.	1.258	1.859	0.989	0.910	0.548	0.874	0.113	0.095
Variance	95.037	207.449	58.772	49.737	18.021	45.863	0.766	0.406
Minimum	2.1	23.6	17.4	14	9.4	9.4	5	0.2
Maximum	38.5	76.2	43.9	41.1	25.4	35	8	2.4

Table 2. Descriptive statistic of weight and shell height of 884 snails *Achatina fulica* Bowdich, 1822 collected in 12 samples from Salvador, Bahia, from September 2006 to August 2007.

	Weight (g)	Height (mm)
Average	17.20	50.17
Median	15.6	50.7
Modal	11.2	56.8
Standard dev.	11.750	12.760
Standard err.	0.395	0.429
Variance	138.078	162.833
Minimum	1.9	23.6
Maximum	104.2	107.6

Set shell height (h) as morphometric variable which better represent the growth of *A. fulica*, histograms of height rate were made monthly (Figure 3).

By analyzing the Figure 3 we can verify that there is, in almost every month, two modals featuring different cohorts, these two cohorts are more evident in August 2006. From March 2007, what is seen is a gradual average increase of shell height and, consequently, a shifting of the modals to right, featuring the aging of the population that is soon balanced by the rising of younger cohorts.

From August to December 2006 and February 2007 it was registered a higher number of young individuals in the population, unlike what occurred from March to July 2007 which there is a predominance of older individuals. The month of January 2007 had its frequency histogram different from other months due to the scarce amount of animals collected.

The growth study of *A. fulica* resulted in values of Lmax = 107.6 mm; L∞ = 113.3 mm; k = 0.75 and to = -0.036mm.

After replacement of these values, the expression was in the following way:

Lt = 113.3 x [1-exp(-0.75(t-(-0.036)].

The figure 4 shows the growth curve following the von Bertalanffy formula, with emphasis on the largest animal collected which measured 107.6 mm of shell height and was

Table 3. Correlations among weight and other morphometric variables for *A. fulica* Bowdich, 1822 from the city of Salvador, Bahia, in September 2006. ld = large diameter; oh = opening height; ow = opening width; sh = spire height. *n* = 60.

		Weight	Height	DM	ha	La	he	Turns
Weight	**Correlation of Pearson**	1	**.978(**)**	.962(**)	.960(**)	.933(**)	.953(**)	.767(**)
	Sig.(1-tailed)		$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$

**Correlation significant < 0,01 (1-tailed).

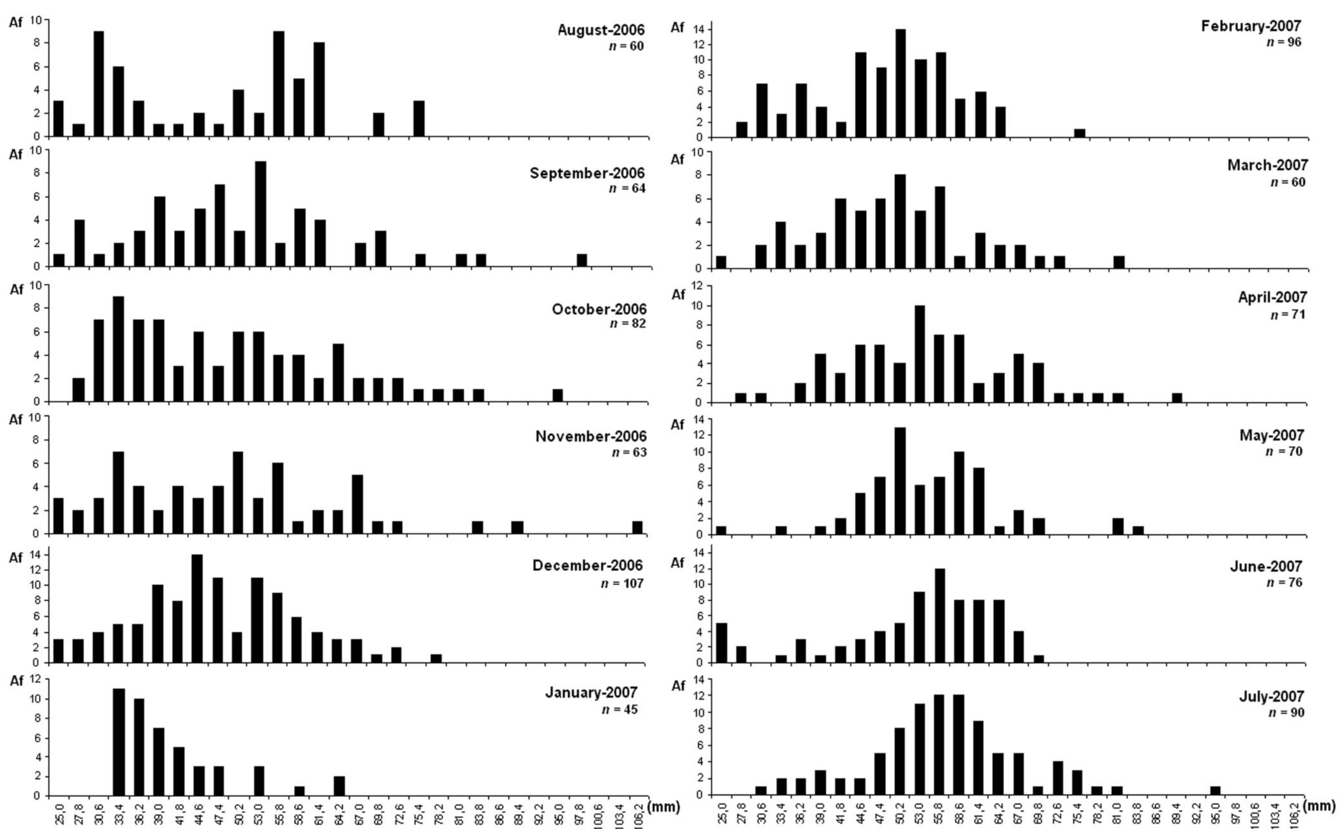

Figure 3. Monthly histograms of frequency of shell height of *A. fulica* Bowdich, 1822 from Salvador, Bahia in 12 sampling campaign from September 2006 to August 2007. Af = Absolute frequency.

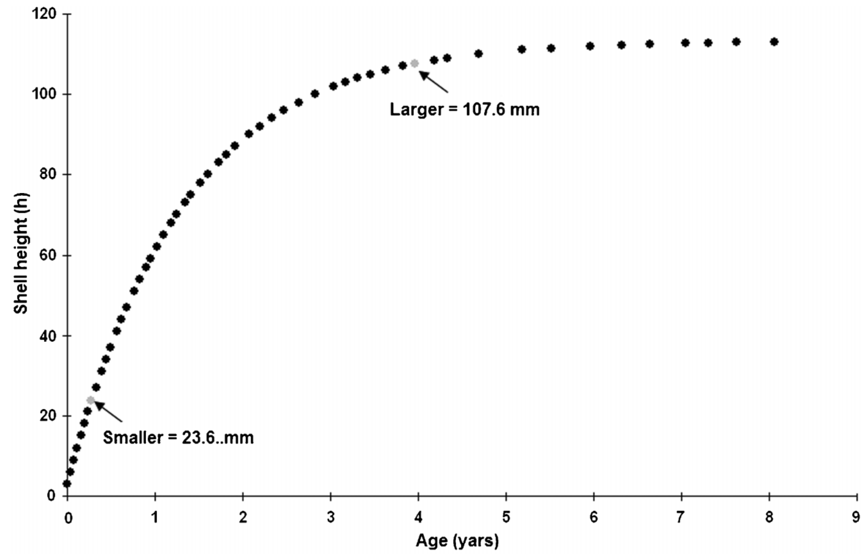

Figure 4. Growth curve to *A. fulica* Bowdich, 1822 from Salvador city, Bahia, obtained through the mathematic expression by von Bertalanffy - Lt = L∞ [1-exp(-k(t-t_0)] where: L∞ = 113.3 mm; k = 0.75 and t_0 = - 0.036). Highlights for the highest and lowest snail collected.

nearly 3 years and 11 months old, and the smallest with 23 mm and 3 months old.

The longevity was estimated in 3 years and 11 months old; in this age the snail would reach 107.6 mm of shell height, the same value of the largest animal collected.

2. *Climatic factors and sexual activity*

The average values of temperature and rainfall to the study period were close to historical values, however, humidity presented, nearly, 14% higher than the historical average, that did not affect the results, since that continues to be able to visualize a division between a humid or rainy season (April to September) and a less humid or dry season (October to March). Also is noteworthy the low average of temperature and humidity, as for historical values as for the study (Figures 5 and 6).

We collected 540 snails at 12 gathering campaign, 100 out of them were sexually active, 318 inactive and 122 could not be determined because did not present protein gland.

The results of this study show that there is a greater relation between rainfall and the sexual activity of *A. fulica* (Figure 6), once that temperature and humidity had low variation and low influence.

In months of higher rainfall, there were a higher percentage of animals sexually active, for example, in May and June 2007, with 180 and 202 mm, and 41% and 43% sexually active snails, respectively. In months with lower rainfall, January and February, with 19 and 37 mm, were found only 5% and 9% sexually active snails, respectively. We can still emphasize the period of March to July 2007, which had accumulated rainfall 916 mm - 56.5% of rainfall on full study period - and average per month 31% of sexually active animal while in the rest of the year the average of sexually active animals was 18%.

December 2006 and April 2007 were exceptions. During these months the precipitation was high, and sexual activity was low.

The Principal Components Analysis drew the two first axis of variation (PC1 and PC2) data. PC1 represented 59.7% of variation and PC2, 32.5% (92.2% total). Among the variables,

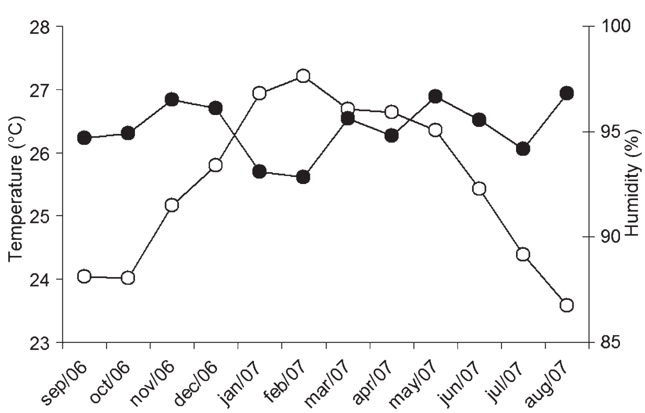

Figure 5. Temperature monthly average (○) and humidity (●) for Salvador, Bahia (September 2006 to August 2007). Source: CPTEC/INPE, 2008.

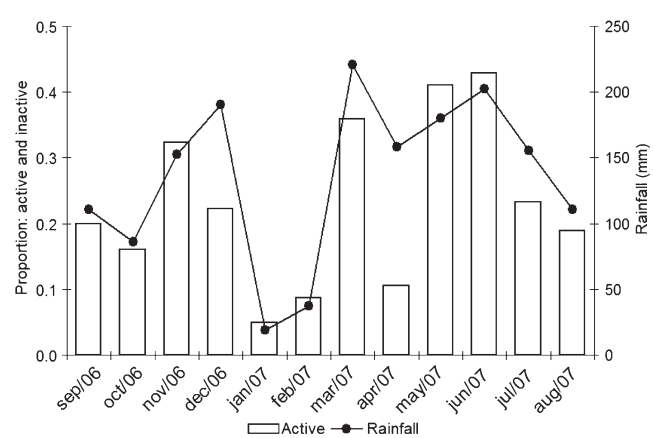

Figure 6. Proportion among active snails *A. fulica* Bowdich, 1822 and the relation with rainfall from September 2006 to August 2007 for Salvador, Bahia.

Table 4. Representativeness of each variable in each axis, extracted by Principal Component Analysis (PCA) to datasets of *Achatina fulica* Bowdich, 1822 from Salvador city, Bahia, collected from September 2006 to August 2007.

	PC1	PC2
Temperature	0.348	**0.883**
Humidity	**-0.701**	0.023
Rainfall	**-0.623**	0.468

humidity and rainfall were more inversely related to PC1 (as the PC1 grows humidity and rainfall decrease) and temperature, to PC2. The rainfall was also related to PC2, almost in the same intensity as to PC1 (Table 4).

When plotting PC1 x PC2 (Figure 7) the spatial distribution of points shows the generation of three clusters.

The first group, formed by the January and February contained the lowest values of sexual activity and was related to the lowest values of humidity and rainfall, in addition to high temperatures, characteristically of dry season. Inversely, November, December 2006 and March, May and June 2007 presented the highest values of sexual activity, related to higher values of humidity and rainfall and mild temperatures (humid season).

The group formed by September, October 2006 and July 2007 (transition between seasons), showed intermediate values of humidity, rainfall and temperature, related to average values of sexual activity.

Only April 2007, which had the highest temperature if compared to rainfall and humidity values showed, and August 2007, with higher humidity, that came out a little of what was expected to average values to sexual activity.

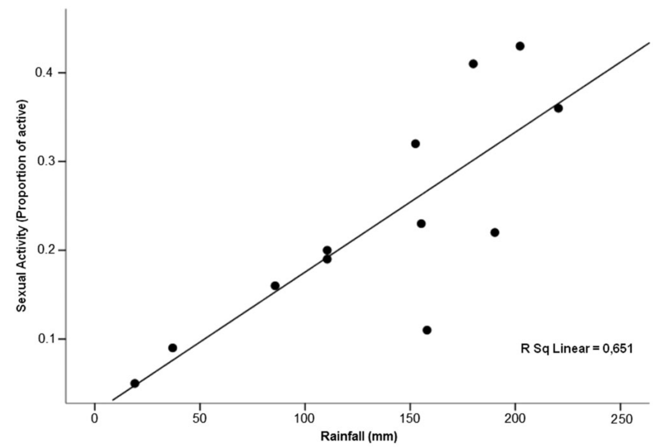

Figure 8. Linear regression between rainfall and the sexual activity (proportion of active) of *Achatina fulica* Bowdich, 1822 form Salvador city, Bahia, from September 2006 to August 2007. F = 18,617; *P* = 0,002; R^2 = 0,651

The regression between rainfall and sexual activity was significant ($P = 0.002$; $F = 18.617$) (Figure 8). So, the higher rainfall the higher the sexual activity is, that is, higher the number of specimen sexually active.

3. *Relationship between peristome and sexual maturity*

A total of 540 snails were collected, being 54% "Old-Adults", 34% "Intermediate" and only 12% "Young-Adults". Observing the monthly rate among "Old-Adults", "Intermediate" and "Young-Adults", shown on figure 9, it is possible to note increase of "Old-Adults" on rainy months.

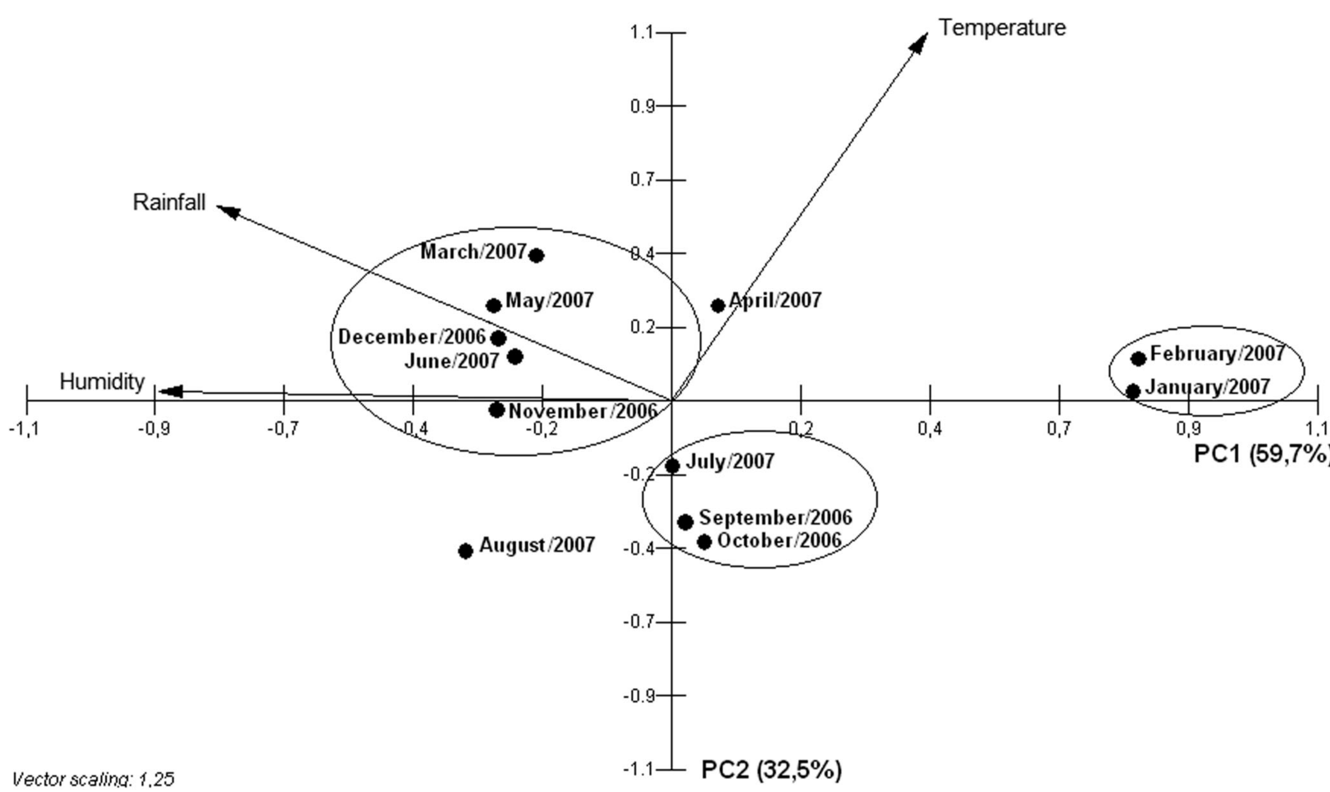

Figure 7. Plotting of the two first axis of variation (PC1 x PC2) of Principal Component Analysis to datasets of *Achatina fulica* Bowdich, 1822 from Salvador city, Bahia, collected from September 2006 to August 2007, shows the generation of three clusters showing three groups.

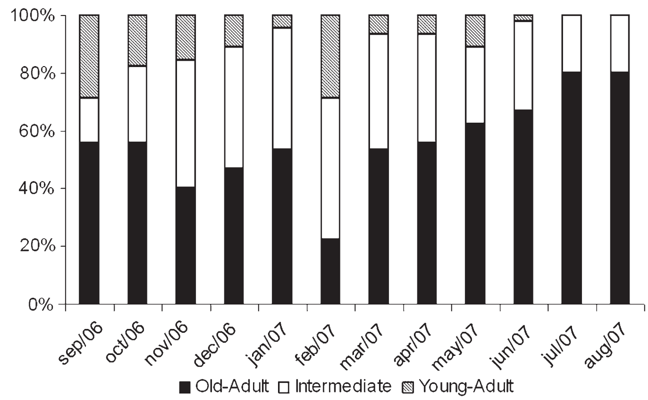

Figure 9. Monthly proportion of "Old-Adults", "Intermediates" and "Young-Adults" of *A. fulica* Bowdich, 1822 in Salvador, Bahia (n = 45 monthly) from September 2006 to August 2007.

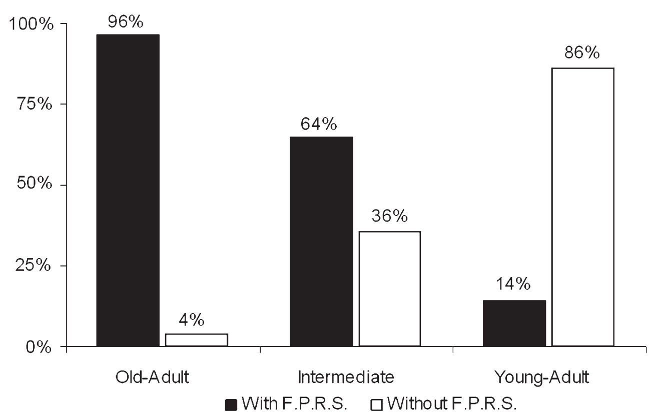

Figure 10. Proportion of *A. fulica* Bowdich, 1822 with and without F.P.R.S. (Female Portion of Reproductive System) per stages of sexual maturity in Salvador city, Bahia.

The thickness of peristome ranged from 0.1 mm to 2.95 mm, with average 0.93 mm, although the most frequent thickness was 0.85 mm.

Almost all snails belonging to stage "Old-Adult" sexual development showed portions of female and male reproductive systems (96%). Among "Intermediates", 65% presented both portions of reproductive systems and, among "Young-Adults" 86% had only the male portion (Figure 10).

Snails with eggs were observed in November 2006, January, March, May, June and July 2007, being found more than one snail carrying eggs only in March 2007. In seven *A. fulica* were recorded 560 eggs, that is, in average 80 eggs per snail. From these, five were "Old-Adults" with an average of 78 eggs per snail and two "Intermediates" with an average of 86 eggs per snail. "Young-Adults", despite the developed female portion of reproductive system, showed no eggs.

Discussion

1. *Aspects of population dynamics of* Achatina fulica

As observed in Paraná by Fischer & Colley (2005), the *A. fulica* population in Salvador is composed of animals of medium to large size and in full sexual activity. Comparing to the data obtained by Caetano (2005) and Ohbayashi & Takeuchi (2007), the weight and height average shell were lower than those obtained by this, as compared to Albuquerque (2003) the average obtained were higher. The specimen large and strong presence, probably with sexual development complete reflects the process of invasion of the species in Salvador, with the occupation of urban ecosystems, not only causing serious ecological and economical problems, but also possible damages to human and domestic animals health (Teles et al. 1997, Vasconcellos & Pile 2001, Raut & Barker 2002, Bender et al. 2003, Silva et al. 2003, Thiengo et al. 2006, Thiengo et al. 2007, Thiengo et al. 2008).

Despite of having young individuals (recruits) throughout the year, it was evident that recruitment was more frequent from August to December 2006 and February 2007 which characterize the end of wet season and the beginning of the dry season. This result corroborates the information obtained on items related to species reproduction. The period of greater sexual activity, measured by the weight of the protein gland, and the largest proportion of "Old-Adults" (present both parts of reproductive system complete) occurs, mostly, during the wet season. So the animals breed in the rainy season, investing their energy in production of gametes and eggs, and the recruitment occurs during the dry season.

In most animals, the body size is closed related to age, but this increase in size is not constant throughout life and usually describes an exponential curve with a rapid growth in the beginning (young animal) that is decelerated as the animal becomes older. As observed in the results, the growth curve of *A. fulica* follows this pattern, with a rapid growth until two years old ($\cong$ 90 mm) becoming slower as the animal becomes older.

Gomes et al. (2004), in studies with land pulmonates gastropods in Rio Grande do Sul, came to the conclusion that the cycle of life of population of *Simpulopsis ovata* (Sowerby, 1822) is annual and the species is semelparous (the species has only one reproductive event, that is, adult individuals die after the reproductive period), also, affirm that annual cycles have been commonly found among land pulmonate gastropods as *Helicella (Xerothracia) pappi* (Schütt, 1962), *Salinator takii* Kuroda, 1928) (Lazaridou-Dimitriadou 1995, Kosuge 2000). Unlike these land pulmonates with short life cycle, *A. fulica* can live, in the wild life, more than four years and reproduce from 15 to 25 times in its life, this fact, combined to series of other makes the species an excellent invader. Another species with long life cycle and because of time of life and fast reproduction may becomes invasive is *Helix aspersa* (Müller, 1774) (Madec et al 2000).

The fact that snails have been found with the same age and close to the value obtained to longevity and living almost four years, suggests how well adapted they are to the environmental conditions in Salvador. Being so, the eradication of the species would be very difficult, being most suitable the population control, since the eradication was only achieved in incipient populations of *A. fulica* in California (EUA), Florida (EUA), Queensland (Australia), Fiji, Samoa and Vanuatu (Raut & Barker 2002, Thiengo et al 2007).

2. *Climatic factors and sexual activity*

Sexual activity at *A. fulica* could be evaluated through albumen gland weight. The albumen gland, also called protein gland, is responsible for producing and storaging of nutrient substances that will "provide" the eggs (Nieland & Goudsmit 1969). Runham & Laryea (1968) showed this gland fluctuates substantially in size during the different phases of reproductive cycle, becoming larger before the egg posture and withering immediately after the egg posture that, according to Tompa (1984) may be the original size of this gland once all fluid contained within it was moved to the eggs. The study of Tomiyama (1993) showed that the maximum size of protein gland in ''Young-Adults'' (not able to produce eggs) was 650 mg, so, glands heaviest than this would characterize sexual activity at that moment.

By taking in mind the low temperature range (3.6°C, Min. 23.6°C and Max. 27.2°C) and humidity (4.0%, Min. 92.8% e Max. 96.8%), it is believed that these variables had little influence on the activities of the snail, once this is a species resistant to environmental variations, probably because they evolved in forests edge (Raut & Ghose 1981). Ruat & Ghose (1984) confirm this sentence showing that the activities of the African snails are only affected by a long time under 10°C or over 30°C and humidity under 80%, when they stow. These limit values of temperature and humidity did not occur during the study period and rarely occur.

The evidence of seasonality of *A. fulica* was recorded by Lai et al (1982) which report the spread of the species, that is, the occupation of new areas by new individuals added to population occurs throughout the year, but is particularly evident during or after winter. Raut & Barker (2002) also consider the seasonality, with cycles related to favorable periods and there may be two pronounced peaks in each season, being the first after the resumption of activity and completion of stowing phase and the second, 2 to 3 months later. In Malaysia, Berry & Chan (1968) also consider the existence of an apparent annual cycle of *A. fulica*, but related to the dry and rainy seasons.

The results of the study showed that there is a clear relationship among the environmental conditions, particularly the rainfall range, and sexual activity of *A. fulica* in Salvador. In addition, we can also say that for the studied period, the sexual activity was more manifested in the rainy period and in March, when it rained more than expected, confirming the hypothesis of interest. Albuquerque (2003) reached similar results; observing the sexual behavior of the snail in Lauro de Freitas - Bahia found that the copulations occurred more frequently from April to August and in rainy days.

Apart from environmental conditions, sexually active individuals were found in all sampled months, which suggest that *A. fulica* is able to reproduce throughout the year.

3. Relationship between peristome and sexual maturity

Studies made by Tomiyama & Miyashita (1992) and Tomiyama (1993, 2002) describe that the thickness of peristome has a close relation with sexual maturity, appearing in the beginning of maturity and developing as the specimen matures, being so, able to feature three stages: ''Young-Adult'' (peristome $<$ 0.5 mm): section of male reproductive system developing or complete, no female section detected; ''Intermediate'' (0.5 to 0.8 mm): section of male reproductive system fully developed, may or not presents female section; e ''Old-Adult'' (peristome $>$ 0.8 mm) presents both parts of reproductive system well developed (hermaphrodites).

Different from presented by Tomiyama (1993), there were found some ''Old-Adults'' without the female portion of reproductive system. This fact combined to the presence of snails presenting hermaphroditic reproductive system complete with peristome of only 0.35 mm (Young-Adult), being the trend suggested by Tomiyama (1993; 2002) that the species completes its sexual development after the thickness of peristome exceed the 0.5 mm (''Intermediate''), suggests an early sexual maturity of the population of *A. fulica* in Salvador. This precocious maturation of the population may have occurred due to abundance of resources (food, shelter) and/or favorable climatic conditions found in the city. Fisher & Colley (2005) also found snails with reproductive system complete (performing posture, inclusive) with peristome smaller than 0.5 mm (0.4 mm).

The presence of nearly 75% of the analyzed population with sexual development complete, that is, ''Old-Adults'' and some ''Intermediates'' and characterized by large and vigorous specimen are indications of the first phase of population establishment suggested by Civeyrel & Simberloff (1996) where there is an exponential increase of population of the species. Despite not having been observed in this study, the increase of the population of *A. fulica* has been reported for some time in Salvador.

The increase in the number of ''Old-Adults'' on rainy months, found in this study, also was noticed by Albuquerque (2003) at Lauro de Freitas. This increase is related to a larger observation of sexual activity in the rainy period, once that these animals (''Old-Adults'') are larger and present sexual development complete, making them more capable to reproduction.

Tomiyama & Miyashita (1992) found in their studies that ''Old-Adults'' present a higher number of eggs per posture when compared with ''Intermediates''. These data are conflicting with those found in this present study becouse the values obtained to ''Old-Adults'' (77.6 eggs per individuals) are lower than the values obtained to ''Intermediates'' (86.0 eggs per individuals). The answer to this observation may be in the insufficient number of animals with eggs collected (seven).

Despite not having been found ''Young-Adults'' producing eggs - a result also found by Tomiyama & Miyashita (1992) - the absence of the female portion of reproductive system as a justification for the fact cannot be used in this case. The most plausible is to consider that these animals, despite of having the female portion of reproductive system, it is not completely developed, not being able to produce eggs. We cannot rule out the possibility that these animals were not sexually active only when collected.

By not obtain a significant number of snails with eggs to perform posture, we cannot make any kind of inference related to period when it is more frequent or the amount of eggs that each individual can stock, requiring further studies to elucidate these points. Specimen with eggs were found as in the top of dry season (November to January) as in the rainy season (March, May, June and July), possibly, because of the low annual climate variation in Salvador, which presents a humid tropical climate, conducive to the development of *A. fulica*. In addition, Raut & Barker (2002) affirm that the storage capacity of sperm provides to the species of Achatinidae ability to produce eggs in any time of year.

4. Conclusions

The favorable climate found in Salvador provides to the African snail optimal conditions for survival and development, reproducing earlier. In addition, the low variation of temperature and humidity requires very few of the ability to resist great environmental variations that the species has, being thus, able to reproduce throughout the year, increasing its activity as rainfall increases.

The relationship between thickness of peristome and the stage of sexual maturity suggested by Tomiyama & Miyashita (1992) and Tomiyama (1993, 2002) is real, but should be adjusted to each specific region. Although there is a relationship between the thickness of peristome and sexual maturity, the limits among stages are not well determined and, depending on where the study is performed, the deemed values of thickness of peristome per each sexual stage may vary. In the case of Salvador "Young-Adults" would have peristome smaller than 0.35 mm, "Intermediate", from 0.35 mm to 0.90 mm and "Old-Adults", larger than 0.90 mm.

As the eradication becomes impossible because of high levels of invasion found in Salvador, it is recommended to control the species. This control, in spite of occur continuously, should be intensified in the rainy periods, since these are the periods when the animals are seen more frequently, just because they are sexually active, looking for sexual partners or for reproduction areas. It is suggested the implement of management and control of *A. fulica* created by IBAMA in 2004 and is already proving successful in another cities where the snail is a pest (Brasil 2007).

Studies about the population biology of the species are essential to the implementation of control programs and eradicate invasive species. The knowledge about population dynamic of *A. fulica* in Salvador can provide further actions to minimize the impacts caused by this species.

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