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Population Dynamics of *Biomphalaria tenagophila* Snails: Simulations Using the Square-Wave Carrying Capacity Model

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Abstract

In this work we studied Biomphalaria tenagophila snails that were collected in bodies of water in Salta city peripheral neighborhoods. We recorded the monthly average of snails in each location, which showed a periodic fit pattern used to estimate the "carrying capacity type square wave $K(\cdot)$" obtaining $\max_t K=160.30$ and $\min_t K=37.50$. With this estimation, we built computational models to qualitatively describe, by Monte Carlo simulation, the population dynamics of the samples. We hypothesized that these descriptions explain the observed seasonal oscillations as a consequence of variations in the volume of water bodies due to hydro-periods that occur in the region.

Keywords: Monte carlo simulation; Square waves; Biomphalaria tenagophila; Monte Carlo

Introduction

This work is part of epidemiological prevention and control studies, carried out in order to monitor the population of Biomphalaria tenagophila (d'Orb., 1835) snails, and their parasites, in areas of peripheral neighborhoods in Salta city, Argentina (24^0 47' 18" S, 65^0 24' 38" W). These snails are susceptible to Schistosoma mansoni, parasites that cause schistosomiasis. Therefore, it is vital to have snail population and epidemiological control in the region. In general, peripheral neighborhoods in Salta lack adequate sanitary infrastructure and housing. Many times, the bodies of water, streams or rivers near these neighborhoods constitute a risk factor for humans that perform different outdoor activities in them, such as swimming and Fishing. However, out of a total of 3082 snails sampled in a survey, none was infected by Schistosoma mansoni [1].

In the work mentioned above, it was observed that the snail population dynamic pattern presented certain oscillations that could be explained by posing the carrying capacity of the variable sinusoidally, or with the generalized logistic model [2]. The seasonal dynamics in this case could be associated to the volume of the water bodies where the snails had been collected from. In turn, it was related to the carrying capacity of the medium, which in this case corresponds to the carrying capacity of the water bodies. It is possible to propose the following hypothesis: the population dynamics of the snails is determined by the hydro-periods (the rainy season and dry season) of the sampling region, which could be described by Monte Carlo simulations [3], considering carrying capacities of simple square waves. Based on the number of snails collected during three years [1] we estimated sinusoidal load capacities, and from them we obtained simple square waves. These square waves were then used to simulate variations in the population of snails due to hydro-periods that occur in the water bodies. With the square wave estimate we conducted intensive computer simulations with the aim of obtaining a qualitative description to dataset of sampled snails.

Modeling and Simulation

Periodic Fit

For the periodic fit we consider the three-dimensional function space $(C_f,+,\cdot,R)$, generated by the base,

$$\mathrm{B}=\{f_1,f_2,f_3\}$$

Where,

$f_1:\mathrm{R}\to\mathrm{R}$, so that, $f_1(t)=1$,

$f_2:\mathrm{R}\to\mathrm{R}$, so that, $f_2(t)=\cos\frac{2\pi}{12}t$

$f_3:\mathrm{R}\to\mathrm{R}$, so that, $f_3(t)=\sin\frac{2\pi}{12}t$

The mathematical expression for the periodic fit model, results

$$D_p(t) = 98.92 - 21.22\cos\left(\frac{2\pi}{12}t\right) + 57.62\sin\left(\frac{2\pi}{12}t\right); \quad (1)$$

Square wave to carrying capacity

Based on the expression (1), the model (2) of the square wave for the carrying capacity $K(\cdot)$ was obtained. Figure 1 shows the graphs of the periodic and square wave estimates obtained for the population dynamics of the monthly average of *B. tenagophila* snails. The monthly data are depicted in the Figure 1 by the bar chart, evidencing that *B. tenagophila* achieves its maximum population at the end of the rainy season (May), and its minimum at the end of the dry season (September).

The expression for the carrying capacity $K(\cdot)$, square wave type, results

$$K(t) = \begin{cases} \max D_p(t) = 160.30 & 1.0 \le t < 6.5 \\ \min D_p(t) = 37.51 & 6.5 \le t < 12.0 \end{cases} \quad (2)$$

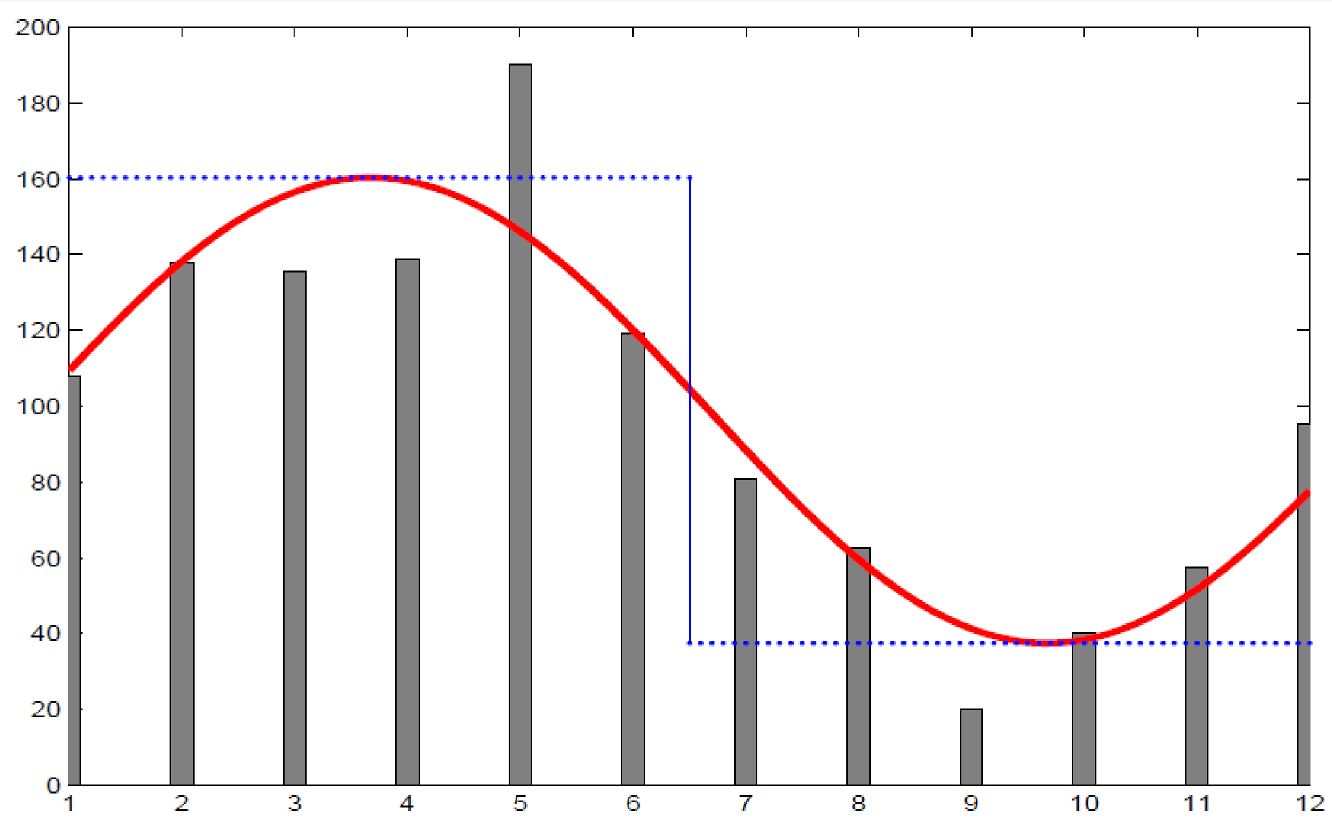

Figure 1: Square wave for carrying capacity K(t) (blue line), for the monthly average *Biomphalaria tenagophila* (gray bar) and periodic fit (red line).

Simulations

Acording to Renshaw [4], a logistic model with a fluctuating square-wave carrying capacity $K(\cdot)$ does not present a new problem, since $K(\cdot)$ simply flip-flops between two constant values. We consider a simple logistic process with the same parameters in relation to per capita growth rates, and carrying capacities with constant values specified in the model (2) for each half of square wave. Stochastic realizations of this process are easy to construct. Simulations were implemented in scripts in Matlab environment similar to developed in [5]. We used a Monte Carlo type Simulation where the random number generator is the rand routine of Matlab (Version 7.6.0.324. 2008) [6], which returns pseudo-random value drawn from a uniform distribution on the unit interval. The modeling was carried out with these settings with the aim of achieving qualitative description of the situation.

Figure 2 show simulations for $N_0 = 110$, initial snails and carrying capacity according to the model of $K(t)$ given by the expression (2). In each half of the square wave, the deterministic logistic processes were plotted according to the parameters estimated in [1], with carrying capacity given by the two constant values of the expression (2). The obtained simulations describe variations in the snail population dynamics, represented by the monthly averages of collected specimens. It is possible to observe the population growth at the beginning of the rainy season, and its decrease corresponds to the dry season.

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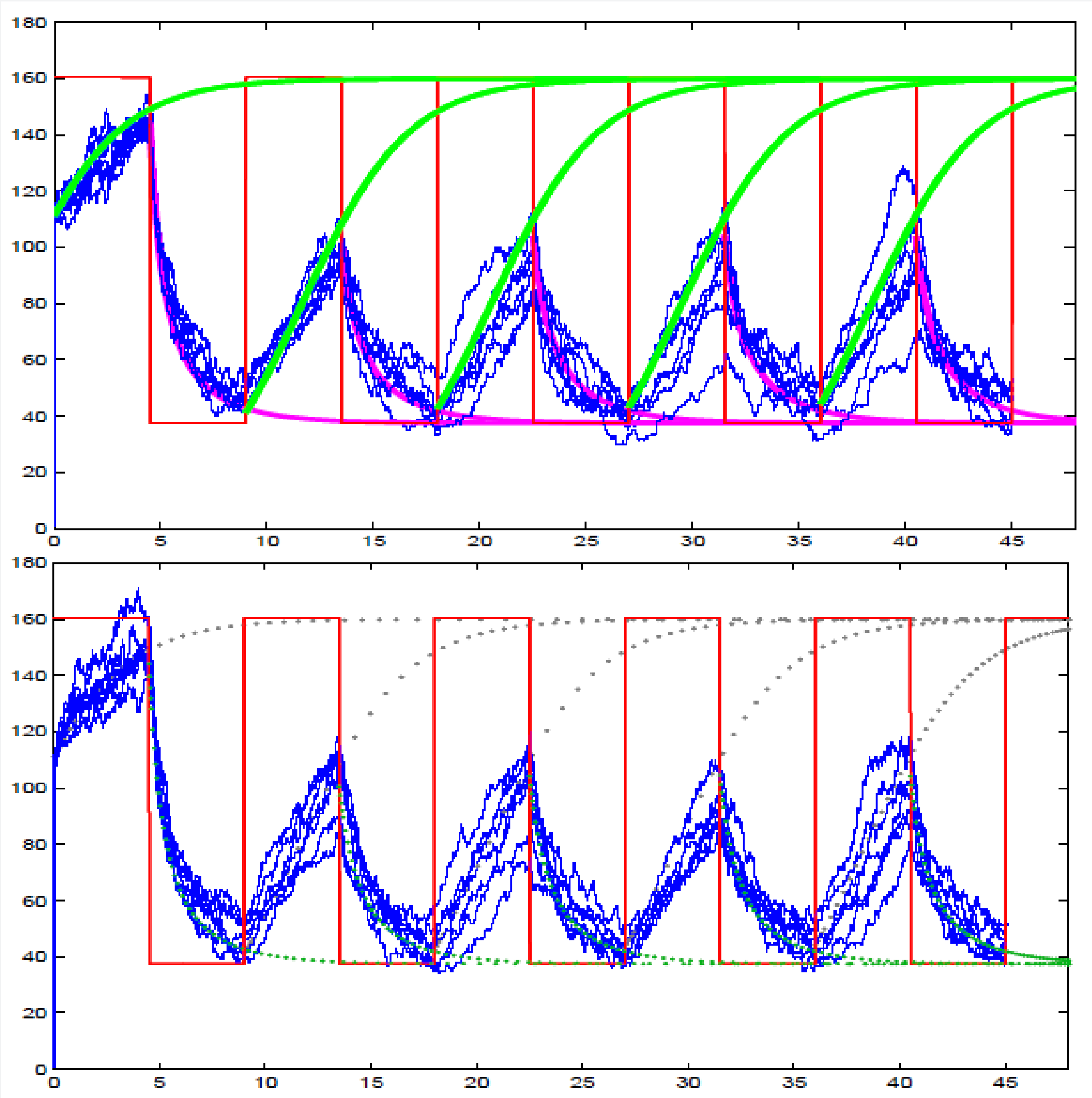

Figure 2: Simulations with carrying capacity *K(t)*, and logistic processes for each half square wave.

Conclusions

The results in the present work represent a contribution to understanding the effect of seasonal rainfall and other environmental variables, like temperature patterns, in the population dynamics of *B. tenagophila* in biotopes from Salta. Similar estimations of this type of carrying capacity can be performed in other geographical regions, in spite differences due to topographical situations, latitudes, thermal amplitudes, absolute temperatures, etc. However, there is a lack of similar works in Argentina allow for deeper comparisons and modelling. We observed demographic stochasticity in the studied area that was not considered in the present work. In addition, models with carrying capacity type square wave can be entered as sub-models in complex models that consider a human population, like those described by Woolhouse [7], Zhao, et al. [8] and Stylianou et al. [9]. Deterministic and computational models and their estimation of parameters can be complemented with studies such as those made by Rumi et al. [10] in order to establish the allometric coefficients for the diameter-weight ratio of *B. tenagophila* species under natural conditions. Such studies would allow an estimation of the different growth rates of snail populations in their natural environments. In areas of high risk of schistosomiasis penetration in Argentina, these studies will contribute to the optimization of snail population growth control initiatives.

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