



A QUALITATIVE APPROACH TO ASSESS THE IMPACT OF PESTICIDE USE ON ECOSYSTEM SERVICE OF POLLINATION

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RESUMO

Pouca atenção tem sido dada à importância dos polinizadores e do serviço que prestam para manter o meio ambiente e atender necessidades humanas de alimentos e matérias primas. O serviço prestado pelos polinizadores nativos é valioso, mas a abundância de abelhas nativas vem diminuindo devido à intensificação da agricultura e à utilização de pesticidas. O objetivo deste modelo é demonstrar o papel da polinização e polinizadores como prestadores de serviços do ecossistema na produção agrícola e como o controle de pragas baseados em pesticidas afetam este importante serviço ecológico. O modelo foi construído com técnicas de raciocínio qualitativo, utilizando-se o software DynaLearn (www.dynalearn.eu). Nesta abordagem de modelagem, destacam-se representações qualitativas de funções matemáticas capazes de tornar explícitas relações causais, e a abordagem composicional, segundo a qual fragmentos semi independentes de modelo são automaticamente combinados para construir modelos de simulação progressivamente mais complexos. De maneira geral, simulações com o modelo mostram o efeito da remoção da cobertura florestal em ambientes naturais perto de terras agrícolas, nas quais se usam pesticidas no controle de pragas, tal que a diminuição do número de árvores e aumento do uso de pesticidas afetarão diretamente a quantidade de polinizadores. São demonstradas situações em que a redução do número de abelhas pode, eventualmente, levar todo o sistema ao colapso e se tornar incapaz de produzir. Este modelo pode ser usado como ferramenta de apoio à tomada de decisão ou a planejamento estratégico, para fins educacionais, ou ser reutilizado para criar composicionalmente modelos de simulação em que a polinização é parte de fenômenos mais complexos.

ABSTRACT

Little attention has been given to the importance of pollinators and the service they provide in maintaining the environment functioning and human needs for food and raw materials. The service provided by native pollinators is valuable but the abundance of native bees has been declining due to agricultural intensification and pesticide use. The goal of this model is to demonstrate the role of pollination and pollinators as ecosystem services providers in agricultural production and how the plague control based on pesticides affects this important ecological service. The model was built using Qualitative Reasoning techniques, and implemented in the DynaLearn workbench software (www.dynalearn.eu). In this modelling approach the main features include qualitative representations of mathematical functions that render explicit causal relations, and the compositional modelling, in which quasi independent model fragments are automatically combined to build up simulation models of increasing complexity. Simulations with the model show the effects of forest cover removal in natural environments near agricultural lands, and the use of pesticides to pest control on the amount of pollinators. Situations are shown in which reduction in the amount of bees lead the whole system to collapse and no longer be able to produce, as well as situations in which conservationist measures contribute for the bee populations to increase and, as a consequence, the production also increases. This model can be used as a reference model for stakeholders to use as decision making or strategy planning tool, for educational purposes, or be re-used to compositionally create other simulation models in which pollination is part of more complex phenomena.



INTRODUCTION

Little attention has been given to the importance of pollinators and the service they provide in maintaining the environment functioning and human needs for food and raw materials. Recent biodiversity inventory suggests that about 90% of all flowering plants depend on birds, bats, insects, and other animal species to assist in delivering the pollen they need to produce seeds, and pollinators are essential for about 35% of global crop production (Klein *et al.*, 2006). At least one-third of the crops used for human needs rely on animal pollinators for successful reproduction. The annual value of this ecological service is estimated to be US\$ 40 billion.

For decades, biologists have been worried about declining populations of both wild and domesticated pollinators. Many factors contribute to pollinator disappearance, including habitat loss, climate change, introduction of exotic species, and the spread of diseases, but one of the most important threats is the indiscriminate use of pesticides that eliminate beneficial species along with the pests they are intended to target.

A great deal of attention has been focused recently on honey bees. The service provided by native pollinators is valuable to humanity but the abundance of native bees has declined due to agricultural intensification and pesticide use. These insects not only make honey, but they play a vital role in fertilizing crops. In fact, their importance spreading pollen is worth at least 100 times the value of the honey they make. Bee-pollinated foods include squash, tomatoes, peppers, apples, and pears. For instance, California almond industry alone is worth \$2 billion annually and relies on over 1 million honey bees hives for cross-pollination (Ratnieks and Carreck, 2010). Some farmers pay commercial beekeepers to bring hives to their fields to pollinate crops (Klein *et al.*, 2006). The increase in US agricultural yield and quality production achieved through pollination by honey bees alone - was \$9.3 billion in 1989 and was \$14.6 billion in 2000 (a 36.3 percent increase) (Morse and Calderone, 2000).

Education, among other things, is required to change this situation and increase awareness on the importance of ecosystem services. Allen-Wardell *et al.* (1998) identified the need for focussing at primary, secondary, and higher education levels to show how pollination services benefit society. The goal of the model described in this paper is to demonstrate the role of pollination and pollinators as ecosystem services providers in agricultural production and how the use of enemies control based on pesticides affect this important ecological service.

The key issues and concepts involving in pollination process are the following: (1) Pollination is an important process that involves the transfer of pollen among flowers mediated by the wind, the water and animals, mostly insects. (2) Pollinator disappearance can be caused by habitat loss, climate change, and introduction of exotic species, the spread of diseases and the use of pesticides. (3) As farmers use pesticides to fight pests in agriculture, they involuntarily kill pollinators and, because of that, they cause a decrease in their own production. (4) After a certain level of pollinator loss, agriculture enters in serious trouble, with significant productivity reduction and low revenue.

MODELLING APPROACH AND IMPLEMENTATION

The model was built using Qualitative Reasoning techniques, which has been successfully used to model ecological systems (see the special issue of *Ecological Informatics* on Qualitative Reasoning, volume 4, issues 5-6, pages 261-412, November-December 2009). The ontology provided by the Qualitative Process Theory (QPT) (Forbus, 1984) was used to describe processes as a mechanism that drives the



dynamics of the system. An important advantage of Qualitative Reasoning consists of the ability to capture both systems' structural and behavioural information, including the notion of causality.

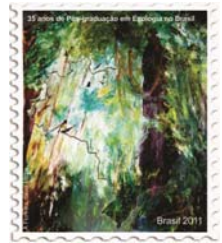
To implement the model it was used the DynaLearn workbench software (www.dynalearn.eu), which is currently being tested and evaluated. DynaLearn provides 6 different modelling environment or layout so called *learning spaces* (LS), and each of them has different number of QPT modelling primitives of increasing complexity (Liem *et al.*, 2009). In the most complex learning space (LS6), it has basically the same reasoning functionalities as Garp3 (Bredeweg *et al.*, 2009; visit www.garp3.org). Concepts that can be reusable knowledge are captured in model fragments. These model fragmentas are further combined by means of a technique called compositional modelling (Falkenhainer and Forbus, 1991). DynaLearn provides two different types of causal modelling primitives: direct influences (I+ and I-) and proportionalities (P+ and P-), allowing for representation of feedback loops. A more detailed discussion can be found in Salles *et al.* (2010).

Model ingredients

To define what elements should be considered to include or exclude from the model is a fundamental step of modelling process. That depends on granularity, refinement and goals of the model. In this modelling approach the main ingredients used to build DynaLearn models are: entities (objects of the system modelled); quantities (variables of each entity) and quantity spaces (a range of possible qualitative values of each quantity). In Table 1 there is a description of model ingredients selected for the model.

Table 1. Entities, quantities and quantity spaces involved in the Introduction of non-native spp model.

Entity	Quantity	Quantity Space
Human activity	Investment	{Zero, Low, Medium, High}
	Agricultural production	{Zero, Low, Medium, High}
	Revenue	{Zero, Low, Medium, High}
	Pesticide use	{Zero, Low, Medium, High}
	Deforestation rate	{Zero, Plus}
Ecological service	Pollination	{Zero, Plus}
Native bee	Number of	{Zero, Low, Medium, High}
Plant	Number of	{Zero, Low, Medium, High}
	Seed mortality	{Zero, Plus}
	Seed	{Zero, Low, Medium, High}



RESULTS AND DISCUSSION

Scenarios and simulations

Scenarios represent initial situations, including configurations of the system of interest, and initial values of the quantities. The most complete scenario in this work is shown in Figure 1.

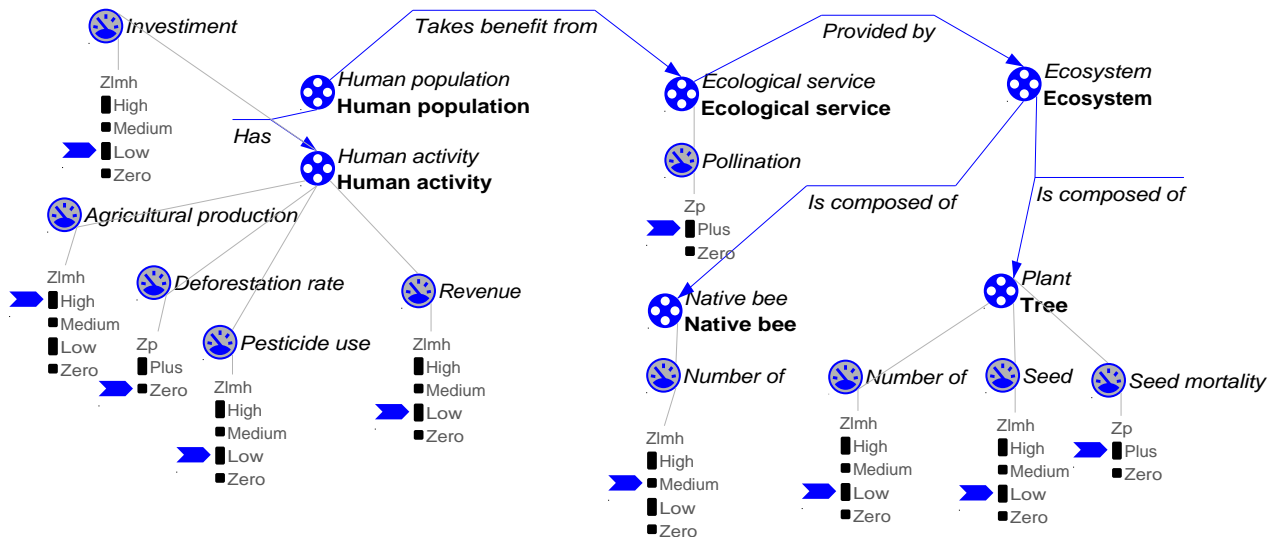


Figure 1. Scenario “Sce02 High agricultural production effects” with initial values.

The full simulation of this scenario presents a behaviour graph with 10 states (Figure 2). This simulation shows the effect of forest cover removal and increased use of pesticides. The path selected in this simulation pass through following states: [2 → 3 → 4 → 5 → 6 → 7 → 8 → 9 → 10]. A diagram showing the causal dependencies in the model is in the Figure 3.

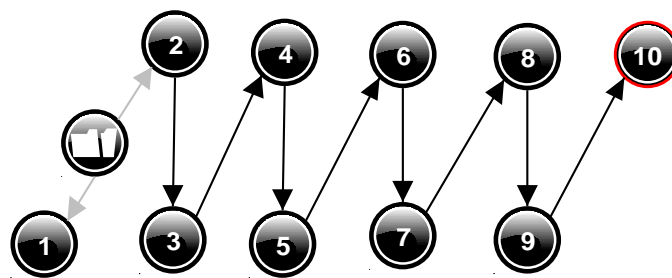


Figure 2. State graph – sce02 high agricultural production effects.

Figure 3 shows that due to pesticide use and reduction in the number of trees, the number of native bees decreases affecting indirectly the pollination ecosystem service, which is related with number of bees by direct proportionality [$P+(Pollination, Number\ of)$]. Despite they are not related by proportionalities, reduction in pollination leads to decrease the number of seeds [$I+(Seed, Pollination)$], because the last one is the result of difference between amount of fecunded seeds (Pollination) and the amount of dead seeds (Seed mortality). Reduction in number of bees leads the number of fecunded seeds to change in the same direction [$P+(Pollination, Number\ of\ (bees))$], that on the other hand determine agricultural production and revenue to decrease.

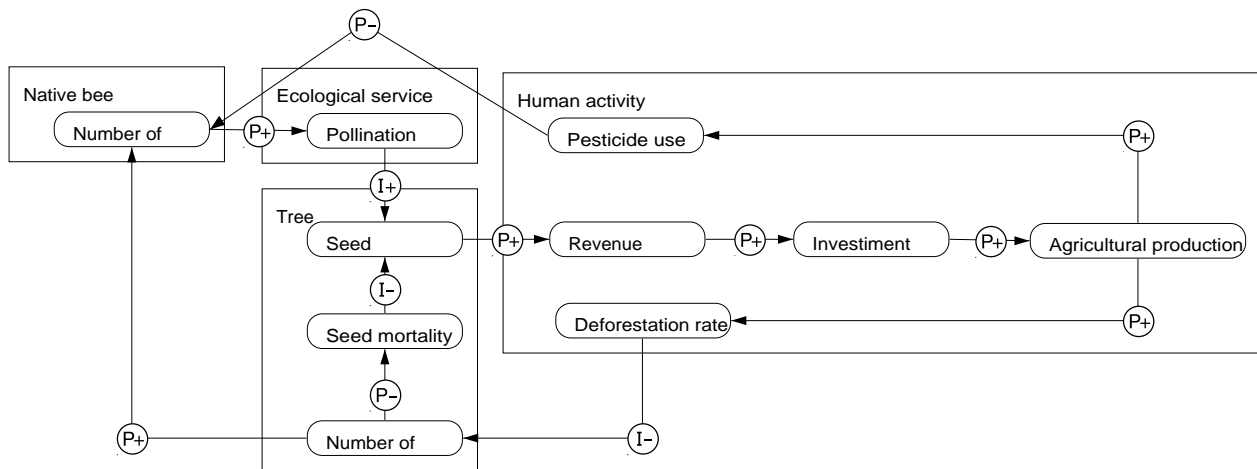


Figure 3. Causal model from State 10 – sce02 high agricultural production.

The value history diagram obtained from the simulation of this scenario can be seen in Figure 4. The reduction in number of fecundated seeds is propagated to revenue, investment and agricultural production by qualitative proportionalities [P+(Revenue, Seed), P+(Investment, Revenue), P+(Agricultural production, Investment)], making these variables to achieve their smallest value - Zero - in the last state.

Reduction in agricultural production cause pesticide use and deforestation rate [P+(Pesticide use, Agricultural production), P+(Deforestation rate, Agricultural production)] to be reduced, closing the feedback cycle in state 10 in which use of pesticide, deforestation and agricultural production tend to Zero value, which allow reestablishment of number of bees to Medium value.

The model shows an explicit representation of causes and effects involved in pollination and its impact on agricultural production improving the understanding of how the system works. As Allen-Wardell *et al.* (1998) pointed out, there is a need of better understanding the relationships among pollinator diversity, pollinator abundance, and changes in crop yields.

An important remark made by Kremen *et al.* (2002) is that restoring pollination services for agriculture could also benefit wild plants and thereby promote conservation of biodiversity across the agro-natural landscape. Adding these informations into the model can affect the entire system and may be a starting point to demonstrate for farmers and stakeholders the importance of conservation of natural areas, restore the degraded lands, and how to manage the system to conserve biodiversity and ecosystem services.

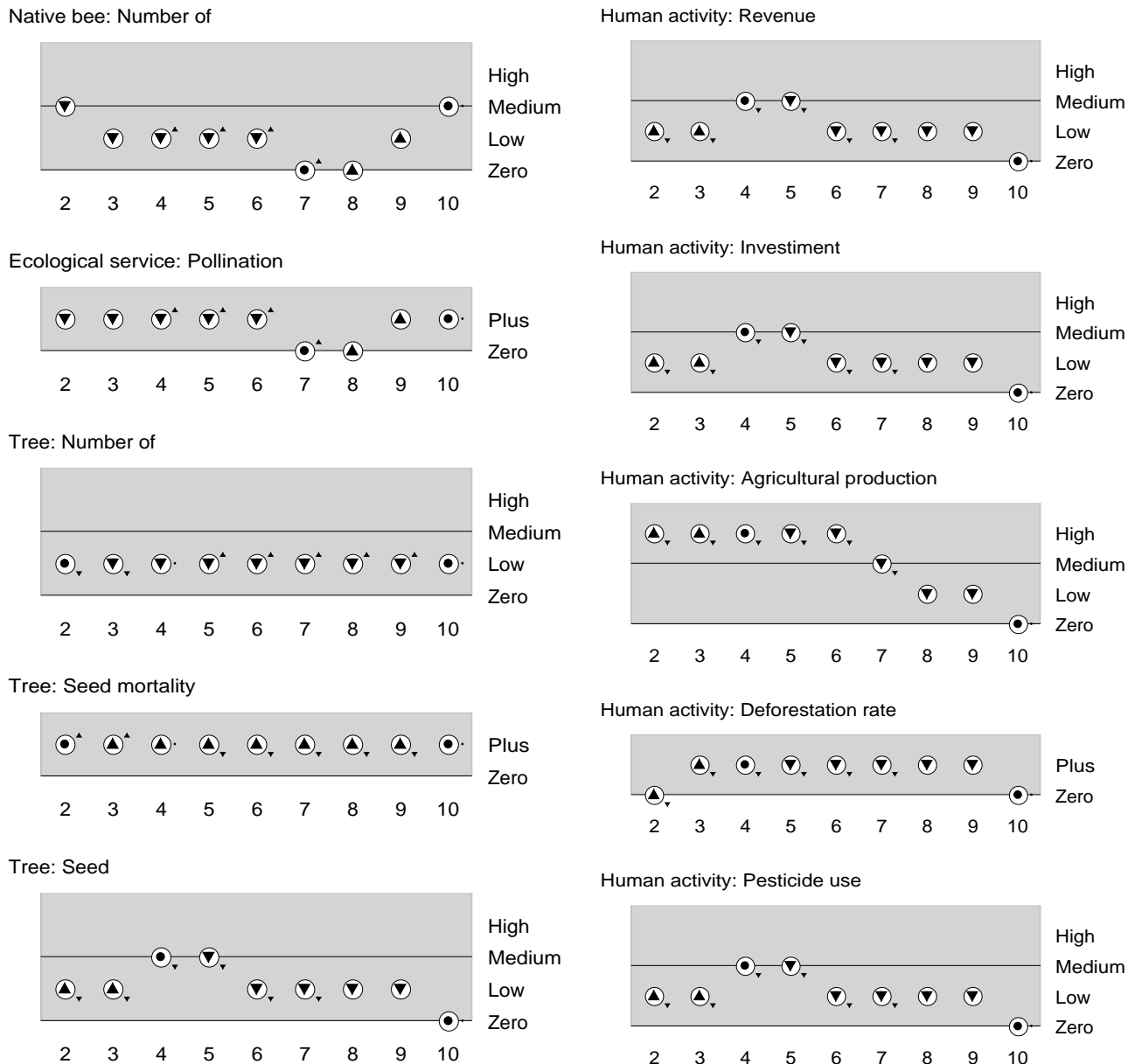


Figure 4. Value history diagram for simulation of Scen02 high agricultural productivity effects.

CONCLUSION

The model is relatively simple, but shows the effects of the use of pesticides on natural pollinators. Simulations present increasingly more details the consequences of killing bees: eventually, the whole system may collapse and no longer be able to produce. This model can be used as a reference model for stakeholders to use as decision making or strategy planning tool, for students to learn about ecosystem services, or to be re-used in order to create models in which pollination is part more complex phenomena. Currently the model is being improved in order to include more details to the simulation, and to better explore the effects of conservation measures to recompose ecosystem services.



ACKNOWLEDGEMENT

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