

## *An app for monitoring the population of Golden Mussels*

### *Um aplicativo para monitoramento da população de Mexilhões Dourados*

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#### Abstract

This work shows the construction of a simple, functional and real-time application to estimate the population dynamics of the Golden Mussel, an invasive species that has been causing great ecological and economic damage, particularly to the electricity sector by obstructing water collection routes of hydroelectric plant equipment. The tool *Golden Mussel App*, developed with *Shiny* package of the R<sup>®</sup> programming language, aims to enable professionals engaged in harm reduction in the energy generation sector to follow the temporal evolution of populations, even without advanced knowledge about the mathematical modeling of the problem. In this way, the application configures itself as an auxiliary tool in the planning of actions to control the Golden Mussel.

**Keywords:** biological invasion; population dynamics; ordinary differential equations; software development.

#### Resumo

Este trabalho mostra a construção de um aplicativo simples e funcional, com o objetivo de estimar em tempo real a dinâmica populacional do Mexilhão Dourado. Esta espécie invasora vem causando um grande prejuízo ecológico e econômico, particularmente ao setor elétrico, por obstruir as vias de captação de água dos equipamentos de usinas hidrelétricas. A ferramenta *Golden Mussel App*, desenvolvida com o pacote *Shiny* da linguagem de programação R<sup>®</sup>, tem como objetivo possibilitar que profissionais engajados na redução de danos do setor de geração de energia, possam acompanhar a previsão ao longo do tempo para a densidade das populações de mexilhões adultos, larvas e algas, mesmo sem conhecimentos avançados sobre a modelagem matemática do problema. Desta forma, o aplicativo se configura como ferramenta auxiliar no planejamento de ações de controle do Mexilhão Dourado.

**Palavras-chave:** invasão biológica; dinâmica populacional; equações diferenciais ordinárias; desenvolvimento de software.

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## Introduction

With the growing development of the transport sector, mainly of cargo by sea, there is also the growth of introduction of exotic species. In Brazil, it is a matter of concern since the invader can cause unbalance the original biome and permanent damage. In this context, the mollusk known as Golden Mussel is inserted once it is an invasive specie in Brazil that causes environmental impacts, affects native species and modifies ecological conditions (SILVA *et al.*, 2016). One of the most obvious consequences of the mussel invasion is its impact on hydroelectric plants, where the invader can obstruct the guardrails and other plant equipment, imposing frequent stops in production to clean those equipment. Thus, to study the population and the density of the Golden Mussel in hydroelectric reservoirs, aiming at population control, is of real importance.

The state of knowledge and trends in the peer-reviewed literature related to the use of smartphone technologies for environmental monitoring was the subject of research by Andrachuk *et al.* (2019). The study brings the perspective of using new technologies for environmental monitoring and thus captured the interest of many scientists, public policy makers and environmental conservation professionals. However, according to the authors, the literature is still incipient and most of the time studies are limited to connect the smartphone monitoring function to tangible conservation action, with community support in the context of so-called citizen science.

Citizen science consists of a partnership between amateurs and scientists in collecting data for scientific research, using participatory methodologies developed by citizens or in collaboration with professional researchers to increase public participation in environmental management, where anyone, anywhere can submit your information through the internet through applications and smartphones. An efficient scientific tool, which generates lots of data with little investment (PARRA, 2015).

As an example of applications built in this context, we can mention Burr, Kline and Perryman (2014) who describe the construction of an application that allows users to report the observation of gopher tortoises in the region of Florida, USA. Boyce and Corrigan (2017) developed an app that allows hunters in Alberta (Canada) to report the number of moose observed during the hunting season.

Malek *et al.* (2018) describe the construction of an application aimed at monitoring the stink bug of the invasive species *Halyomorpha halys* in agricultural regions in northern Italy.

On the other hand, the main objective of our work is to develop a tool that not only collects data but also provides mathematical support for decision making. A similar objective was addressed in the article by (BARROS *et al.*, 2021). The work describes a mathematical model of three populations to describe the tumor response to CAR-T cell immunotherapy. The proposal was tested by analyzing immunodeficient mice, covering interactions between a non-solid tumor and CAR-T cells themselves. In the same work, the authors present an easy-to-execute open-source simulator called *CARTmath*. The model developed together with the *CARTmath* platform would have great potential for use in the evaluation of different immunotherapy protocols with CAR-T cells and their associated efficacy.

Some mathematical models can be complex for some professionals who deal directly with the problem of species invasion, such as ecologists and biologists. Thus, we propose the construction of an application to facilitate the study of the population dynamics of the golden mussel, through a friendly graphical interface. To achieve this goal, the language chosen was R<sup>®</sup> (R CORE TEAM, 2020).

For the construction of the interface, the package *Shiny* was used, a facilitator for the creation of sites and applications intended mainly for statistical and mathematical implementations. It produces display panels containing interactive buttons and bars, in addition to the possibility of displaying results in the form of graphs or tables.

In order to build an environment where the user, in most cases, does not have mathematical knowledge, a fluid construction was sought, with only relevant information. The application uses the modeling of the Golden Mussel population dynamics described by Silva *et al.* (2022) where a system of ordinary differential equations (ODE'S) is solved using the fourth order Runge Kutta numerical method (RK4).

The work describes the details of the temporal model used and the construction of the application, presenting the aspects and characteristics of the graphical interface. Tests for validation of use are presented, as well as an attempt to predict insertion errors by the user.

## Materials and methods

### *The Golden Mussel*

The *Limnoperna Fortunei* (Dunker, 1857) known in Brazil as *Mexilhão Dourado* and internationally as *Golden Mussel*, it is a small mollusk that gets its name due to its yellowish shell. It is an exotic species in Brazil, classified as invasive because it is a specie that has an abundance or geographic dispersion capable of interfering with the survival of other species in a wide geographic region or even in a specific area, or when the established species causes impacts measurable in socioeconomic activities or human health (MANSUR *et al.*, 2012). The species was artificially introduced in South America in the 1990s, in the Rio de la Plata and is currently found in Argentina, Uruguay and Brazil, including the south of the country, the Pantanal and even the São Francisco river (BOLTOVSKOY *et al.*, 2006).

Some of its natural characteristics facilitate the success of its infestation in different places. Some of the main reasons is that its larva is freely dispersed in the water and its potent incrustation in the most varied types of surfaces when adult, including those of vessels that transport them over long distances. Some other information can also be taken into account, for example, the fact that they reproduce continuously, are resistant to various pH levels and their survival after passing through the digestive tract of some fish species (IBAMA, 2020). These facts may contribute to their reaching distant areas, even against the currents of the rivers, where some vessels cannot access. It is a bivalve and filtering species, with external reproduction, which releases gametes into the water. Thus, they produce larvae that can be transported by water currents, which according to studies (CATALDO *et al.*, 2005) can last up to 10-20 days. After this period, the species undergoes the so-called recruitment, where the larvae seek a suitable substrate for fixation, which is done through a structure called byssus. The larvae are very small, ranging from 80 to 350  $\mu\text{m}$  in the length of the larval shell, which greatly facilitates their dispersion and makes control difficult.

Studies on how infestation occurs in hydroelectric reservoirs, how to count mussels and how to combat the harmful effects of their presence are of interest to companies that finance the Research & Development Project "Control of golden mussel infestation by genetic induction of infertility (CTG Brasil, SPIC Brasil and Tijoá Energia), which is being developed in a partnership between UFRRJ, CEFET-RJ, UFES and Hubz (<http://hubz.com.br/biotecnologia/>).

The development of the application is one of the products of the project and it aims that the professionals involved, having only some local data, can obtain a quick result that can help them to making decisions about the control of mussels in places of interest.

### *The mathematical model*

The objective of mathematical modeling of population dynamics is to establish a method to quantify the golden mussel population in hydroelectric power plant reservoirs. Silva *et al.* (2022) developed a two-dimensional model that combines hydrodynamics and population dynamics simulating the density of mussels in a reservoir. It was developed to study mussel growth dynamics and identify critical points of mussel population accumulation that could affect the schedule for cleaning reservoirs and maintaining hydroelectric plant equipment. In the model, three populations are considered: adult mussels ( $M$ ), mussels in the larval stage ( $L$ ) and the algae population ( $A$ ), the mussels' main food.

In this work, we study the one-dimensional behavior, that is, only the temporal variation of populations. Each equation relates population densities with respect to time  $t$  (days). By dispensing with spatial conditions, the model can be simplified and expressed by the ODE system:

$$\frac{dL}{dt} = r_1 M \left( 1 - \frac{L}{K_L} \right) - b_1 L - \lambda L \quad (1)$$

$$\frac{dM}{dt} = \lambda \frac{A^2}{c_1^2 + A^2} L \left( 1 - \frac{M}{K_M} \right) - b_2 M \quad (2)$$

$$\frac{dA}{dt} = r_2 A \left( 1 - \frac{A}{K_A} \right) - b_3 \frac{A^2}{c_2^2 + A^2} M \quad (3)$$

In the equations (1)-(3),  $r_1$  represents the reproduction rate of adult mussels;  $r_2$  represents the algae reproduction rate;  $K_L$  represents the carrying capacity of the larvae population;  $K_M$  represents the carrying capacity of the mussel population;  $K_A$  represents the carrying capacity of the algal population;  $b_1$  represents the predation mortality rate of the larvae population;  $b_2$  represents the predation mortality rate (by fish) of the mussel population;  $b_3$  represents the mortality rate of the algae population;  $D_L$  represents the larval diffusion rate;  $D_M$  represents the mussel diffusion rate;  $D_A$  represents the algal diffusion rate;  $\lambda$  represents the maturation rate;  $c_1$  and  $c_2$  are half-saturation constants.

For the larvae equation (1), is considered a proportional growth rate to the density of adult mussels and a constant loss due to the hostility of the environment.

To write the equation this way, we considering that logistical growth rate is limited by the larvae carrying capacity  $K_L$  (EDELSTEIN-KESHET, 2005; MURRAY, 2007), and that the loss is given by the sum of the larval mortality rate ( $b_1$ ) and maturation rate ( $\lambda$ ).

For the adult mussels equation (2) it is assumed that their growth depends on the maturation of larvae and algae availability. The modelling of the mussel-algae interaction can be done by adding an intraspecific competition, evidencing a logistic term (VAN DE KOPPEL *et al.*, 2015; ZHOU *et al.*, 2021). In this way, the equation can be written assuming that the term  $\frac{A^2}{c_1^2 + A^2}$  is the mussel-algae interaction function,  $b_2$  is the mortality rate of adult mussels due to fish predation and  $K_M$  stands for the carrying capacity of adult mussels.

The algae population variation equation (3) is modelled given they growth rate  $r_2$  and carrying capacity  $K_A$ , where the loss is modeled by the mortality rate by predation  $b_3$ , considering the mussel-algae interaction  $\frac{A^2}{c_1^2 + A^2}$  and the adult mussel population  $M$ .

The methodology was applied to the reservoir of the Três Irmãos plant in São Paulo and later applied to other reservoirs. Currently, it is being expanded to serve as a guide for environmental preservation measures and for the recovery of already impacted reservoirs. To solve the system of equations, the fourth order Runge Kutta numerical method was used, a well-known and cost-effective method. It presents itself as an alternative tool for hydroelectric operators, who can use information from on-site inspections in planning maintenance intervals before infestation damages equipment.

## Results and discussion

### *The app*

The application was built using the R<sup>®</sup> programming language with the graphical interface molded from the *Shiny* web application development package. It was inspired by the *CARTMath* project (BARROS *et al.*, 2021; PAIXÃO *et al.*, 2022) which uses an application also designed through the package *Shiny*, to estimate the number of modified T lymphocytes in immunotherapies with cells CAR-T. In addition, an application to simulate the SIR model (Susceptible - Infected - Recovered) presented by Hester, Nomura and Dennis-Knierim (2020).

The tool creates an interface in the form of a panel where you can insert input values, change, view or, as in the case of the application produced in this work, use pre-

entered values as an example or allow the user to change them, so that after a instruction routine, which in this case is a mathematical application and ODE's resolution, returns to the user the solution in graphic form. It is also possible to obtain the results by downloading a file with the solutions at each time step.

Figure 1 shows the main screen of the application. It can be noted that the simulation time can be changed in the left sidebar, from 7 to 730 days. Access to the Instruction Manual is also via the left sidebar.

In the central part of the application, Figure 2, is the column where it is possible to insert the initial populations of Larvae, Mussels and Algae, and also the size of the time step used by the ODE's resolution method, equations (1)-(3). The input values for these populations are limited above to values close to the carrying capacities of the respective populations. The time step size can be changed from 0.2 to 1.

In the actions panel, Figure 3, there is a window where it is possible to insert the name of the simulation that the user chooses and to have access to the mathematical model used. In addition, it is possible to access and choose the model parameters. For operational purposes, a standard experiment was implemented, using a set of values chosen from the results of the research group when analyzing reservoirs of the Urubupungá complex, such as the Três Irmãos hydroelectric reservoir, in São Paulo (SILVA *et al.*, 2022).

The simulation tab also accompanies the set, Figure 4, where it is possible to generate the graph with the behavior of the three populations, Figure 5, in addition to allowing the obtaining of the results in a file in *.dat* format, which contains the populations at each time step. This file generated by the application loads the data set that can easily be used in other graphics generation programs or even for the composition of a database, with the possibility of creating a histogram based on the data obtained as a response.

The minimum configuration for installation in a Windows environment is 64bits and Windows 10. It is recommended to use R software in version 3.5 or higher and RStudio to view, edit and run *R scripts* in version 2022.02.2+485 or superior.

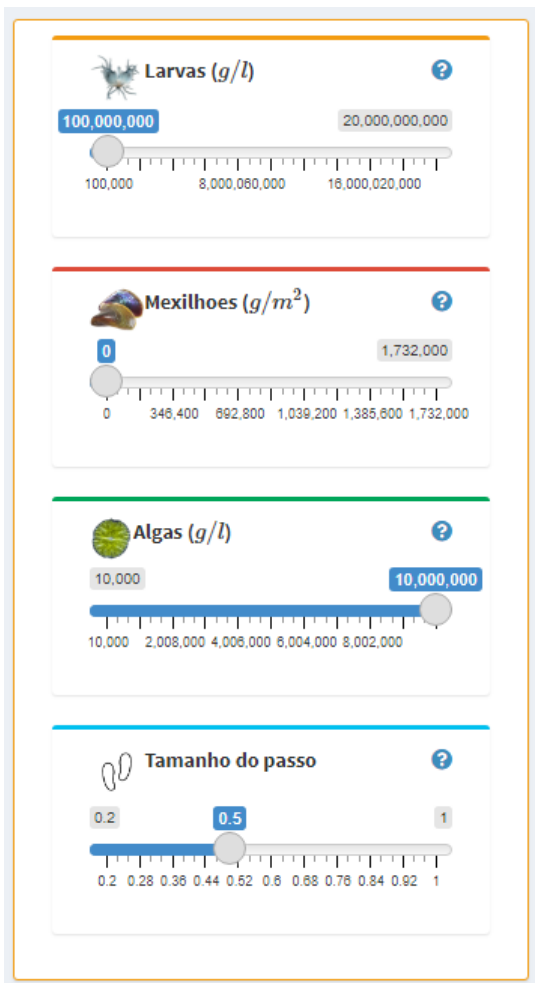
The app is available on a web page, which makes it easy to access, no installation is required. Through the web, it is only possible to use the app. For edits and customization, it is necessary to use your source code in the *RStudio Desktop* environment.

Figure 1 – Application main page.



Source: The authors.

Figure 2 – Initial data column.



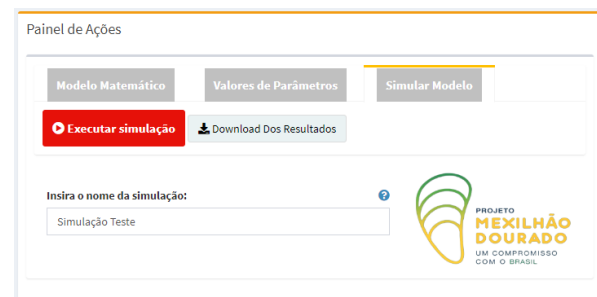
Source: The authors.

Figure 3 – Panel for displaying and changing parameter values. Standard values found in Silva *et al.* (2022).



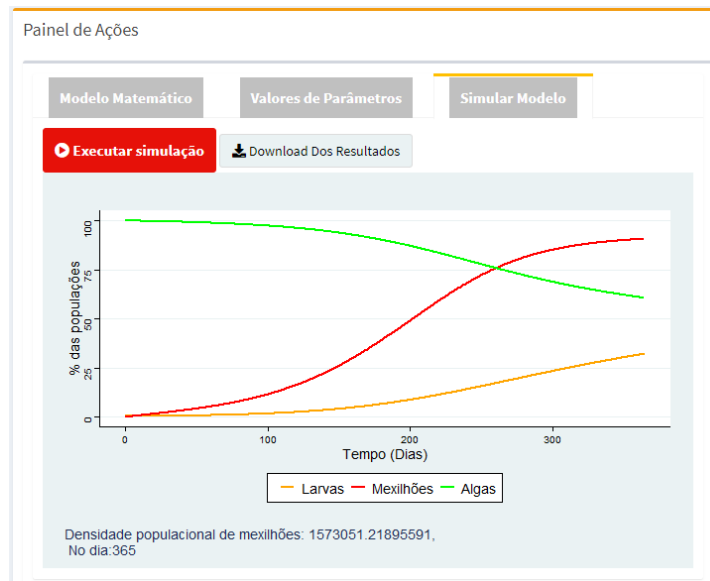
Source: The authors.

Figure 4 – Simulation panel.



Source: The authors.

**Figure 5** – Result of the simulation of the standard experiment.



**Source:** The authors.

A quick use guide has been prepared in 5 steps indicating the places where the user can enter and change the values, as well as the correct order of the use process. Even if the user does not make any value changes and uses the standard experiment set, it is only necessary that he open the "Parameter Values" tab so that the values are inserted into the equation, and right after the "Simulate Model" tab, so that the graphical response is produced immediately afterwards.

*Validation tests*

The standard experiment available to the user considers the set of input data presented at Table 1, based on information obtained by the research group, collected in the field, in theoretical review or even estimated when no information was available, see Silva *et al.* (2022) for details.

**Table 1** – Input data.

Parameter	Value	Unit
$r_1$	$0.07 \times 10^3$	$\text{km}^{-1}\text{day}^{-1}$
$r_2$	0.12	$\text{day}^{-1}$
$b_1$	0.004	$\text{day}^{-1}$
$b_2$	0.01	$\text{day}^{-1}$
$b_3$	$0.0002 \times 10^3$	$\text{km}^{-1}\text{day}^{-1}$
$K_L$	$20 \times 10^9$	$\text{kg km}^{-3}$
$K_M$	$1.732 \times 10^6$	$\text{kg km}^{-2}$
$K_A$	$0.01 \times 10^9$	$\text{kg km}^{-3}$
$\lambda$	$0.03 \times 10^{-3}$	$\text{km}^{-1}\text{day}^{-1}$
$\gamma$	$0.001 \times 10^9$	$\text{kg km}^{-3}$

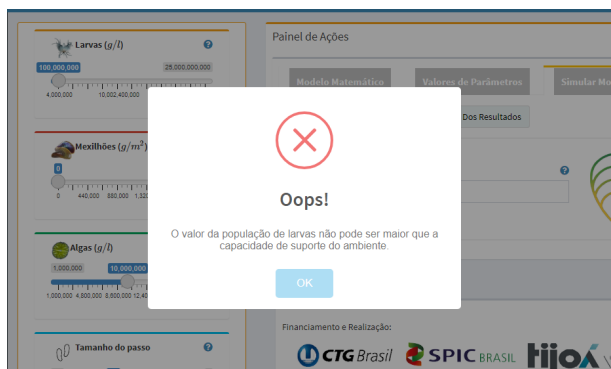
**Source:** The authors.

All parameter values can be easily changed by the user according to the experiment of interest. We chose to consider  $c_1 = c_2 = 1000000$ . For the standard infestation scenario, consider the initial conditions for the system solution (1)-(3), such as  $M = 0, L = 0.005, K_L$  and  $A = K_A$  and  $h = 0.5$ , which corresponds to the results for 1 year of infestation presented in Figure 5. It is observed that after one year of analysis the mussel and larvae populations approach their respective carrying capacities, while the algae population decreases as it is consumed by the mussels. As the scale of the quantities that describe the quantities are different between the populations, a proportion was made, dividing the result of each population by its respective carrying capacity, in order to make it possible to visualize the populations in the same graph.

As mentioned before, the user can easily change or update any input parameter or initial condition in order to simulate the situation of interest. The default experiment will remain available as a reference, so that the user can return to the default experiment values at any time through the "Reset Initial Values" option, Figure 3. If the user enters a negative value in any field intended to receive parameter values (strictly positive), the app does not run, and a message warning in the box of the nonconforming value appears in red until the error is corrected. As the carrying capacity limits the number of individuals, the value entered as the initial population is less than or equal to this number, but if the user somehow enters a greater value for the population, the program returns an error message, in pop-up form indicating the population with

the wrong value, as illustrated in Figure 6 which indicates an error when entering the initial larvae population by mistake.

**Figure 6** – Error in sizing the population of larvae.



**Source:** The authors.

## Conclusions

The motivation of this work was to build a simple and functional application that could be used by professionals, mainly in the area of biological sciences, without requiring them to master the mathematical content inserted in the construction and solution of the problem.

The application, in its current phase, shows enormous potential in fulfilling this task, where the answers obtained in the validation tests are consistent with the results obtained by the research team. The latest version, (GOLDEN MUSSEL APP, 2022), is available for use at <https://goldenmussel.shinyapps.io/GoldenMusselBeta/>.

The implementation of design elements ensured the necessary balance between the initial data entry, the resolution method, with a view to the application, and in a single screen. The result was an interface that allows for one-way use, facilitating navigation, where the user scrolls the screen from left to right, checking and entering the necessary data for the intended simulation and which, in a few seconds, returns to graphic response and a ready-type file in .csv format that store the data in the form of tables. The possibility of documenting each analysis point in an isolated and personalized way describes an important application for the technician who will use this tool, since the construction of an analysis history has extremely important applications, such as the counting of mussels for population control purposes.

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