INDEPENDENT JOURNAL OF MANAGEMENT & PRODUCTION (IJM&P)
http://www.ijmp.jor.br _v. 11, n. 1, January-February 2020_
ISSN: 2236-269X
DOI: 10.14807/ijmp.v11i1.978

CONSIDERING AN INTEGRATED MALACOLOGY APPROACH TO ECOSYSTEM ASSESSMENT: A SOCIO-ECOLOGICAL SYSTEM ANALYSIS OF THE TERRESTRIAL MOLLUSKS IN AN ATLANTIC RAINFOREST AREA, SOUTHEASTERN BRAZIL

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Submission: 1/21/2019
Revision: 4/13/2019
Accept: 5/2/2019

ABSTRACT

The invertebrate group is not considered in environmental studies. When they are remembered, the studies are vague, superficial and do not give the due importance that the group has in the ecosystem dynamics. This paper aimed at placing the terrestrial mollusks in the discussion agenda of complex socio-ecological systems and analyzed the interactions of these mollusks with the other components of the socio-ecological subsystems. The analysis was based on the theoretical-methodological framework proposed by Ostrom and discussed how terrestrial mollusks have the potential to support actions for decision-making in biodiversity conservation, public health and local economy. The framework presented four subsystems categorized as ecological, political, social and economic, with the Sooretama Biological Reserve in the Northern state of Espirito Santo as a geographical boundary. The results allow us to perceive that terrestrial mollusks have essential characteristics that reflect into ecosystem health, acting in an integrated way with the dynamics of environmental services and the equilibrium of habitats.

Keywords: land snails; bioindicator; Sooretama Biological Reserve; mollusks as socio-ecological indicator; vectors; ecosystem management.

http://www.ijmp.jor.br v. 11, n. 1, January-February 2020
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1. INTRODUCTION

The socio-ecological system approach studies the relationship between ecosystems and society through three channels (COLLINS *et al*., 2011; BODIN; TENGÖ, 2012). First, it analyses the incidence of ecosystems in the satisfaction of human needs through the services provided by the former. Second, it studies how the social dynamics of demand and catchment of ecosystem services modify and determine the ecological integrity of the ecosystems (BURKHARD *et al*., 2012).

In these two channels, the consolidation of ecosystem services conceptual framework supports the development of different research areas like identification, evaluation, mapping and economic valuation of ecosystem services (CONSTANZA *et al*.,1997; Millennium Ecosystem Assessment, 2005). These research areas have provided useful tools for the design of policy instruments for conservation, preservation and management of ecosystems at a regional level (BERROUET *et al*., 2018).

The third channel addresses the way in which both social and ecological systems respond to endogenous and exogenous drivers of change (BIER *et al*., 2008; COLLINS *et al*., 2011; BURKHAND *et al*., 2012; VAN OUDENHOVEN *et al*., 2012).

Land snails have an important role in the ecology of the forest floor by providing food for different species, including invertebrates (FREST; JOHANNES, 1995; MARTIN, 2000; NYFFELER; SYMONDSON, 2001), amphibians (DREWES, ROTH, 1981), foraging birds (SOUTH, 1980), snakes (MAIA-CARNEIRO *et al*., 2012) and small mammals (RUDGE, 1968; WHITAKER; MUMFORD, 1972; CHURCHFIELD, 1984). Once shells of terrestrial mollusks are rich in calcium, they have an important role in the storage, release and cycling of calcium in the ecosystems they inhabit (CALDWELL, 1993).

Shells from terrestrial mollusks are the primary source of calcium for eggs of some bird species, and declines in mollusks abundance in some forest ecosystems have been related to defects in eggshells, which tend to reduce the reproductive success and fall of some birds' species populations (GRAVELAN *et al*., 1994; GRAVELAND; VAN DER WAL, 1996). They also participate as intermediate hosts in the reproductive cycle for several parasitic helminths that affect wild animals (RASKEVITZ *et al*., 1999; BLL *et al*., 2001; LU *et al*., 2018).

Different species of terrestrial mollusks have a status of indicators of environmental quality due to their relatively lower dispersibility (SHIMEK, 1930), associated with stable microclimate dependence, susceptibility to the decrease of moisture (which can lead to

ISSN: 2236-269X
DOI: 10.14807/ijmp.v11i1.978

desiccation) and by relatively strict habitat preferences, resulting in high sensitivity to changes in environmental conditions (STRÖM, 2004; KAPPES, 2006; NOWAKOWASKA, 2011).

As they cannot escape quickly from areas subjected to disturbances (STRAYER *et al*., 1986; DOUGLAS *et al*., 2013), the impact effects on terrestrial mollusks can be measured through the richness, abundance and diversity in their habitats (HAWKINS, 1997). These characteristics make terrestrial mollusks a good study model for measuring quality parameters and environmental biodiversity (SANTOS; MONTEIRO, 2001; DOUGLAS *et al.*, 2013), and can also subsidize management actions in environmental change assessment processes.

The socio-ecological system is an important tool for monitoring and evaluating ecological and socio-economical aspects of the complex systems and its progress to sustainability target (HAIDER, *et al*., 2014). To understand the operation of a socio-ecological system is necessary to comprehend their parts and especially how these parts relate. Thus, under a complex socio-ecological systems perspective, based on the framework proposed by Ostrom (2009), the present paper sought to analyze the socio-ecological interactions of the terrestrial mollusks of the Sooretama Biological Reserve, Atlantic Forest domain, and how these interactions can drive actions for decision making in an ecosystem assessment.

2. RESEARCH METHODOLOGY

The study area is part of the largest Atlantic Rainforest remaining in the state of Espirito Santo, southeast region of Brazil. The Sooretama Biological Reserve is a natural area with dense biodiversity and a high rate of endemism, which reinforces the need for studies on biodiversity. The region is characterized as a dense ombrophilous forest with trees up to 40m in height. The Reserve together other contiguous natural areas protect around 50,000 hectares of Atlantic Rainforest that contain a large biological diversity still little known by science. In 1999 the UNESCO World Heritage Committee included this unit in the list of areas of exceptional ecological value for humanity, currently integrating the Atlantic Forest biosphere reserve.

The Reserve is located north of the state and is surrounded by rural properties, whose agropastoral activity moves the economic activity of that region. The scenario is marked by extensive pasture areas for production of beef cattle and milk and cultivation of such coffee, eucalyptus, pine, cacao and pineapple. The region is part of an important road corridor that connects the Southeast with the Northeast region. For this, the Governor Mario Covas Highway

http://www.ijmp.jor.br v. 11, n. 1, January-February 2020
ISSN: 2236-269X
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(BR-101) crosses the 5 km extension of the Reserve, which causes a lot of impact on the local fauna.

In the present paper, socio-ecological systems are understood as systems that permeate interactions between nature and humanity, with ecosystems and human societies interconnected in a single network. The definition of Folke *et al*. (2010), the elements of this type of system have reciprocal feedback and interdependence. For Ostrom (2009), socio-ecological systems have multiple subsystems composed of internal variables that interact at multiple levels.

To overcome the challenges created by the Cartesian and linear method of disciplinary sciences which exclude the social sciences from the ecological ones, thus creating simplistic theoretical models, holders of ready and universal solutions to complex problems associated with specific contexts, this analysis applies the framework proposed by (OSTROM, 2009). The application of the framework consists of analyzing four main subsystems: resource system, resource units, users and governance systems; each of these subsystems being composed of several variables at different levels. From the analysis of these subsystems and their components, as well as the contexts (social, economic, political and ecological) in which the socio-ecological system is inserted, it is possible to identify the interactions and their results, contributing to a deeper understanding on the structure and dynamics of the socio-ecological system (Figure 1).

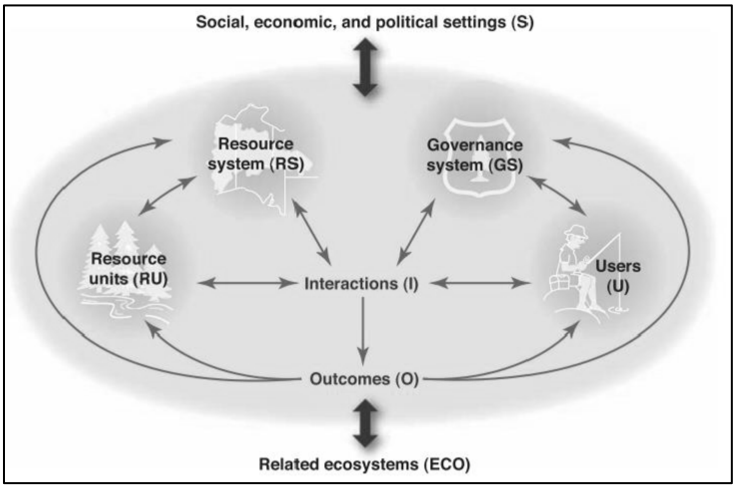

Figure 1: The core subsystems in a framework for analyzing social-ecological systems Source: Ostrom (2009).

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ISSN: 2236-269X
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3. RESULTS AND DISCUSS

3.1. The terrestrial mollusks from the perspective of the socio-ecological systems

Practically all the country's natural regions require detailed studies on terrestrial mollusk's biodiversity. Faunal surveys, environmental impact studies and related issues rarely considers mollusks faunal. Despite the importance of terrestrial gastropods as indicators of environmental conditions (SANTOS; MONTEIRO, 2001; DOUGLAS *et al.*, 2013), there are no systematized studies on the biology and ecology of these organisms in Brazil, contrary to some other countries.

As they are sensitive to changes in the structural and climatic parameters of the habitat and therefore, good study models, the increase in the knowledge about terrestrial mollusk communities, especially those inhabiting the leaf-litter, may better subsidize conservation strategies and actions of forests and other environments in which they occur. So far, the knowledge on the terrestrial mollusk fauna in natural environments in Brazil is relatively low, with the knowledge available being, in general, restricted to a few records of species that were found in different locations.

Against the lack the knowledge about terrestrial mollusks and their relationship with the socio-ecological aspects and, considering an integrated malacology approach to ecosystem analysis, the network interactions of terrestrial mollusks were mapped (Figure 2).

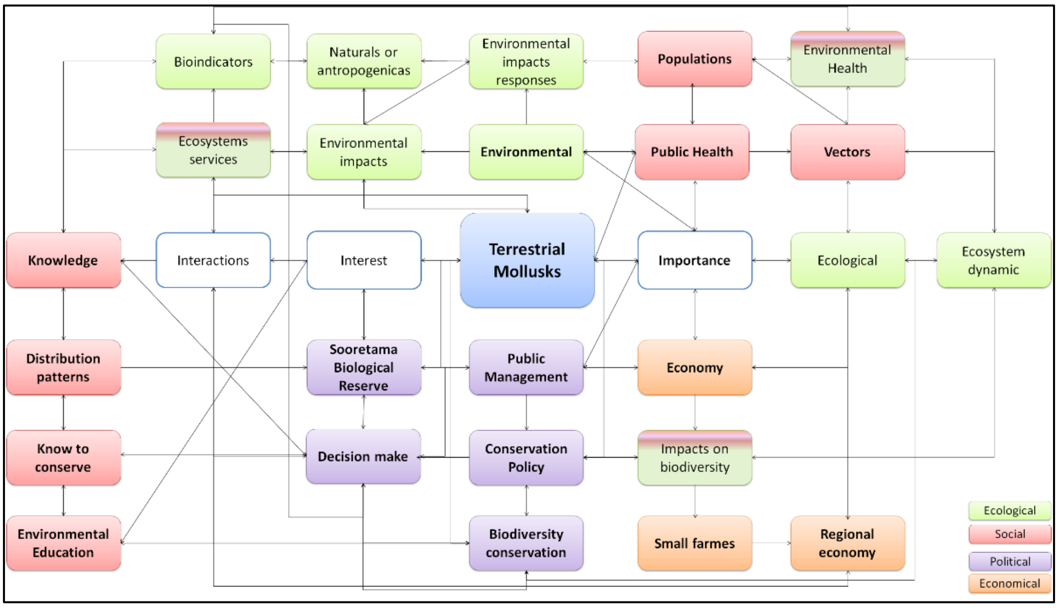

Figure 2. Terrestrial mollusks of Sooretama Biological Reserve mapping of interactions in subsystems (ecological, social, political and economic).

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Applying the key subsystems of the framework, the Shared Resource System (SR) is the use of the Atlantic Forest, whose main Resource Unit (RU) is the terrestrial mollusks. The Reserve acts as the main System of Governance (SG), managing the resources to benefit the entire population of the municipality (U), based on the way in which the terrestrial mollusks respond to the environmental impacts within Reserve and how these answers can subsidize the decision making (I) (Table 1).

Table 1. Some second-level variables under first-level core subsystems (S, RS, GS, RU, U, I, R and ECO) in a framework for analyzing social-ecological systems. The framework does not list variables in an order of importance, because their importance varies in different studies.

Social, Economic and Political Context (S)
S1 Economic development **S2** Environmental laws **S3** Agricultural frontier **S4** Biodiversity Policy **S5** Water resource

Resource System (SR)	**System of Governance (SG)**
SR1 Sector: Atlantic Forest fragment	**SG1** Reserve Management
SR2 System frontier	SG1.a Management plain
SR3 Size of resource system	SG1.b Deliberative Council
SR4 Phytophysiognomy type	SG1.c Scientific committee
SR5 Primary productivity	**SG2** ICMBio
SR6 Equilibrium properties	**SG3** Conservation Policy
SR7 Microclimate	**SG4** State Government
SR8 Environmental impacts	**SG5** Federal Government
SR9 Land use	**SG6** State Concessionaire – BR-101
SR10 Location	
Resource Unit (UR)	**Users (U)**
UR1 Terrestrial mollusks species	**U1** Surrounding population
UR2 Communities	U1.a Producers
UR3 Spatial and temporal distribution	U1.b Residents
UR4 Leaf-litter composition	**U2** Fauna and flora
UR5 Climate condition	**U3** BR-101 users
UR6 Ecosystem services	**U4** Researchers
UR7 Interaction among resource units	**U5** Location
UR8 Economic value	
UR9 Biodiversity	
UR10 Knowledge	
Interactions (I) →	**Results (R)**
I1 Natural bioindicators	**R1** Environmental Performance
I2 Ecosystem services	R1.a Immediate responses
I3 Environmental health	R1.b Nutrient cycling
I4 Small farmers	R1.c Food providing
I5 Land use conflicts	**R2** Social Performance
I6 Biodiversity conservation	R2.a Ecosystem dynamic
I7 Water crisis	R2.b Ecological balance
	R2.c Vectors
	R3 Economical Performance
	R3.a Agricultural pests
	R3.b Medical and veterinary interests
	R4 Political Use
	R4.a Make decision
	R4.b Species conservation

Related Ecosystems (ECO)
ECO1 Biodiversity **ECO2** Habitat dynamic **ECO3** Environmental impacts **ECO4** Atlantic Forest

3.2. About the Contexts

ISSN: 2236-269X
DOI: 10.14807/ijmp.v11i1.978

For the relationships of the socio-ecological system analyzed to make sense it is necessary to understand the social, economic and political contexts in which this system is involved. It is only through the mapping of the structuring factors of the system from the context that it becomes possible to analyze in detail the relations between aspects of interest.

The Sooretama Biological Reserve was created in 1941. It is the oldest protected area of Espirito Santo state and is among the oldest in Brazil. Its 27,858 hectares help preserve an important remaining area of Atlantic Forest in the state.

The basis of the economy of the northern region of the Espirito Santo state is agropastoral, and the municipality of Sooretama is a major contributor of areas for cultivation and pasture. This economic characteristic demonstrates the fragility in the process of protected area management, due an explicit disharmonious relationship between economic development (S1) of areas whose dominance activity is represented by agropastoral and the protection of preserved areas.

The strong pressure for the advance of agricultural production areas (S3) is always a factor of extreme importance in areas bordering on Conservation Units and constitutes an important piece for the understanding of the socioecological system. The economic and political context are provided in legislation by National System of Conservation Units (SNUC) (S2) and contrasts in many ways with the National Biodiversity Policy (S4).

The SNUC was published in 2000 by Federal Law 9,985 and categorizes and establishes the set of Conservation Units with specific objectives for public management at the federal, state and municipal levels. As the creation of the SNUC came long after the creation of the Sooretama Biological Reserve, it is natural that the socio-political context is troubled, since the new legislation, the communication with the surrounding neighborhood became more fragile because, according to category Biological Reserve is not allowed the permanence of dwellings or activities that do not scientific research.

The main threats currently faced by the Reserve are the presence of the Governador Mário Covas Highway (BR-101), the hunting inside the Reserve, the construction of dams in the surrounding area to irrigate the plantations, the use of fire by surrounding communities and the use banned pesticides in the plantations on the edge of the Reserve. Such human activities affect irreversibly the environmental integrity of the Reserve.

Regarding the present socio-ecological system, specifically the relevant impacts on the construction of dams for irrigation of plantations and for the animals for consumption in the

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DOI: 10.14807/ijmp.v11i1.978

surroundings areas of the Reserve contribute a lot to consolidate the local reality. Recently the state of Espirito Santo suffered the greatest water crisis of the last 100 years and the use of water resources (S5) is vital for the maintenance of the environmental health, social harmony and economic situation of the region.

3.3. Resources, Users and Governance

As already mentioned, terrestrial mollusks (UR1) perform ecosystem services (UR6) of extreme importance for environmental quality. They respond quickly to environmental stressors (SR8), are dependent on stable microclimate (SR7) and favorable environmental conditions (UR5), characteristics that give terrestrial mollusks good environmental bioindicators.

The main idea underlying this study is the possibility of using these characteristics of terrestrial mollusks as a tool for public management of biodiversity conservation (UR9), in an Atlantic Forest domain environment (SR1). In addition to providing data that promote public health actions, since many species of terrestrial mollusks are intermediate hosts of parasites (R2.c) that cause diseases in humans, as well as actions in the economic sphere, since certain terrestrial mollusks are agricultural pests (R3.a).

Knowledge about the bioecology of terrestrial mollusks (UR10) can explain much about how the ecological dynamics in the Reserve (SR10) and, consequently, around the Reserve (U1) interact and consolidate in the local context, favoring the environment for the agricultural production, being a limiting socio-environmental factor.

The Reserve has a phytophysiognomy characterized as a Board Forest (SR4), a type of dense and flat ombrophilous forest with trees of more than 30 meters in height. Having a tool that assists in environmental diagnosis and subsidizes decision-makes (SG1) in biodiversity conservation represents a great leap in the management of Conservation Units (SG3), contributing to the Chico Mendes Institute of Biodiversity Conservation (ICMBio) - environmental department responsible for protected areas - in the prioritization of areas requiring management actions (SG2).

Thus, an integrated approach considering the terrestrial mollusks as integrators of the interactions range from the equilibrium of the primary productivity (SR5) produced in the forest to the changes in the climatic conditions (UR5), passing by the composition of the leaf-litter (UR4), a very important component for forest health. From the integrations between the terrestrial mollusks and the other socio-ecological components of the analyzed system, the interactions between resource units (UR7) can be used by public managers, be it the Federal

ISSN: 2236-269X
DOI: 10.14807/ijmp.v11i1.978

Government (SG5), the State Government (SG4) and the direct users of the socio-ecological system, such as the concessionaire that administers the BR-101 in the ES (SG6), which crosses the Reserve, as well as users (U1), the researchers associated with the Reserve (U4) and, inevitably, the components of local fauna and flora (U3), integrating therefore the biophysical, social, economic and political resources.

3.4. Interactions and Results

The authors Anderies *et al.* (2004) provided many examples of complex interactions between the components of a socio-ecological system around the world. According them, many are farmer-organized irrigation systems, such as those of Bali (LANSING, 1991), the zanjeros of the Philippines (SIY, 1982) and of Spain (MAAS; ANDERSON, 1986). These are examples of long-lived, socio-ecological systems with robust irrigation. Other examples come from managed fisheries, forests, and dike systems.

Some of these are long-lived and remain robust, *e.g.*, the Dutch water boards (KAIJSER, 2002), the lobster fisheries in Maine (ACHESON, 2003), or the Hatfield Forest (RACKHAM, 1988), but others were long-lived and yet eventually collapsed, *e.g.*, early Mesopotamian civilization, the lowland Mayas (TAINTER, 1988), Chacoan culture (MILLS, 2002), Mesa Verde (LIPE, 1995), the northern cod fisheries (FINLAYSON; McCAY, 1998), and the customary marine system of the Tonga (MALM, 2001).

The framework proposed by Ostrom (2009) is useful in providing a common set of potentially relevant variables and their subcomponents to use in the design of data collection instruments, the conduct of fieldwork, and the analysis of findings about the sustainability of complex socio-ecological systems. It helps identify factors that may affect the likelihood of particular policies enhancing sustainability in one type and size of resource system and not in others.

In this study, I analyzed the complex network of the terrestrial mollusks socio-ecological system to understand how the interactions act as a tool for ecosystem management (UR7). The terrestrial mollusks interact with environmental, social and economic agents that might reflect useful instruments for creation of public policies.

The key aspect of the complex network of interactions of terrestrial mollusks in the socio-ecological system of the Reserve is the condition of being good natural bioindicators (I1). Mollusks, in general, are indicators, not only of environmental quality, but are also social

ISSN: 2236-269X
DOI: 10.14807/ijmp.v11i1.978

indicators. The presence or absence of certain species of mollusks translates into a socio-environmental condition that explains a history that may be natural or anthropogenic.

In the public health field (R3.b), different species of terrestrial mollusks can act as intermediate host (R2.c) of two nematodes of medical importance, *Angiostrongylus cantonensis* (CHEN, 1935) and *Angiostrongylus costaricensis* (MORERA; CÉSPEDES, 1971), etiological agents of eosinophilic meningoencephalitis and abdominal angiostrongyliasis, respectively, among others of medical and veterinary interest (THIENGO; FERNANDEZ, 2010; COURA, 2013; RODRIGUES *et al.*, 2016).

The presence of each species of terrestrial mollusk indicates its own reality in the specific context of the system unit analyzed. The presence of natural vectors of parasites of medical and veterinary interest reinforces the need for a systemic approach, with actions of public health surveillance in the areas where the mollusks were found. The context of the analyzed geographical area (SR10), the Sooretama Biological Reserve is located in a poorly developed municipality.

A strictly rural area that presents favorable conditions for the proliferation of populations of terrestrial mollusks. The rural area where the Reserve is located favors the advance of the populations of terrestrial mollusks to the plantations (R3.a). The plantations provide food for many species of terrestrial mollusks, which have dense populations, causing economic damage to farmers (I4).

Terrestrial mollusks are sensitive to moisture and they have been responding very well to a specific problem of the region, which is the water crisis (I7) in the state of Espirito Santo. Too much use of water resources by rural properties around the Reserve can drastically reduce populations of terrestrial mollusks. The interaction between land snails with natural resources must be used in public management. This response of mollusks means that the misuse of water resources by the productive sector (SR8) is affecting the local biodiversity richness (I6), not only in terrestrial mollusks biodiversity, but in all fauna and flora groups (U2). However, the response of the water crisis (I7) is easily observed through land snails due their bioindicator characteristic.

The set of interactions and results allow to evaluate the gears that move the complex socio-ecological system analyzed. From the perspective of the socio-ecological system of the terrestrial mollusks of the Sooretama Biological Reserve, it is possible to verify that the presence or absence of certain species of land snails can indicate the occurrence of

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DOI: 10.14807/ijmp.v11i1.978

environmental and social impacts (SR8) that reflect the use and occupation of areas (SR9) necessary for the understanding of public order problems. It is important to note that the analysis of a particular socio-ecological system is unique to the contexts associated with it. However, some similarities can be replicated to socio-ecological systems of the same characteristics.

4. CONCLUSIONS

In an environmental context, land snails are good environmental bioindicators, responding rapidly to microclimate changes and playing important ecosystem services. Regarding public health, the occurrence of certain species of land snails indicate risks to human and animal health due to the transmission of zoonoses. In economic activity, some species may be agricultural pests, indicating the need for control actions and environmental management to avoid economic losses.

However, we rarely observe this group being considered in studies or environmental analyses. The experience of the Sooretama Biological Reserve case through the theoretical-methodological framework used in this analysis shows that terrestrial mollusks have great potential in subsidizing measures and actions of public management for ecosystem assessment and decision making for the construction of environmental policies, municipal strategic health surveillance guidelines and ecological approach for agricultural pests control.

5. ACKNOWLEDGEMENTS

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES) – Finance Code 001.

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