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PHYTORREMEDIATION IN AQUATIC ECOSYSTEMS USING *Eichhornia crassipes*: A QUALITATIVE REASONING APPROACH.

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RESUMO
Este artigo apresenta o processo da fitorremediação, utilizando modelagem qualitativa. O modelo de fitorremediação é baseado no conhecimento de especialistas, que têm utilizado macrófitas, tal como *Eichhornia crassipes* (Mart.) Solms*,* para remover a poluição de ecossistemas aquáticos. O excesso de nutrientes leva à eutrofização dos corpos d'água, aumentando a produtividade primária e matéria orgânica, reduzindo a quantidade de oxigênio e afetando a biota aquática e o bem estar humano. Os pontos focais do modelo são as relações entre a emissão de esgoto em um lago, o aumento de nutrientes, introdução de *E. crassipes* para remover os nutrientes e a remoção das macrófitas, evitando o aumento de nutrientes causado pela decomposição das plantas.

ABSTRACT
This paper presents a Qualitative model of the phytorremediation process. The phytorremediation model is based on expert knowledge that has utilized macrophytes, as *Eichhornia crassipes,* to remove pollution from aquatic ecosystem. The excess of nutrients leads to eutrophication of water bodies, increasing primary productivity and organic matter, reducing the amount of oxygen and affecting all aquatic biota and human welfare. Focal points of the model are the relationships between emission of sewage in a lake, increase of nutrients, introduction of *E. crassipes* to remove nutrients and removal of macrophytes, avoiding the increase of nutrients caused by the decomposition of plants.

INTRODUCTION

The model described here aims at improving the understanding of the phytorremediation process. Phytorremediation is a method used to clean contaminated water bodies and polluted, ensuring the maintenance of the aquatic ecosystem.

In recent years, there has been a reduction of water quality in rivers and reservoirs caused by the wide availability of nutrients, particularly nitrogen and phosphorus (Velini et al. 2005). Sewage is the main source of nutrients release into water bodies, especially in cities that have no water treatment, compromising the water quality and use.

In these environments, aquatic macrophytes play an important ecological role. In eutrophicated environments, these plants are extremely productive, especially if environmental factors are favorable, such as in tropical climates, with high luminosity incidence and low salinity. Many of those aquatic plants are known for their ability to accumulate pollutants, in a process that happen due to physical-chemical interactions or to metabolism dependent mechanisms (Costa et al. 2000). This way, the phytorremediation in contaminated areas is an alternative, capable of recruiting photosynthetic vegetal systems and its microorganisms, with the intention to detoxify degraded and polluted environments (Mees 2006).

Eichhornia crassipes (Pontederiaceae), commonly called water hyacinth, has great nutrient absorption and incorporation to its biomass potential, being utilized as water purifying mechanism. With 95% of water composition and quick growth, the water hyacinth is capable of absorbing more nutrients than necessary, according with the

water fertility in which it is growing (Santos & Germano 1989). This suggests the possibility of use these macrophytes as soil fertilizer, because of high levels of macronutrients and micronutrients in the biomass of these plants (Henry-Silva & Camargo 2006). This plant is also capable of absorbing heavy metals, being very important in filtration of water coming from industry (Santos & Germano 1989).

Qualitative reasoning (QR) offers a modeling paradigm which allows the explicit representation of the main process operating in a lake when there is a sewage issuance rate and an *Eichhornia crassipes* insertion rate, capable of removing such pollution. Furthermore, the ontology provided by QR facilitates education about these processes, which will be useful for explanation to decision makers and stakeholders—those people who have a vested interest in the outcome of sustainable decisions (Nakova et al. 2007).

For this modeling effort, we chose the Qualitative Process Theory (QPT) approach proposed by Forbus (1984). This is a process centered approach that defines systems consisting of objects which properties are described as quantities and the system behavior is determined by process leading to changes in the states of the objects.

Since we are dealing with a conceptual representation of an alternative for the removal of pollutants in water bodies, this model describes the dynamic of a polluted lake, to promote the understanding of how the introduction of *Eichhornia crassipes* works. Biorremediation is a well-known technique that is being recognized as a clean way to solve problems (Salles et al. 2011). The way it is addressed will facilitate the vision of the system as a whole, helping the decision makers manage, in an adequate form, the water resources that receive sewer. These features are offered by DynaLearn, an interactive learning system that integrates techniques developed in three areas: qualitative conceptual modeling, semantic technology and virtual pedagogical agents (Bredeweg et al., 2009).

The presented model aims to describe the entrance of nutrients in a lake, the introduction of *Eichhornia crassipes*, the removal of nutrients by the roots of the plants and the withdraw of these macrophytes from the lake.

METHODS

Tipical Dynalearn models involve many different ingredients: Entities represent the structural elements of the system, agents represent the structural elements exogenous to the system, configurations indicate the structural relations between entities (and agents) and quantities are associated to entities and agents, representing their dynamic properties (Cioca et al. 2009). A model is built from scenarios representing starting configurations of ingredients, and model fragments that represent conditional knowledge chunks using the above described ingredients (Cioca et al. 2009).

The phytorremediation model involves 2 different entities, 1 agent, 2 configuration types, 9 quantities, 8 model fragments and 2 scenarios (Salles et al. 2011). All the entities, agents quantities and quantity spaces are listed in Table 1.

Table 1. Agents, entities, quantities and quantity spaces involved in the Phytorremediation model.

Entity or agent	Quantity	Quantity space
Lake	Amount of sewer	*{Zero, Low, Medium, High}*
	Nutrient variation rate	*{Minus, Zero, Plus}*
	Amount of nutrient	*{Zero, Low, Medium, High, Critical, Eutrophic}*
Eichhornia crassipes	Biomass	*{Zero, Low, Medium, High, Carrying capacity, Overcapacity}*

Entity or agent	Quantity	Quantity space
Eichhornia crassipes	Amount of absorbed sewage	*{Zero, Low, Medium, High}*
	Introduction rate	*{Zero, Plus}*
	Eichhornia remotion rate	*{Zero, Plus}*
	Growth rate	*{Minus, Zero, Plus}*
Human population (Agent)	Sewer emission rate	*{Zero, Plus}*

RESULTS AND DISCUSSION

The behavior covered by the model is limited because other variables should have been included, like necromass, aquatic biota, oxygen, pH and sedimentation. The first scenario illustrates how the amount of nutrients in the lake is quantified (Salles et al. 2011). The most complete scenario in this work is shown in Figure 1. This scenario shows the full causal phytorremediation mechanism. Initially, the lake is eutrophic and the *introduction rate* of *Eichhornia crassipes* starts with the value 'plus'. This variable has exogenous behaviour (decrease), just like *sewer emission rate*.

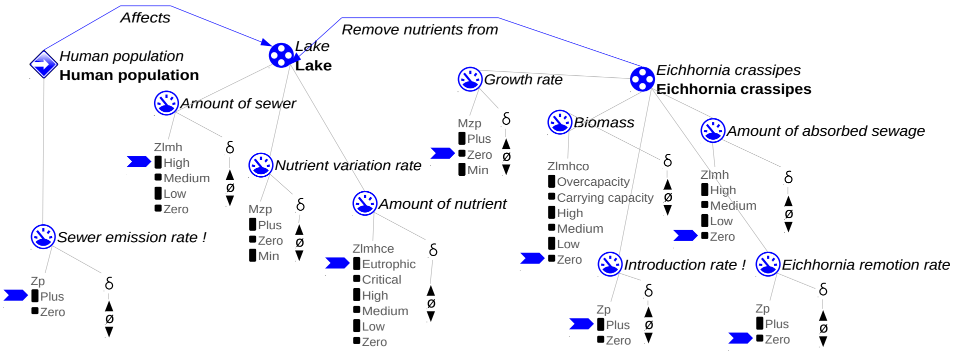

Figure 1. Scenario 2, starts a simulation with all the influences.

The state-graph for this simulation is shown in Figure 2 and, in Figure 3, the causal model that shows all the active influences in state 5

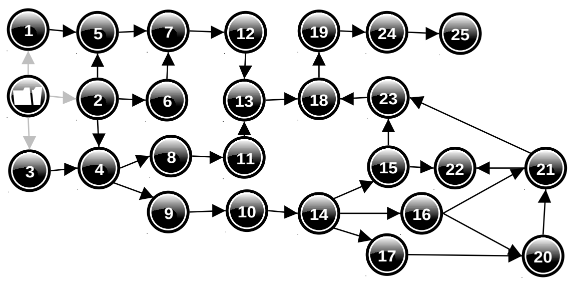

Figure 2. State-graph of simulation of scenario 2.

While the state-graph (Figure 2) shows all the states produced in the simulation and the possible state transitions, Figure 3 shows the causal model, which demonstrates the causality flow operating in the system in state 2 of the simulation. The pollution process is represented by *Sewage emission rate*. This process determines the *Amount of sewage* introduced in the Lake, which in turn positively influences the *Nutrient variation rate*. This quantity determines the *Amount of nutrient*. *Growth rate* of E. crassipes is influenced by availability of nutrients, and the plant *Biomass* influences the *Amount of absorbed sewage*. Two processes control the plant population growth: introduction of *Eichornia* when the biomass is low, and removal of the plant when the biomass is equal or above the carrying capacity. As in state 2 only the introduction process was active, the *Removal rate* is not connected to *Biomass*.

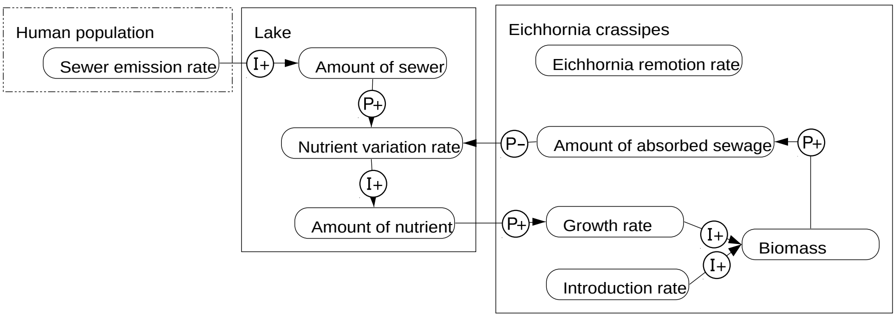

Figure 3. Causal model State 10 – scenario 2

Figure 4 shows the system behavior in the sequence of states [2,4,9,10,14,15,23,18,19,25].

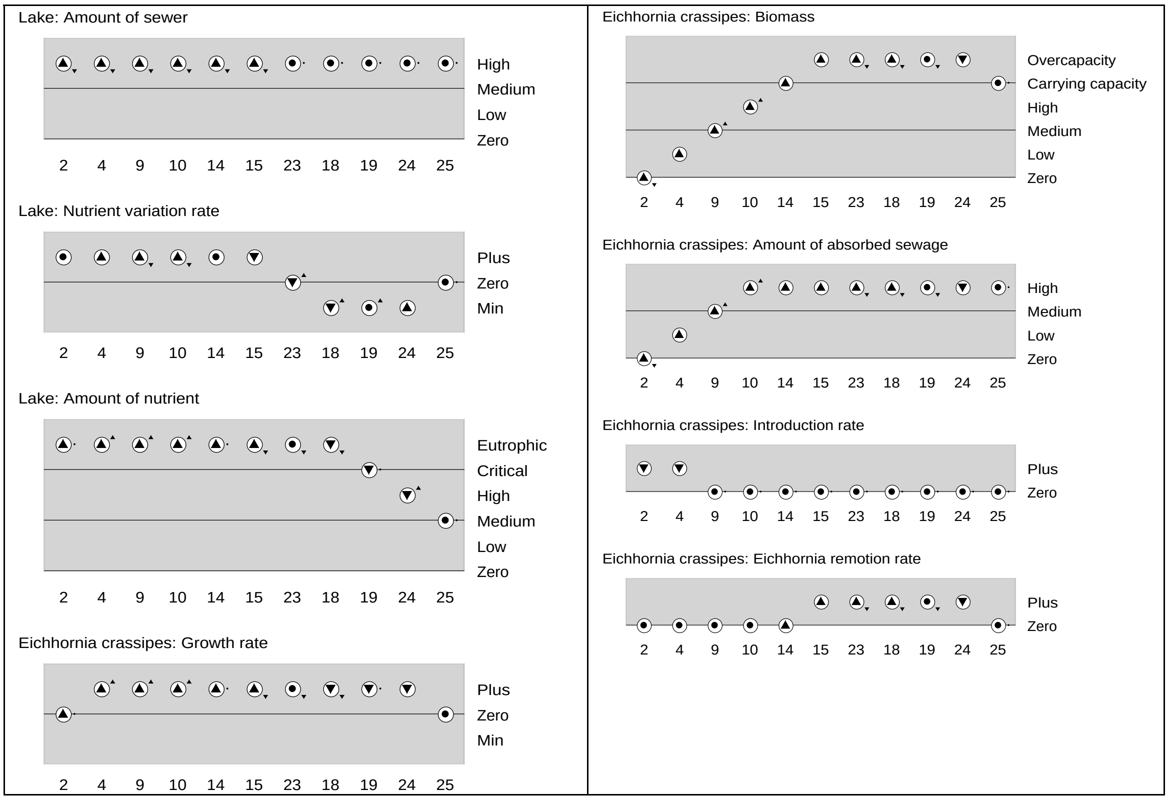

Figure 4. Value history of quantities in a single behaviour path.

Simulation with scenario 2 illustrates the phytorremediation mechanism, with the introduction of *E. crassipes* in a eutrophic lake, the removal of nutrients and, finally, the removal of the macrophytes when the plant population is above the carrying capacity, and the system reaching a dynamic stability in state 25. Interesting to note are the equilibrium at a lower level of nutrients in the lake although the amount of sewage is stable in high, with Eichornia entering also in equilibrium at the carrying capacity.

The whole set of scenarios and simulations produced by the current version of the model focuses on the introduction and removal of *E. crassipes* to illustrate the important effects of these factors on nutrient reduction, and allows for exploring the model under different conditions.

Future work could also focus on increasing biomass leading to an increase in the amount of nutrients (caused by necromass), to illustrate the importance of the management, removing biomass. Old leaves of *E. crassipes* gradually become senescent and decompose, while still attached to the plant, allowing time for nutrients translocation for new growth, resulting in the conservation limiting nutrients (Greco & Freitas 2002). The rapid growth of this species also increase evapotranspiration and bring a negative effect on recreation (Greco & Freitas 2002).

Oxygen also should be included in future studies, as a quantity of the entity lake, since the decomposition of *E. crassipes* occurs rapidly with a high consumption of this element (Negrisoli et al. 2006). The temperature could be a quantity that influences *E. crassipes* biomass, because the plants grew faster under the warmest temperature regime provided (27.6° C) (Bock 1969; Greco & Freitas 2002). Low temperatures may have negative influence on growth rate (Bock 1969; Greco & Freitas, 2002).

Some authors found a trend of higher occurrence of aquatic plants floating in water with higher turbidity. Thus, this element could be added to the model, as a quantity of the entity Lake, influenced negatively (P-) by the biomass of *E. crassipes.* (Carvalho et al. 2005). Those macrophytes are effective in reducing turbidity mainly due to its great root development (Henry-Silva & Camargo 2008).

As nutrient removal by *Eichhornia crassipes* occurs not only by direct absorption, but also by a combination of physical mechanisms, biological and chemical agents, such as sedimentation and transformation of nitrogen by bacteria (Henry-Silva & Camargo, 2008), it would be important to include some of these elements at the model.

Another quantity that can be included in future works is pH of the water. The pH of water is higher in areas without *E. crassipes* (Martins & Pitelli 2005). This fact is related to the respiratory activity of the root system, which produces carbon dioxide, with the interception of sunlight, which prevents the photosynthetic activity, and to death and decomposition of plants (Martins & Pitelli 2005).

CONCLUSION

A qualitative reasoning model of phytorremediation, using Dynalearn, was presented. The main objective of this model is to represent the process of phytorremediation using *Eichhornia crassipes* to remove nutrients of the lake, showing that, at the time these macrophytes can be used to clean up the lake, they must be withdrawn when the biomass reaches the carrying capacity. If not removed in the appropriate time, *E.crassipes* can be the source of pollution. This way the model constitutes a basic knowledge, with feedbacks, of a useful mechanism to human populations.

The model produces valid simulations, illustrating how the macrophytes can absorb the pollution and the effect of the removal of biomass, keeping the population within the range where its beneficial effects to the environment outweigh the harmful effects.

ACKNOWLEDGEMENT

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