

Modeling and Simulation of the Population Dynamics of Snails *Biomphalaria tenagophila*, in Tres Palmeras, Salta, Argentina

Research Article

Abstract

Aims/ objectives: We have analyzed the parasitic infections and the monthly samples dynamics of snails species *Biomphalaria tenagophila* in water bodies caused by floods of tributaries of the river Arias in Salta, Argentina, in the Tres Palmeras zone.

Study design: Longitudinal and Cross-sectional studies.

Place and Duration of Study: Department of Mathematic and School of Biology for Studies of the Diversity of Invertebrates. National University of Salta, Argentina, between January 2005 and December 2007 also between January 2016 and May 2017.

Methodology: Samples were taken at least twice per season in the period January 2005-December 2007. Snails were observed daily for to detect emergence of cercariae for 7 days and, in negative cases, the snails were dissected for observe prevalent infections. Technique of the power spectrum, tools data exploratory analysis and estimation of parameters by linear adjustment for logistic model were applied to the data. We carry out experiments of simulations in order to describe qualitatively the dynamics presented.

Results: The highest prevalence found correspond to *Australapatemon magnacetabulum* (1.44%) and *Echinostomatidae gen sp. III* (2.99%), while no infections by *Schistosoma mansoni* were found. The data show the frequencies most important at the 12, 18 and 3 months in this order. The parameters for the net growth rate, density dependent, they were estimated as $r = 0.32$, $s = 2.07$ and the corresponding carrying capacity like $K \approx 1069$ for the annual case.

Conclusion: The frequency most important at the 12 months is the that describes best the situation and could justify the annual seasonal variation and opportunistic growth of the specie. The function corresponding to net growth rate, density dependent provides estimation for the growth coefficient and so-called "crowding coefficient" however the data present oscillations about of the fit curve or simulations that would be explicated with the generalized logistic model or expressions for the carrying capacity of type, sinusoidally variable carrying capacity. Simulations describe qualitatively the annual population dynamics.

Keywords: Models Theoretical; Simulation; Helminthology; Snail; *Biomphalaria tenagophila*; Prevention & Control;

2010 Mathematics Subject Classification: 62P10; 92B05; 92D30;

1 Introduction

Snails *Biomphalaria tenagophila* (d'Orb., 1835) from Argentina behave as potential vectors of schistosomiasis, since this species is susceptible to *Schistosoma mansoni*, according to studies performed with populations of *B. tenagophila* from the province of Corrientes and in the neighboring country of Brazil, with strains SJ2 of *S. mansoni*. Besides *B. tenagophila* has a wide distribution in southern Brazil and Mesopotamia Argentina and lately they have reported their presence in this region of northwestern Argentina [Borda and Rea1995], [Borda and Rea1997], [Borda and Rea2006], [Borda and Rea2007], [Borda and Rea2010], [Rumi *et al.*2008], [Davies2014]. Schistosomiasis is most widespread of all the vector borne diseases, contributes to poor nutritional status and poor school performance. Intestinal schistosomiasis can cause abdominal pain, diarrhea, blood in the stool, liver and spleen enlargement, fluid in the peritoneal cavity and hypertension of the abdominal blood vessels [WHO2014].

1.1 Situation in South America and local situation

Of the five species of schistosomes that affect humans, only *S. mansoni* is endemic in South America, being affected countries Brazil, Suriname and Venezuela [Utroška *et al.*1989]. In Brazil there are endemic foci in the southern states of Paraná and Santa Catarina, bordering with Argentina and Paraguay. However, in Argentina, Uruguay and Paraguay epidemiological surveys carried out until 1985 transmission have not shown, nor have been reported recent human cases [Paraense1986].

Snails *B. tenagophila* are distributed in the Province of Salta (PS), Argentina and so far have not been found infected with *S. mansoni* in surveys carried out in the area known as Tres Palmeras (TP) [Rumi *et al.*2008], [Davies2014], where two tributary streams flow into the river Arias, southwest of the city of Salta. These rivers and streams, in their floods form bodies of water where the snails were collected. The site is easily accessible for residents of the surrounding which with its human activities influence the dynamics of biotic and abiotic components of the ecosystem. TP zone represents an area of risk to human health [Pellegrino2008], as the population living around presents low socioeconomic status and lacks adequate health infrastructure. All this together with the new conditions of the weather change and without adequate sanitary control in the border areas, the activities of migration could favor the transmission of vector-borne diseases, particularly the of interest of the presente study.

1.2 Scope and objectives

The key concept in designing parasite control is that the populations involved are dynamic [Medley1994]. It is necessary to increase the knowledge about population dynamics of *B. tenagophila*, determine parameters that can be useful for models and mathematical tools, and improve knowledge of macroparasites that employ *B. tenagophila* as vector in TP zone.

In this work, we have investigated infection prevalence of different parasites in the snails *B. tenagophila* collected by monthly samplings in the TP zone during the 2005-2007 period. This intend to alert the need to design actions to initiate adequate epidemiological surveillance in the Province. In this sense the dynamics temporarily of the snails population it was studied along three years by examining of specimens obtained. In particular, discusses some aspects that present the samplings data about the population of snails and provides elements and parameters for modeling and simulation of the dynamics, seasonality, of these snails that live in bodies of water caused by floods of rivers the TP zone.

The fits obtained are considered models that allow describing qualitatively the population dynamics of *B. tenagophila* in the TP zone. These results provide bases from which can be improved the

estimation of parameters for descriptions of these populations and knowledge of their parasites that could provide, basic control and prevention measures to avoid any risk of infection to the residents of the TP zone.

2 Materials and Methods

2.1 Sampling site

The TP zone (24° 47' 33" S, 65° 28' 14" W) SW of city of Salta is located in the Valle de Lerma, PS, situated between the Sub-Andean mountains and the eastern saws, about 1,200 meters above sea level. The climate is subtropical with a dry season from May to October, maximum rainfall in summer, and an average of 805 mm per year, measured in the nearby town of Las Costas (period 2000-2002); annual average temperatures range between 11.2 ° C and 24 ° C. In this area are the San Lorenzo River and some streams that are tributaries of the Arias River.

2.2 Samplings and procedures

Samples were taken at least twice per season in the period January 2005-December 2007. The extractions were performed with hand nets, mesh 1 mm in one hour period. The collected snails are packaged in containers with wet paper to be transported to the laboratory, where they were placed in receptacles of 5 ml with unchlorinated water. They were observed daily for to detect emergence of cercariae for 7 days and, in negative cases, the snails were dissected for observe prevalent infections.

2.3 Mathematical modeling

The study of behaviour can be made by using a time-series technique called spectral analysis, this analysis determines the presence of cycles by splitting the variance of series into distinct parts, each part being a measure of contribution of specific frequency of occurrence to the overall pattern. An important consequence is that the sum of these measures over all possible frequencies is equal to the variance of series [Renshaw2008]. Estimation of cycles frequencies, $\omega = \frac{2\pi}{T}$ was performed using the technique of the power spectrum. Using this technique the contributions of specific frequencies that determine the cycles that presents the data set are determined. The analysis allows to characterize in some sense seasonality. On the other hand, tools data exploratory analysis have allowed some descriptions thereof. The empirical cumulative frequency distribution was obtained. By the method of Ford-Walford, carrying capacity K was estimated, also other parameters were estimated by linear adjustment for logistic model, solution of the differential equation

$$\begin{cases} \frac{dS_c}{dt} &= f(S_c)S_c \\ S_c(0) &= S_{c0} \end{cases} \quad (2.1)$$

where S_c , represents the number of accumulated snails collected in sampling, the function f represents the net growth rate, density dependent. If $f(S_c) = r = \text{constant} > 0$, the exponential model or Malthus's model is recovered, r denote the intrinsic rate of natural increase for growth with unlimited resources. If $f(S_c) = r - sS_c$, we have the Verhulst-Pearl model known as the logistic equation [Renshaw2008], [Banks1994]. The parameters are then obtained for the stochastic version based on the methodology developed for general birth-death processes in reference [Renshaw2008]. The logistic fit for the empirical cumulative distribution for the number of snails collected, provides rates that can be used to simulate a stochastic process, type birth - death (see methods in reference [Renshaw2008]), in order to qualitatively describe the population dynamics of specimens of snails collected in TP zone. For the simulations, the implementations of the methods and algorithms were used similar to those developed in the work of Rosales et al. [Rosales et al.2017]. In order to describe the seasonality presented in the period the results provided by the simulation were modulated by type functions

$$P(a, \omega, \alpha, t) = a + \sin(\omega t - \alpha) \quad (2.2)$$

with a , ω , α the parameters to be estimated. The parameter a corresponds to the monthly average value of the number of snails collected in the samples, ω correspond to one the frequencies estimated as indicated above. The parameter α correspond to the phase shifting, corresponding to 1, 2, 3, 4, 5 and 6 months, estimated from the samples data by simulation, based on the best qualitative descriptions obtained and t represents the time variable measured in month.

3 Results

In the Table 1, we show the infection prevalence of the diverse parasites found. Among the most prominent parasites, that infect the snails were found *Australapatemon magnacetabulum* (1.44%) and *Echinostomatidae* gen sp. III (2.99%), no infections by *Schistosoma* were found.

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Table 1: Prevalence of taxa of digeneans parasitizing *Biomphalaria tenagophila* in Tres Palmeras zone during 2005, 2006 and 2007 years. N: Number of hosts examined.

	Prevalence	Year	2005	2006	2007
	Digeneans	N	1046	1066	970
1	<i>Australapatemon magnacetabulum</i>		1.72	1.97	0.62
2	<i>Trichobilharzia</i> sp.		0.19	0.28	0.21
3	<i>Zygocotyle lunata</i>		0.09	0.47	0.21
4	<i>Clinostomum</i> sp.		0.38	0.56	1.13
5	<i>Magnivitellinum simplex</i>		0.09	0.28	0.31
6	<i>Xiphidiocercaria</i> sp. II		0	0.47	0.72
7	<i>Strigea</i> sp.		0.19	0	0
8	<i>Echinocercaria</i> sp. I		0.09	0	0
9	<i>Echinostomatidae</i> gen. sp. III		6.79	1.97	0.21
10	<i>Echinostomatidae</i> gen. sp. I*		0.86	0.84	0

*: only metacercarial stage

Figure 1 top, shows the time series of monthly data for the number of snails collected in the TP zone and it can be seen the maximum and minimum values throughout the year. In 2005 the two main maximum values corresponding to August and February, while July and September have the lowest values. In 2006 the maximum values occurred in June and December and minima in September and October. Finally in 2007 the largest numbers of snails were collected in April and March and lower numbers in August and September. In Figure 1, middle, shows the periodogram of the samplings data and in the bottom of the same Figure 1 the power spectrum that allows us to see the most significant periods in order of importance, in this case correspond to 11.66, 17.50 and 3.18, from which we estimated the frequencies 12, 18 and 3 since possible frequencies allowed for the 36 sample data are 2, 3, 4, 6, 9, 12 and 18.

The box plot corresponding in Figure 2, left, evidence that highest value of snails collected, 312 specimens corresponds to an outlier of the samples obtained in the study period. The higher number admissibility of snails obtained was 191 snails. The interquartile range was [40 151.5], the parameters of centralization, mean, median were 98 and 96 respectively. In Figure 2, right, shows the monthly average in throughout period and it is observed that the maximum and minimum values corresponds the month of May and September respectively.

The adjustment obtained for monthly averages of population provide the coefficients of the function $f(S_c)$, in this case they resulted $(r, s) = (0.32, 2.07)$ and the carrying capacity resultant was $1.0687e +$

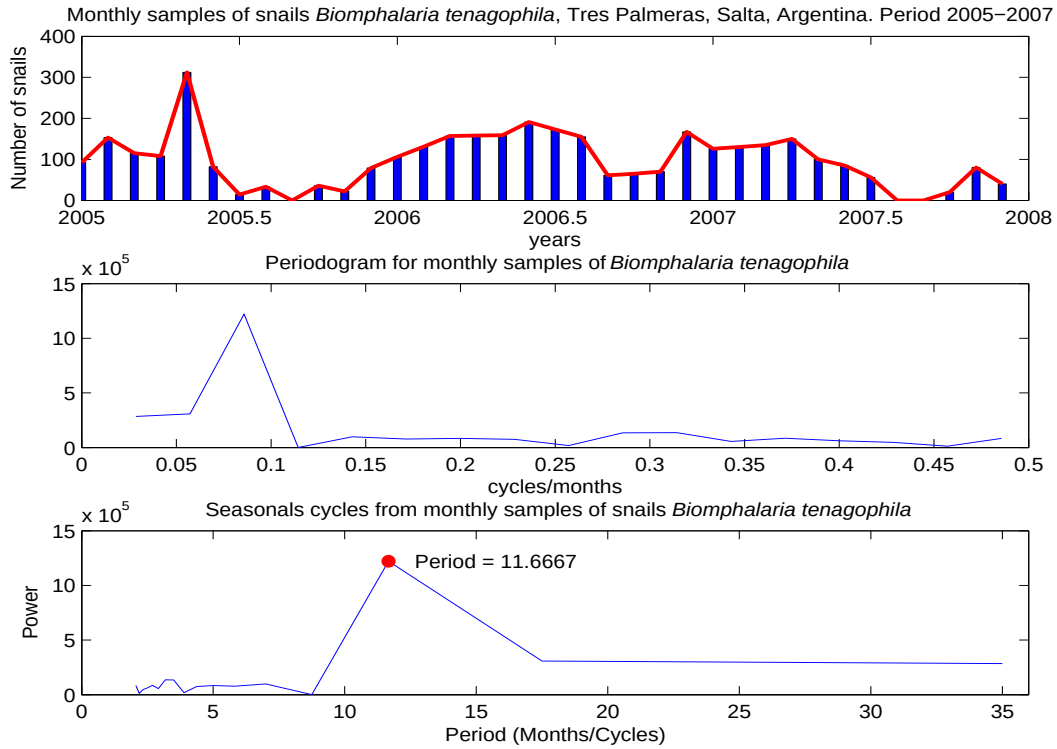


Figure 1: Top: Time series of monthly sampling of specimens *Biomphalaria tenagophila* 2005-2007. Specimens were collected for one hour in the Tres Palmeras zone, Salta, Argentina. Middle: Periodogram for monthly samples. Bottom: Power spectrum.

003 from which $K \approx 1069$ was estimated. On the basis of the samplings the deterministic model for the cumulative frequencies of the number of snails collected in the TP zone is

$$S_c(t) = \frac{1069}{1 + e^{2.07t - 0.32t}} \quad (3.1)$$

Figure 3 Left: shows the model and the cumulative frequencies corresponding to the monthly average during the three years of sampling. Although the fit allows describe the situation for some months, in a more acceptable way than others, however provides qualitative descriptions of the growth rate presented by the dynamic of the samples as well as the posing of possible scenarios for carrying capacity, which in a sense is related to the variability of the volumes of water bodies of the TP zone where the specimens of snails were collected. This case correspond to cross-study. Figure 3 Right: shows simulations of the stochastic logistic version obtained from a particular random seed, $S_{c0} \in [140, 180]$.

Figure 4 shows simulations for the data of the full period analyzed from a particular random seed, $S_{c0} \in [246, 250]$, of the stochastic logistic version. This case correspond to the description for the longitudinal-study. The qualitative behavior is similar to that discussed for the deterministic case.

Figure 5 shows eight realizations of simulated situations order to qualitatively describe the annual dynamic presented by the monthly averages of the samplings of the population of snails collected in the bodies of water mentioned, modulated by sinusoidal function $a + \sin(2\frac{\pi}{T}t)$ or $a + \sin(\frac{2\pi}{T}t - \frac{\pi}{3})$, with $T=12$ and $\omega = \frac{2\pi}{T}$ main frequency estimated by the power of the spectrum and a represents the monthly average of the snails number of the samplings. Simulations (blue lines) describe in some sense the stochastically component that could be present in the monthly averages along the

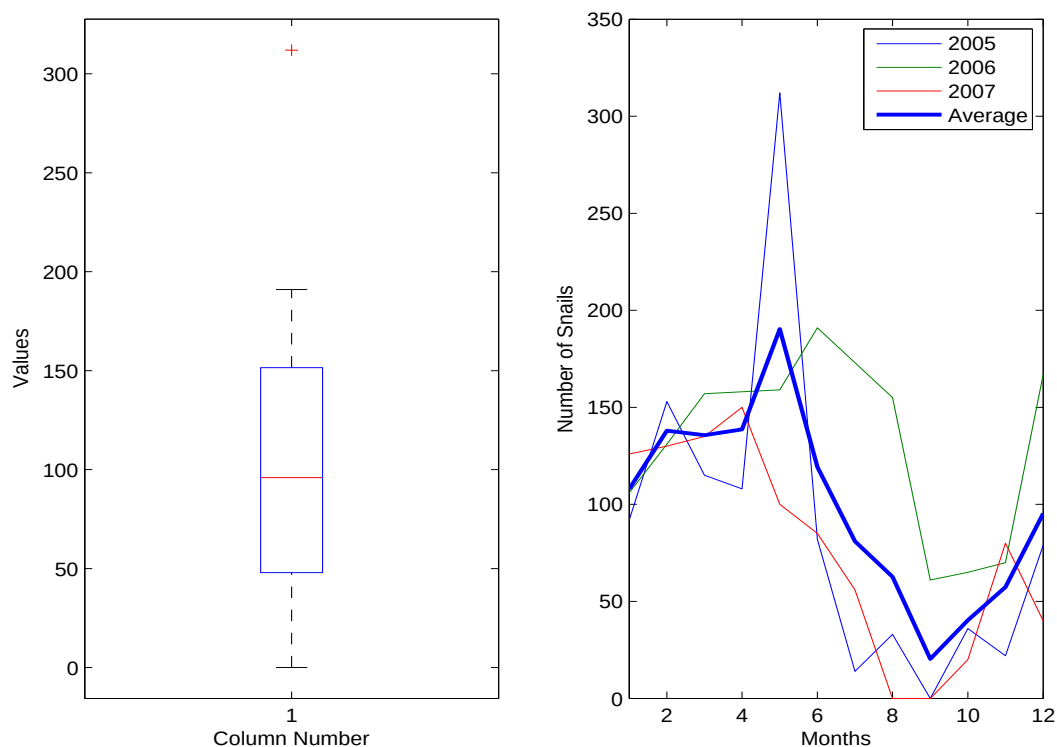


Figure 2: Left: The boxplot for the monthly samplings of snails *Biomphalaria tenagophila* in Tres Palmeras zone. Right: Dynamics of the samplings of the number snails *B. tenagophila*, in three years of samplings and the monthly average of the data.

year and these follows the pattern of the samplings qualitatively accompanying the maximum and minimum values which have the monthly data averages (red line).

Simulations generally described the annual seasonal pattern that occurs in the zone, the dynamic in the rainy season is described acceptably, also the months of completion of the dry season and start of the rainy season; in the latter case it is observed that in general, the stochastic realizations are more suited to the monthly average values of the samplings data.

4 Discussion

Figure 1: above, shows that year 2005 was different to 2006 and 2007, the which were more similar in their dynamics. The periodogram and the power spectrum of Figure 1 middle and below respectively, show that the main frequency corresponds to a period of 12 months. The observed fluctuations are evident to corroborate the annual seasonality with period $T = 12$, which has presented the samples dynamics based on data from the three years analyzed.

The box plot, in Figure 2 left, allows us to observe that the greatest value of snails collected corresponds to an outlier and a certain bias towards higher values of the samples of snails population, a result that could sustain the opportunistic characteristic of population growth of snails *B. tenagophila*. The average monthly population dynamics, Figure 2 right, allows us to observe that the maximum population is presented at the end of the rainy season (May) and the minimum at the end of drought season (September).

Model (3.1) obtained and its graph, Figure 3, left, as well as the stochastic model, Figure 3 right;

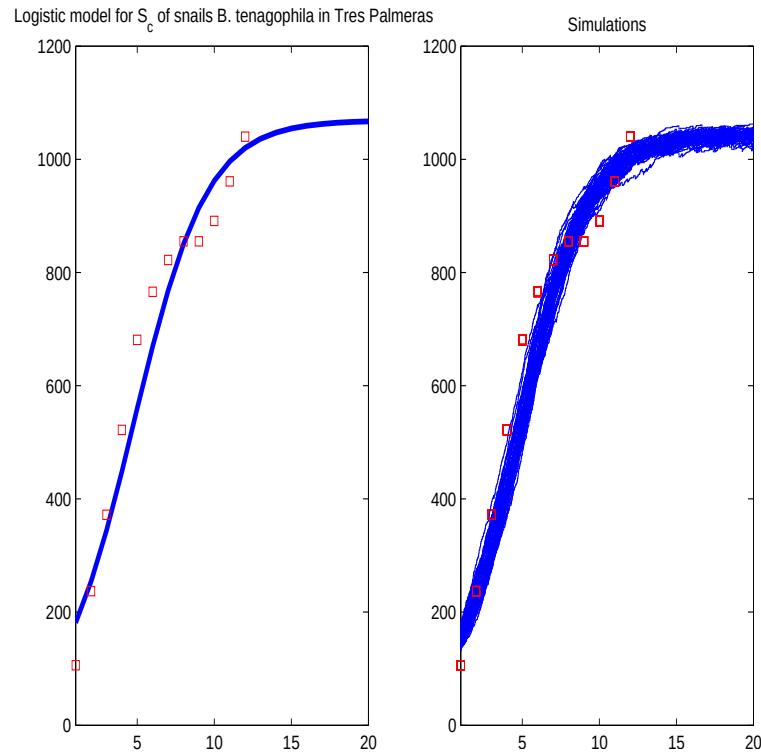


Figure 3: Left: The model (3.1) and the cumulative frequencies corresponding to the monthly average during the three years of samplings of snails *B. tenagophila* in Tres Palmeras zone, Salta Argentina 2005-2007. Right: Simulations of the logistic model stochastic version.

also the Figure 4, allows us to hypothesize, based on the analysis made by Banks [Banks1994] of the logistic equation in its more generalized form, that the most appropriate setting correspond to a carrying capacity of sinusoidally type. This makes sense because would seem that exist an oscillatory carrying capacity for the situation presented, because the bodies of water in times of floods and droughts they correspond with the increase and decrease of your volumes. The function of net growth rate, dependent density, $f(S_c) = 0.32 - 2.07S_c$ and the main frequencies $\omega_1 = 2\pi/12$ and $\omega_1 = 2\pi/18$, are estimates of importance for the design of models that attempt to describe the dynamics of infection in populations of *B. tenagophila* or could help discover the mechanisms that can produce cyclic patterns or multiple stable states, in the levels of infections in the host populations, as they pointed out by May and Anderson [May and Anderson1979]. These parameters can be used to incorporate realism in mathematical models for interactions between hosts, pathogen and parasitoids which shows the presence of an infection that can preserve and promote diversity in such multi-species systems, as in the case presented by Preddy *et al* [Preddy2007], also can be used in models with parameters and confirm that snails populations are regulated by nonlinear density-dependent mechanisms as suggested by Mangal *et al* [Mangal *et al.*2010]. Figure 4 makes us think that if we increase the frequencies of the samples the estimation of the parameters could improve. Obtaining the same allowed to check the performed implementations. Perhaps from the biological point of view this description requires the incorporation of other hypotheses.

The realizations obtained by simulation, exemplified in Figures 5, could be accepted as qualitative descriptions stochastic, annual and could help to describe the dynamics of the three-year period of study. Experiments for the annual seasonal case obtained, in our opinion, are better than the

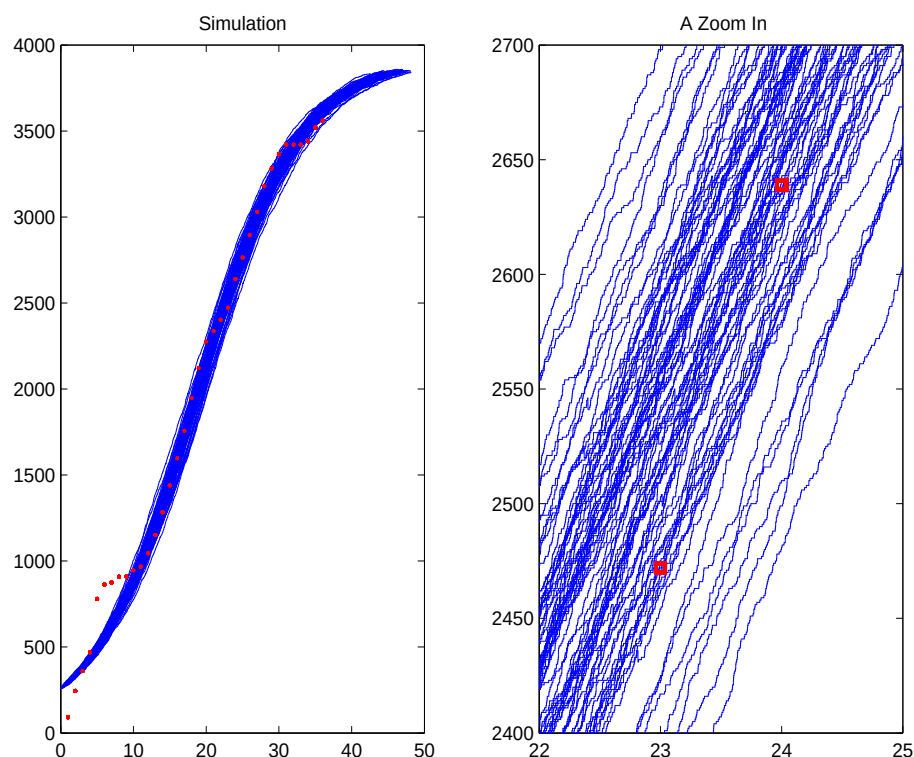


Figure 4: Realizations simulated for the monthly samplings of snails collected in water bodies of the Tres Palmeras zone, Salta, Argentina, 2005-2007.

experimentations for the whole sampling period. Although they adjusted reasonably only when they have the highest population densities of specimens *B. tenagophila*. The importance of this type of numerical, computational analysis, as noted Cornell [Cornell2010], is that they allow to experience different events such as other stochastic processes; different seeds, birth rates, mortality and especially different relationships and / or ratios between them, the which can be modified in each simulation. In simulation models many other factors may easily be integrated, as indicated for example, in Keeling [Keeling1999], Hess [Hess1996]. These results could be complemented by the study of the effect of seasonal rainfall and other environmental changes, as the temperature patterns, population density dynamic and infection rate; in order to verify whether there are relationships inversely proportional between these variables, such as in the study developed by Odongo-Aginya *et al* [Odongo-Aginya *et al.*2008]. In our case it was determined that only 68% of the collected snails corresponds to the rainy season and 32% in the dry season.

No infection has been detected of *B. tenagophila* by *S. mansoni* and analyzed its dynamics in these regions of Northwest Argentina. In the next step of preventive actions, it could be update the existing database, and initiate investigations to measure the compatibility between *Schistosoma* and these intermediate hosts, as suggests Borda and collaborators [Borda *et al.*2003], obtaining the Frandsen index to classify if susceptibility correspond to Class II or III, for strains, SJ, SJ2 of *S. mansoni* for this zone. We currently maintains populations in laboratories in order to assess mortality, oviposition, and recreate some transmission cycles in *B. tenagophila* parasitized, for example *Australa-patemom magnacetabulum*; some results and descriptions detailed can be seen at in the reference [Davies2014]; because as pointed out by Barbosa *et al* [Barbosa *et al.*1992], the populations of *Biomphalaria* can be maintained satisfactorily under semi-natural conditions for at least 220 weeks. This method, they conclude, opens perspectives for other types of studies such as snail ecology,

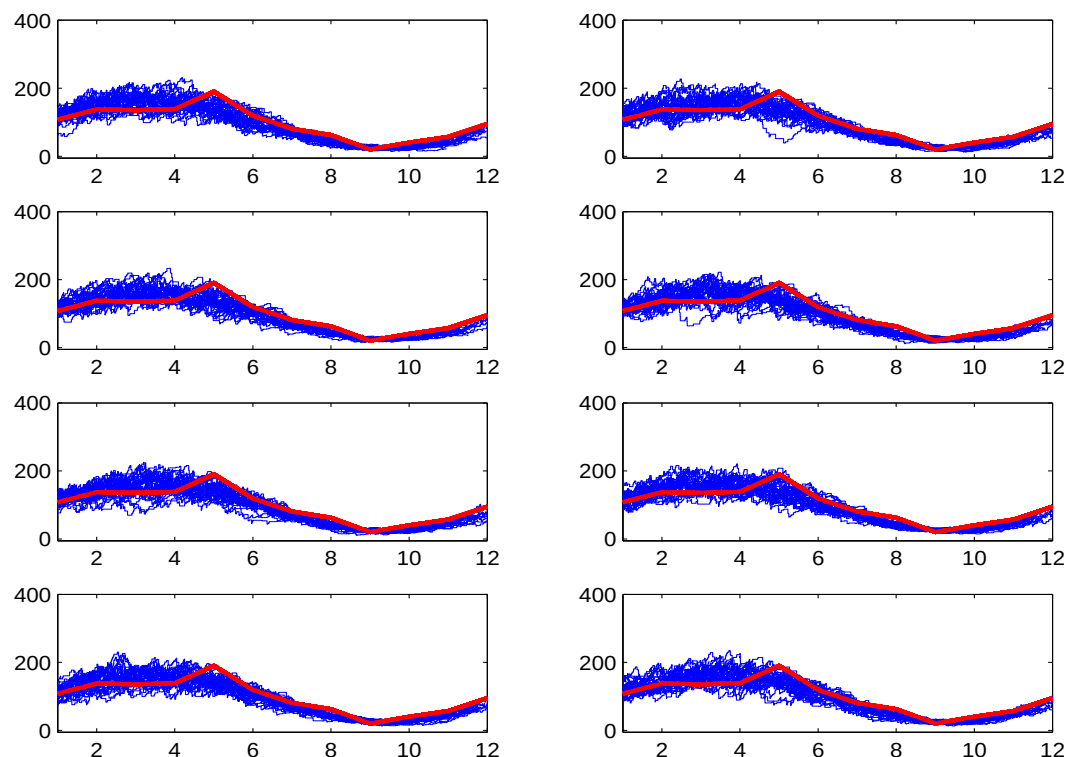


Figure 5: Monthly population average dynamics of snails during the year based on data collected in three years in the Tres Palmeras zone, Salta, Argentina, 2005-2007 period, (Red line), accompanied by simulated realizations.

genetics and related subjects, which also they are important for estimating parameters for modeling and simulation.

5 CONCLUSIONS

In this work we have analyzed the sampling population dynamics of snails *B. tenagophila* in TP zone. Among the most remarkable parasites species that infect the snails were, *Australapatemon magnacetabulum* (1.44%) and *Echinostomatidae gen sp. III* (2.99%), while no infections by *Schistosoma mansoni* were found. The monthly average of snails captured in the period had a maximum and minimum value in the months of May and September respectively. The data shows the frequency most important at the 12 months which describes best the situation and could justify the annual seasonal variation. The logistic model provides an acceptable framework for the description of the data. The function $f(S_c) = r - sS_c$ corresponding to net growth rate, density dependent provides estimation for the growth coefficient $r = 0.32$ and so-called "crowding coefficient" $s = 2.07$ however the data present oscillations about of the fit curve or simulations that would be explicated with the generalized logistic model or expressions for the carrying capacity of type, sinusoidally variable carrying capacity. It is necessary actualize the scenario of distribution of population of snails *B. tenagophila* to design actions and initiate adequate epidemiological surveillance in the Province.

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