Assessing the Ecological Impacts of Agriculture Intensification Through Qualitative Reasoning

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Abstract

How to feed the world without loosing what is left of biodiversity? Two answers for this question are found in the literature. On the one hand, the "Land Sparing" paradigm suggests that increasing yield by means of intensive agricultural systems would fulfill the needs of human population and save natural landscapes. On the other hand, "Biodiversity Friendly Farming" argues that agricultural intensification has deep impacts on both biodiversity and ecosystem properties and suggests that non-intensive farming practices keep the ecological balance and still may produce large quantities of high quality food (food security). This work presents a Qualitative Reasoning (QR) model that compares the impacts of intensive and non-intensive agriculture on water resources, biodiversity and productivity. The simulations show the inefficiency of intensive agriculture in protecting water resources and biodiversity, and the efficiency of non-intensive approach in terms of food production and ecosystem conservation.

Introduction

How to conserve biodiversity in a world with increasing food demand? Some authors suggest that by increasing the productivity of agricultural systems the demand of converting unfarmed areas into productive ones would decrease, leaving more space to conserve wildlife (Green *et al*. 2005; Balmford, Green and Schalermann 2005). However, Perfecto and Vandermeer (2005), among others, argue that ecological impacts of agriculture intensification can go far beyond farmed areas. The debate on whether agriculture intensification can or cannot prevent further biodiversity loss is now polarized between two opposite paradigms: "Land-Sparing", based on the idea that intensification could spare land for biodiversity conservation, and "Biodiversity-Friendly Farming" that suggests less intensive farming practices may combine food production and biodiversity conservation.

Land Sparing X Biodiversity Friendly Farming

Agriculture intensification is known to be one of the main causes of extinction all over the world (Benton, Vickery and Jeremy 2003). Despite these negative effects, the Green Revolution, an intensification process that since 1945 raised the world's gross yield in 106% and contributed to population growth and relative increase of well-being worldwide (Cassaman 1999). Defenders of the "Land Sparing" paradigm (Green *et al*. 2005) claim that productivity of existing farmed systems should increase in order to leave more space for conservation purposes. However, intensive agriculture may cause serious harm to native habitats in many ways. The use of pesticides can seriously threat non-target organisms, including human beings. Intensification also decreases agriculture matrix permeability by isolating populations living in natural habitat patches. Ecological theories (McArthur and Wilson 1967, Levins 1970) predict that no population or community can be maintained if it is not connected to others. Finally, as pointed out by the "Biodiversity-Friendly Farming", many studies show that less intense managed systems (eg. agroforests) can support high levels of biodiversity and yet have high productivity (Perfecto and Vandermeer 2008). In this context, the use of QR techniques (Weld and de Kleer 1990) may be useful to compare assumptions and consequences for the environment of these two approaches.

A model to express the relationships between farming and environment services

The model has been built following the Qualitative Process Theory (Forbus 1984) and the compositional modeling approach (Falkenhainer and Forbus 1991). Accordingly, processes are the initial cause of changes in the system, modeled by direct influences (I+ and I-) they put on state variables. Such changes may propagate to other quantities via qualitative proportionalities (P+ and P-). The model was implemented in the Garp3 workbench (Bredeweg *et al.* 2006) and consists of 53 model fragments involving 7 entities and 18 quantities. It holds, in the current version, 57 simulations. Entities and configurations are shown in Table 1.

Tabel 1: Source entity, configuration and target entity of the model

Source Entity	Configuration	Target Entity
Investor	invests in	Agriculture
Agriculture	occurs in	Farmed area
Farmed area	contains	Natural area
Farmed area	Has	Source
Farmed area	Has	Water resources
Source	affect	Unfarmed area
Emigration	Emit	Source
Agriculture	Uses	Water resources
Agriculture	impacts	Natural area

The model describes a landscape composed by many relatively small natural patches (natural area) and few large ones (sources), embedded in an agricultural matrix (the farmed area). It is known that the maintenance of species diversity in small natural areas depends on the colonization by individuals coming from a large area, the species source. Therefore the rate of species variation in an isolated natural area is the balance between colonization from external sources and extinction rates caused by the insular nature of small habitats.

The colonization process depends on the permeability of the farmed area. Permeability is defined in terms of physical and biological characteristics that facilitate or render the flux of propagules (fruits, seeds, larvae or individuals) through it. For instance, if an animal have to cross a large area of pasture (low permeability) before colonizing a forest fragment, it probably would suffer some harm before reaching its destination. In the model described here, permeability should be equal or greater than value medium as a condition for propagules to cause influence (P+) on species variation rate of unfarmed areas, as shown in Figure 1.

What happens if intensification takes place in a non-intensified landscape? Agriculture intensification main characteristics are mechanization, the use of artificial fertilizers and pesticides, irrigation and loss of spatial heterogeneity. Heterogeneity is considered here as the physical structure of the ecosystem. Intensified systems are characterized as homogenous (as they hold monocultures). Non-intensified systems have high spatial heterogeneity (vertical and horizontal) as they are composed by a mosaic of associations between different cultures. Water resources have fundamental importance for both the survival of natural ecosystems and the productive system. In this model, irrigation is a main factor that may impact water quantity in farmed areas and changes in water quality are determined by the quantity of fertilizers.

Productivity is influenced by the intensification parameters mentioned above and by ecological factors and by biodiversity, both in farmed and unfarmed areas. Biodiversity and environmental services are important for agricultural production such as they provide, among others, climate stability, water and nutrient cycling, pollination and protection against pest outbreak (Matson *et al.* 1997).

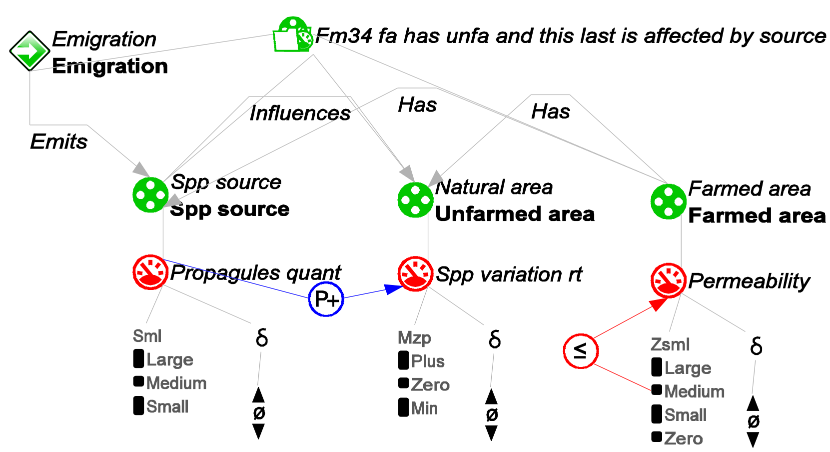

Figure 1: Model fragment showing that *Permeability* value should be equal or greater than medium for *Propagules* to influence *Species variation rate.*

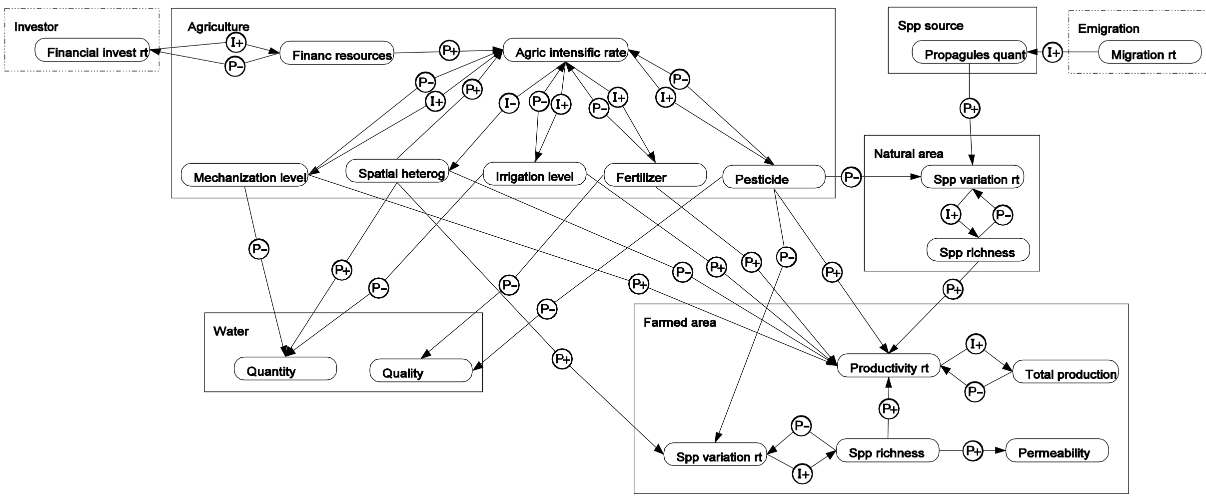

Figure 2: Causal model obtained in state 1 in simulations starting with both intensive and non-intensive agriculture scenarios.

Causal explanations for the effects of intensive and non-intensive agriculture

Intensive agriculture. The more complex simulation supported by the model starts with a scenario showing a landscape with non-intensified agriculture changed by the intensification process, which is triggered by investments on mechanization, fertilizers, pesticides and irrigation. Initially water quality, water quantity and spatial heterogeneity are in the highest values of their quantity spaces. Species richness in both farmed and natural areas have medium value, with propagules coming in large quantities into the natural area from a source area. Production is medium and stable.

The simulation produces one initial state, and the full simulation produces 43 states. The causal model obtained in state 1 (figure 2) reads as follows: a positive *Investment rate* causes *Financial resources* to increase and this change activates the intensification process (*Agriculture intensification rate* becomes positive). This process causes the quantities *Mechanization level*, *Irrigation level*, *Fertilizer* and *Pesticide* to increase, and *Spatial heterogeneity* to decrease. Influenced by these changes, *Water quantity* and *Water quality* decrease. *Species variation rate* in natural areas receives opposite influences from *Propagules quantity* and *Pesticides.* Considering that these two quantities are increasing, the result is ambiguous and *Species variation rate* may increase or decrease. This way *Species richness* in natural areas also may increase, stabilize or decrease. In farmed area, *Species variation rate* decreases due to the influences from *Spatial heterogeneity* and *Pesticides*, and as a consequence *Species richness* decreases. This change causes *Permeability* to decrease, making the propagule movement harder. *Productivity rate* in farmed area is influenced by *Species richness* both in natural and farmed areas, and by the five quantities affected by the intensification process. The final result is ambiguous, and the production may decrease, when the negative forces are greater than the positive ones, or increase, when environmental services provided by biodiversity have stronger influence on the farmed area.

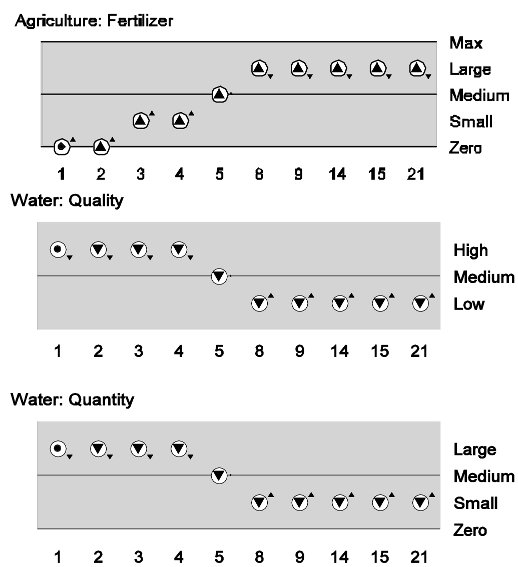

Figure 3. Value diagrams showing the effects of agriculture intensification on water quality and quantity.

The behaviour path [1 → 2 → 3 → 4 → 5 → 8 → 9 → 14 → 15 → 21] illustrates some of the consequences of intensive agriculture. *Fertilizers* and *Irrigation level* increase up to value large in state 8, and keep increasing within this interval until the end state 21, causing water quantity and quality to decrease (Figure 3).

Besides that the key for understanding the system behaviour can be found in the values *of Permeability*. As *Spatial heterogeneity* is decreasing, it eventually causes *Species richness* in farmed area to decrease, which in turn causes *Permeability* to decrease too. As soon as *Permeability* became smaller than medium in state 8, the influence from *Propagules* on *Species variation rate* is no longer active (see model fragment in Figure 1). The balance between the influences of *Propagules* and *Pesticides* on *Species variation rate* in the natural area was changing already and in state 8 the rate starts to decrease. As a consequence, *Species richness* in natural area starts to decrease in state 9 and eventually reaches the value small in state 21 (Figure 4).

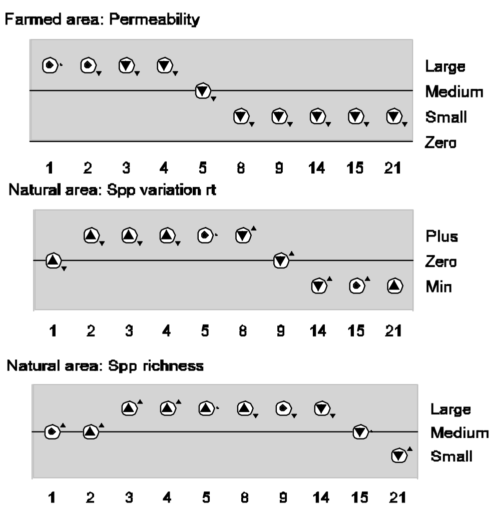

Figure 4. Value history diagrams of the quantities of permeability, species richness and species variation rate showing the effects of agriculture intensification.

The decline of productivity when ecosystem services collapse in intensive agriculture is shown in Figure 5. The *Productivity rate* is increasing until state 4. The opposite forces become equal in state 5, and the negative forces become stronger in state 8, causing the rate to decrease. *Total production* stabilizes in state 9 and decreases until the end of the simulation, when spatial heterogeneity, permeability, biodiversity, water quality and quantity, and production also have the lowest values.

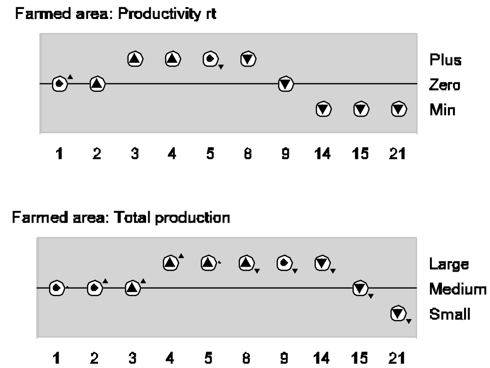

Figure 5. Value diagrams of the quantities showing the effects of agriculture intensification in the total production.

Non-intensive agriculture. In the initial scenario the rates of both processes, finance investment and agriculture intensification, are zero. As a consequence, the quantities that represent the main features of intensive agriculture have values zero too, as if they don't exist. *Spatial heterogeneity*, *Water quality* and *Water quantity* are also constant, at their maximum values. The other quantities have the same value as in the intensive agriculture simulation. The simulation produces one initial state and 6 states in total, being the causal model the same as the one shown in Figure 2. Water quality and quantity and spatial heterogeneity do not change during the simulation, and the biodiversity of both natural and farmed areas increase. Despite the low-input characteristics of this approach, total production increases and the environmental services are kept functioning. This pattern is known to happen empirically in sustainable agricultural systems (Perfecto and Vandermeer 2005).

Discussion and final remarks

There is a growing concern about the fact every day millions of people go to bed hungry. Apparently the dilemma is the following: shall we use what is left of natural land to produce food or to conserve biodiversity? From the point of view of the work described here, the question is conceptually wrong. There are alternative agricultural practices that can harbor high levels of biodiversity with satisfactory productivity (Vandermeer and Perfecto 2005). Also, agriculture intensification involves high ecological, social, cultural, public health and economic costs (Perfecto and Vandermeer 2008, Matson *et al.* 1997). The contribution brought by the model described here to the intensification *versus* conservation debate is to ground the simulation results on explicitly represented causal relations. The simulations showed the superiority of agro-ecological practices for both community (species) and ecosystems (environment services), keeping the productivity at a low cost.

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