How does agricultural intensification will affect bird's species inhabiting a savanna-forest mosaic? A qualitative modelling approach

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Abstract

Great part of the world´s biodiversity inhabits agrienvironment or natural patches embedded in a farmed matrix. Here, we present a qualitative model to compare impacts of two managements, intensive farming and traditional management, on bird community inhabiting a mosaic of Cerrado-forest landscape. We built qualitative reasoning model using Garp3 simulation engine. Three groups of species were considered based on their differential use of the forest-savanna mosaic: forest specialist, forest generalists and non forest. Our results suggest the intensive agriculture leads to the decline non-forest and forest specialist, while forest generalist might either decline or be kept stable. On the other hand, traditional management may lead to either a decline or maintenance of Non forest and the maintenance of both forest groups. The substitution of traditional management for intensive agriculture may negatively affect birds. Qualitative reasoning can indeed be used to predict behaviors of biological under different scenarios offering a framework for decision making.

1.1 General introduction

Nowadays there are two opposing forces on agriculture production. On the one hand, intensive farming management evolves high industrial inputs (fertilizer, mechanization and pesticides) and low farmland raised/cultivated biodiversity (monoculture). Non intensive land-use, on the other hand, characterizes low input farming practices such as cattle raised at native pasturelands in low stocking rates, subsistence farming, polyculture and agroforestry. Considering that great part of biodiversity worldwide inhabits agrienvironment or adjoining areas to farmlands, the understanding of how different farming practices affect biodiversity at landscape scale is keynote to biological conservation. Here we present a qualitative model comparing the impacts of two farming practices on bird community inhabiting a mosaic of savanna and forest in a naturally patchy landscape of Brazilian Cerrado. Qualitative reasoning is a technique used to build simulation model of systems to which allows reasoning with scarce, imprecise and low resolution datum. We choose this technique because understanding how different farming affect bird communities require comprehension of the species dispersal ability, territory size and sensitivity to disturb. These informations are found in a punctual, sparse and fuzzy manner, so that highly sensitive numerical models would not capture the systems structure because of the great variability and impreciseness of the available data.

1.2 Different farming practices and effects on birds

Agriculture Intensification began with the Green Revolution as a natural consequence of the expansion of the capitalist economy and is based on the replacement of agrobiodiversity (productive specialization) by croplands heavily dependent on the use of machinery, irrigation systems, fertilizers and pesticides [Brumbach and Flynn, 1980]. Despite that each intensive crop systems has its particular structure (e.g. single-species forestry stands are different from annual crop monocultures), great majority of them are based on the same basic principles: high input and output of energy and matter and low spatial temporal heterogeneity [Benton, 2003]. Impacts of agricultural intensification on biodiversity are widely recognized, and some authors have suggested that its one of most significant threat to biodiversity worldwide [Benton *et al.*, 2003]. Despite of this, most of the literature concerning impact of intensive farming practices focus on the impact of specific characteristics of intensive farming practices, such as pesticide and heterogeneity, few have assessed the overall impact agricultural intensification the agroenvironment (e.g. Green *et al.*, 2005). Non-intensive systems, in turn, represent wide range of low input cropping systems. These systems are very diversified and unique in their structure, so that, contrarily to the intensive systems, non intensive management are much depended on the local environmental and cultural characteristics. Indian management, subsistence farming, raising cattle at low density in native grasslands, extractivism, home-gardens, non-tillage farming and agroforestry systems are examples of non intensive practices. Concerning the impacts of these non intensive farming, they must be understood in their specificity, so that some intensive extractivists may cause significant impact on the harvested species [Oliveira, 2009], while rustic agroforestry systems may harbor high bird richness [Faria et al., 2006]. Classifying different managements (intensive or non intensive) on environmental impact gradient is keystone to blurry land-use decision at landscape scale. Aiming at assessing ecological impact, birds are particularly important because occurring in sufficient abundance and richness, enabling great amount of data; they can be use as bioindicator representing other groups and they play important ecosystems functions, such as plant dispersal, biological control, pollination.

We aim at comparing the impact of intensive agriculture and traditional management on birds inhabiting a forest-savanna mosaic on the Cerrado Ecoregion. The Cerrado (woodland savanna) is one of the largest savannas in the world and it is a naturally patchy landscape, harboring high levels of biodiversity, being considered a world conservation hotspot [Myers *et al*., 2000]. Because we assumed that both managements will happen the Cerrado matrix leaving forest areas, three groups of species were considered based on their differential use of the forest-savanna mosaic: Forest specialist that inhabits forest but may migrate through the matrix, Forest generalists that may feed, breed and migrate thought the matrix and Non forest species that inhabits exclusively the Cerrado matrix.

1.3 Qualitative Reasoning

Generally models on the ecological impact of farming rely on numerical and quantitative relationships [Balmford *et al*., 2005; Butler *et al*., 2007]. However, building numerical models is a difficult task as many ecosystems lack of the basic biological knowledge. Because gathering the detailed numerical data generally takes too long, and alarming biodiversity lost rates requires immediate actions, simple and predictive models are necessary [Butler *et al*., 2007; Benton, 2007].

We used Qualitative Reasoning models (see the special issue of *AI Magazine*, 24(4), 2003), which simulates systems to which there are imprecise, scarce and fuzzy quantitative data about [Salles and Bredeweg, 2006]. For comparing the impacts of different farming on bird communities of the Cerrado, we choose a modeling technique that could reason with the data available, which is in essence found in low resolutions with huge knowledge gaps.

Qualitative Reasoning has been successfully used to model ecological systems (see the special issue of *Ecological Informatics*, 4(5-6): 261-412, 2009) and can be implemented in the Garp3 workbench (www.garp3.org). In qualitative models, continuous properties of *entities* are modeled as *quantities*. Relations between quantities include causal dependencies of two types: *direct influences* (I+ and I-) and *qualitative proportionalities* (P+ and P-). Direct influences represent processes and are the initial cause of change in the system and qualitative proportionalities are the consequence of such changes. For example, I+(SV,R) reads as that the rate R is added to the derivative of the state variable SV after a certain period of time. On the other hand, P+(AV, SV) means that the derivative of the auxiliary variable AV will take the same value of the derivative of SV, that is, if SV is changing, then AV changes in the same direction. Combined, these primitives build up causal chains: R → SV → AV [Forbus, 1996].

Among of the simulation outputs, Garp3 produces a behavior graph, that includes: States, defined as specific situations the modeled system can be found, that are described by a set of specific values of quantity that occur together, reflecting a qualitatively unique behavior; State-graphs which are sets of states, and the possible transitions between those states which represent the behavior of a modeled system; Value history diagrams describe how quantity values change throughout a sequence of states [Bredeweg *et al*., 2009].

2 The model

2.1 Dividing Cerrado´s birds into groups

To understand the impact of land use intensification on Cerrado's birds, three functional groups (group of species that have share ecological characteristic and respond to changes in the environment in a similar way) were defined, which correspond to bird species sensitivity to disturbs [Stotz *et al*, 1996] and relative dependence of forest habitat [Silva, 1995]. These groups can be characterized as (A) forest specialists, (B) forest generalists and (C) non-forest. Specialists are forest dependent species [Silva, 1995] with medium to high sensibility to disturbs [Stotz *et al*., 1996]. Species from group 'A' were assumed to breed and feed exclusively in forests and use the matrix as a pass-through during dispersion or home range movements. These are often composed by understory passerines insectivores [Stratford and Stouffer, 1999], species that show mixed-flock behavior [Maldonado-Coelho and Marini, 2000] and ant followers [Faria and Rodrigues, 2009]. Group 'B' is formed by species that show semi-dependence on forest habitat [Silva, 1995] and low to medium disturb sensibility [Stotz *et al*., 1996]. These are often species that inhabit forests, but can use agricultural landscape as a part of their home range or breeding habitat [Tscharntke *et al*., 2008]. These forest generalist species often show great habitat and diet breadth with disproportionately greater richness of frugivores and nectarivores [Tscharntke *et al*., 2008;].

Finally, non forest species are species of group 'C' that occur independently form forest formations inhabiting non-forest physiognomies of the Cerrado, such as grasslands to savannas [Silva, 1995] having medium to low sensitivity [Stotz *et al*., 1996]. Species typical of habitats that are non cultivable, such as rocky out crops were excluded, as the model represents birds inhabiting landscape that could be subjected to agriculture.

2.2 Landscape description

The model assumes that the landscape was converted into two areas maintained under farming practices approaches according to different degrees of intensity, hereafter called “agriculture intensification”. Agriculture intensification is defined as the increase in farm inputs and/or output per cultivated area [Angelsen Kaimowitz, 2001], and consists in increasing machinery (e.g. trucks), use of industrial fertilizers and pesticides (herbicides and insecticides), irrigation systems, as well as increase in spatial-temporal homogenization (monoculture management) [Benton *et al.*, 2003]. It is also assumes that farming affects directly the matrix, so that matrix management doesn't influence forest loss. This is obviously an oversimplification, as is known that agriculture can increase [Angelsen and Kaimowitz, 2001; Balmford *et al.*, 2005] or decrease deforestation [Goulart *et al.*, 2009; Angelsen and Kaimowitz, 2001].

The model is used to compare responses of bird species to six different different scenarios, being one scenario by each species group in each of the two landscape management (intensive and traditional). In all the initial scenarios, Cerrado matrix is composed of a mixture of native woodlands and grasslands in which *Predation risk* is high, *Food resources* and *Nest abundance* are medium, *Horizontal heterogeneity* and *Vegetation complexity* is maximum and *Permeability to forest species* is large. In all initial scenarios *Species richness* of non forest, forest specialists and forest generalists are very high.

The model describes a hypothetical landscape composed by *Forest target patch* which is a small (<1 and >10 ha) and structurally disconnected (distanced by ≈ 1 km) forest patch and a *Forest species source*, which is larger (more than 20 ha) and more connected forest fragment, embedded in the Cerrado matrix. *Target forest patch* has *Forest specialist sp variation rate, Forest specialist richness, Forest generalist sp variation rate and Forest generalist richness*.

Migration may occur from Source to Target forest patch depending on the *Permeability to forest species* of the matrix. *Permeability to forest species* is defined in terms of physical and biological characteristics that facilitate or render the flux of propagules (fruits, seeds, larvae or individuals) through it [Perfecto and Vandermeer, 2010]. In the model, *Permeability to forest species* of Cerrado matrix should be equal or greater than value “medium” as a condition for Propagules *quantity* to cause influence (P+) on *Forest specialists variation rate* that inhabit Forest Target Patch. In the case of *Forest generalist spp richness*, *Propagules quantity* of Forest Sp Source will always affect positively *Forest generalist sp variation rate*. This was done under the assumption that forest birds travel relatively long distance of non-forest habitats in home-ranges and dispersal movements [Marini, 2010].

Concerning the Cerrado Matrix, it has *Vegetation complexity*, *Permeability to forest species*, *Predation risk, Nest site abundance, horizontal heterogeneity, Food resources, Non-forest bird richness, non-forest species variation rate, non-forest bird survival and fitness*. *Vegetation complexity* is considered here as vegetation layers that vary according to micro vertical habitat heterogeneity. The quantity *horizontal heterogeneity* is a measure of inter-farm plot diversity at a larger scale and it is basically the diversity of management types. *Non forest Survival and fitness* is negatively affected (P-) by *Predation risk* and positively affected (P+) by *Nest site abundance* and *Food resources,* and these last two variables are affected positively by *horizontal heterogeneity* and *Vegetation complexity*. *Non forest Survival and fitness* affect positively (P+) *Non forest generalist variation rate* (the amount of species that are added or subtracted of the community by a defined time) which thus affect positively (I+) *Non forest species richness*. The relationship between *Non forest Survival and fitness* evolve additionally a derivate inverse correspondence (dQ) that the derivate of both variables co-vary inversely. *Non forest species richness* affect negatively *Non-forest variation rate* via feedback loops that stabilize the systems. Figure 1 shows the causal model of the relationship that take place on the Cerrado Matrix.

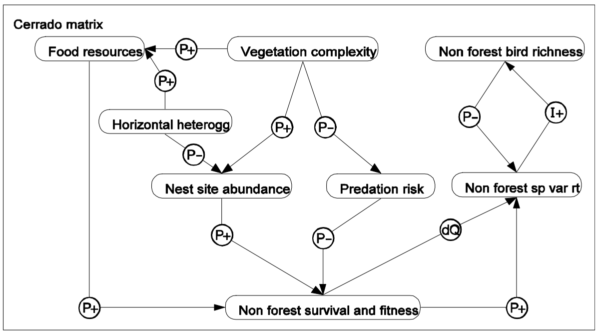

Figure 1: Causal model representing the relationships that take place on the Farmed Matrix

Feedbacks like this also appear on *Forest specialist* and *Forest generalist richness*. *Permeability to forest species* is positively affected by *Vegetation complexity* and negatively affected by *Predation risk.* Emigration was considered an external agent and it has *Migration rate*. The model also states that if *Nest site abundance* is greater than medium values, it affects positively *Forest generalist survival and fitness* because they can breed on the matrix in such situations.

We considered that *Horizontal heterogeneity* affects positively *Nest site abundance* at low *Horizontal heterogeneity* levels. On the other hand, if the level of heterogeneity trespass “medium” values, increasing of *Horizontal heterogeneity* will negatively affect *Nest site abundance*. This non linear relationship between landscape heterogeneity and bird species and is explained by the fact that, at low levels of heterogeneity, increase in habitat diversity correlates positively with richness. At high levels of heterogeneity, landscape functionality can be destroyed and patches will become too small to hold territories and home-ranges [Machado, 2000]. On the other hand, we assumed that food abundance is always affected positively by *Horizontal heterogeneity* and *Vegetation complexity* as it has been found for arthropod species as well as fruit availability. Concerning Forest Target Patch, *Floated/riparian forest* affects positively survival and fitness of forest specialists and generalist groups. In the case of the Cerrado, *Floated/riparian forest* is basically the presence of floated areas which have been highly related to forest bird richness [Marini, 2001].

2.3 Intensive agriculture

Intensive farming practices are treated here as an entity as is a sum of process that usually acts together in a discrete space and time. *Agriculture intensification rate*, defined here as the degree in which intensive practices are added to the landscape in a certain time, influences (I+) *Mechanization, Irrigation, Pesticide* and *Monoculture management*. All these quantities affect negatively *Agriculture intensification rate* via feed-back loops that stabilizes the systems. All these features require heavy private or public investment of financial resources, guaranteed by an external Investor agents (e.g World Bank, Rockfeler Foundation [Brumbach and Flyn, 1980]) Therefore, the model considers that *Financial investment rate* from an Investor agent affects (I+) *Financial resources* which thus affect (P+) *Agriculture intensification rate*. Intensive agriculture acts indirectly by reducing *Vegetation complexity* (active removal of non crop plants) through *Monoculture management*, increasing *Mechanization level,* affecting negatively *Nest site abundance* and by increasing *Pesticide* which impact *Non forest survival and fitness.* Relationships between Agriculture Intensification and Cerrado matrix entity is shown in Figure 2. Note that irrigation is not shown because it is assumed not to influence Cerrado matrix.

Figure 3 shows the causal model representing the relationship among Investor agent, Intensive farming, Cerrado matrix, Target forest patch, Emigration agent and Forest species source. In this figure, the influence of Pesticide impact on forest species is not active because it´s values value is lower than medium. *Irrigation* is assumed to affect *Floated/riparian forest* negatively because of drainage of riparian or floated forest. *Pesticide* can also affect (P-) forest generalist and specialist, *Species survival and fitness* if *Pesticide* is greater than medium values.

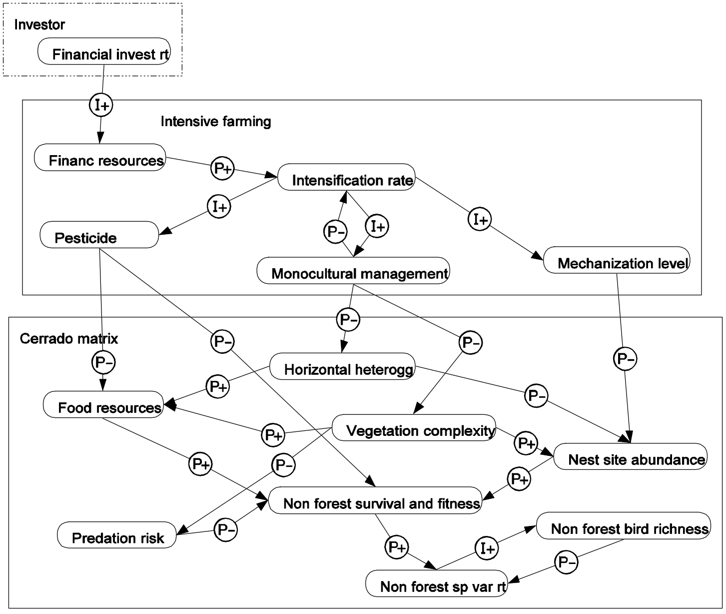

Figure 2: Causal model of the relationships among Investor agent, Intensive agriculture and Cerrado matrix

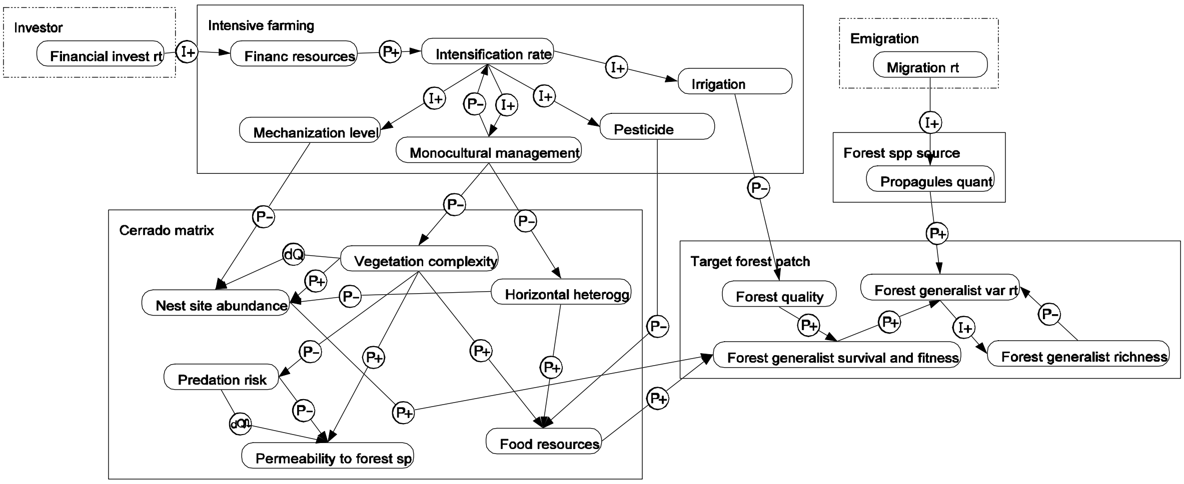

Figure 3: Causal model of the relationships among Investor agent, Intensive agriculture, Cerrado matrix Emigration agent and Forest species source

2.4 Traditional management

We modeled non-intensive traditional practices of the Cerrado of the *Sertanejo* and or *Geraizero*'s managements (both *Sertão* and *Gerais* are Portuguese words that refers to woodland savanna and grasslands landscapes typical of the Brazilian Cerrado). In the model, we define the traditional management practices as: *Smallholder agriculture*, which is subsistence mixed farming (e.g. cassava, beans, corn, pumpkins, avocado, bananas, peppers among others [Bustamante, *et al.*); (b) *Hunting*, which is basically the use of bush-meat of large birds [Sick, 1997]; *Annual fire,* which is how these traditional cultures manage native pasturelands. Fire is used to stimulate plant re-growth, making the vegetation more palatable; *Traditional cattle rising* is characterized by livestock rose at low density (low stoking rates) over large tracks of native grasslands. (c) *Plant extractivism,* is characterized by non timber products, such as fruit gathering [Oliveira, 2009] and medicinal plants [Rodrigues and Carvalho, 2001] as well as timber products, like coal and construction [Bourlegat and Costa, 2009].

All these quantities are affected positively *Traditional management rate,* defined here as the amount of traditional practices that a landscape is being subject by a certain space of time. In order to stabilize the system, all these variables affect *Traditional management* rt via feed back loops. *Traditional management* is thus affect positively by *Ethoecology mantainance.* We use Toledo's definition on Ethnoecology, that is the association of the *corpus* (repertory of symbols, perceptions and concepts about nature) and *praxis* (set of actions that evolve material appropriation of nature) [Toledo, 1992]. *Ethnoecology mantainance* is positively affected by *Folk knowledge cons rate* that comes from *Folk knowledge* agent. The abbreviation "cons" refers to construction and/or conservation in an effort to not consider traditional societies as "living museums". The relationships among Folk knowledge agent, Traditional management and Cerrado matrix entities are represented in the causal model of figure 4. Note that in this state, neither *Plant extractivism* nor *Traditional cattle raising* are not affecting *Vegetation complexity* because both variables are assuming values bellow medium.

3 Results

3.1 Simulation on the effect of intensive farming on the three functional groups

Causal chain starts by investment of external agents increasing *financial resources,* allowing intensification take place (via positive *agriculture intensification rate*). Intensification affects *Nest abundance* by means *Mechanization level* increase, reducing *Horizontal heterogeneity*, and *vegetation complexity*. *Food resources* are directly affected (P-) by pesticide and indirectly by decreasing *Vegetation complexity* and *Horizontal heterogeneity*. Decrease in *Vegetation complexity* increases *Predation risk*, which thus decreases *Non forest survival and fitness* and consequently affects negatively Non-forest *species variation rate*. Because of this, *Non forest species richness* declines from high to very low values.

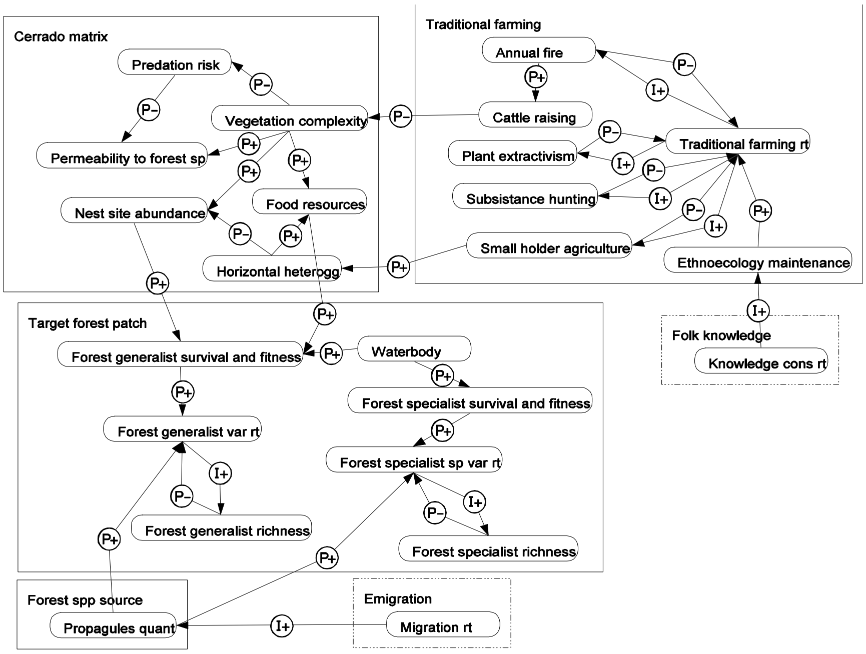

Figure 4: Causal model produced by the simulation of the scenario in which traditional management affects Cerrado Matrix and Target Patch

The value history of the Non forest, Forest generalist and Forest specialist richness under the agriculture insensitive scenario are showed on figure 5.

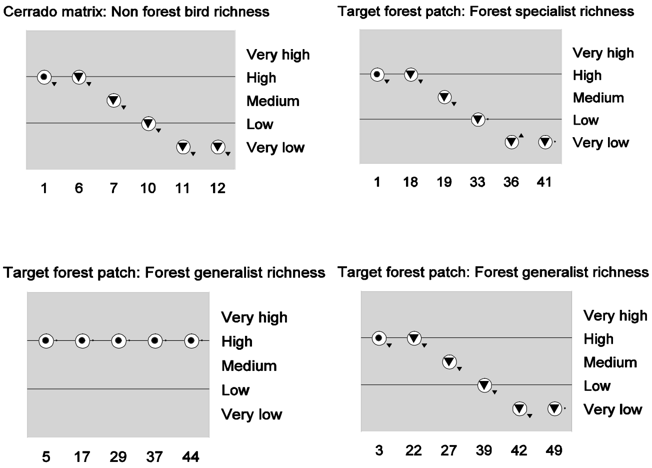

Figure 5: Value history of the *Non forest, Forest generalist* and *Forest specialist richness* under the agriculture insensitive scenario. Note that there are two possible behavior paths for generalists.

3.2 Simulation on the effect of Traditional management on the three bird groups

Causal chain starts with Folk knowledge agent enhancing *Ethnoecological maintenance,* which increases *Traditional rate.* All traditional practices (*Annual fire, Traditional cattle rising, Small-holder agriculture, Plant extractivism* and *Subsistance hunting)* increase affecting Cerrado matrix quantities, such as *Vegetation complexity*). Because of the contradictory effects of this management on *Non-forest variation rate*, such as increasing *Food abundance* and *Predation risk, Non forest sp richness* may be kept at high values or decline to very low.

Concerning forest generalist, *Subsistence hunting* affect negatively (P-) *Forest generalist survival and fitness* and thus decreasing *Forest generalist sp variation rate.* On the other hand, *Propagules quantities* form the Species source increases *Forest generalist sp variation rate* increasing of the *Forest generalist sp richness*. Because of the multiple forces acting positively and negatively on *Forest generalist sp variation rt* and because many of these forces have a “if” condition based on the quantities values, *Forest generalist species richness* is kept at high values in all possible paths. The state-graph of the forest generalist scenario is shown in figure 6. This represents all the possible behavioral paths which simulation can have, so that there are three initial states (1, 2 and 3) and three final states (18, 16 and 17).

Value histories for simulation of the scenario representing the impact of non-intensive practices on forest species is shown in figure 7.

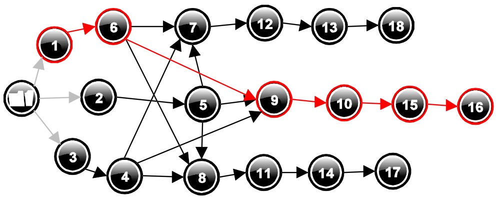

Figure 6: State-graph of the simulation of the scenario in which Traditional management affect forest generalist.

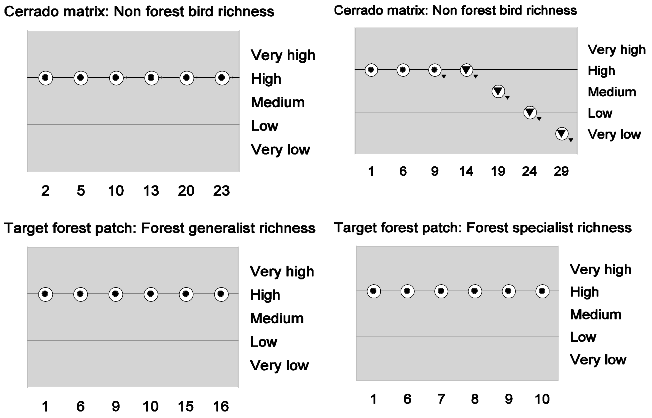

Figure 7: Value history of the *Non forest, Forest generalist* and *Forest specialist richness* under the Traditional management scenario. Note that there are two possible behavior paths for non forest.

4 Discussion

Intensive agriculture leads to the decline non-forest and forest specialist, while forest generalist might decline or be kept stable. On the other hand, Traditional management of the Cerrado is predicted to lead to a decline or maintenance of non forest and the maintenance of both forest groups. Intensive agriculture management may affect negatively bird species by direct affect of pesticide and machinery use or indirectly by reducing spatial heterogeneity. Heterogeneity loss leads to increase of *Predation risk* on the matrix. As stated by Benton and colleagues [2003]: Heterogeneity is the key for farmland biodiversity! Our results, not only corroborates these findings but also expand it showing that heterogeneity of the matrix may play major role in its permeability directly and indirectly (by affecting predation). Other than at community scale heterogeneity erosion caused by farm intensification must also be seem from ecosystems to genetic scale [Silva, 2011].

Intensification can impact forest birds non-trivially, such as the impact of *Irrigation* on *Floated/riparian forest*. In the Cerrado ecoregion, flooded areas inside forests are more important of bird richness than forest fragment size [Marini, 2001].

Main impact of traditional management is hunting [Silva and Tabarelli, 2000], fire [Sendoda, 2009] and cattle raising [Taylor, 1986]. Hunting is a considerable threats to tropical forests [Peres, 2001] but, because only large-body birds, it should not lead to a decline of the whole avian community, but mainly large frugivores [Silva and Tabarelli, 2000]. Despite of this, hunting impact should not be neglected and environmental projects should be use decrease hunting pressure.

In the case of fire, although most of the Cerrado species seem to be adapted to fire [Cavalcanti and Alves, 1997; Machado, 2000], despite of this long-term effect on community could be detrimental [Sendonda, 2009]. In the case of both cattle rising and fire, the decrease in livestock rates and reduction in the fire regime should attenuate the impact of traditional management. Other impacts, such as of the plant extractivism in plant community [Oliveira, 2009] and consequently on birds at long term should be considered.

Concerning Intensive agriculture, it's unlikely that it could be done with less impact, as it depends deeply on the monoculture management, pesticides, and machinery and so on. Agriculture intensification of the savanna-forest landscapes should lead to a loss of bird species, so that future richness of those landscapes might be only a subset of today's species. As forest generalist are not directed affected at the same degree as non forest and are less sensitive than forest dependent, it is likely that future community is more restricted to those forest generalists.

Finally, it is not likely that the model has capture all relationships regarding the system in study (no model could). Building qualitative models requires excluding relationships that may exists in certain specific circumstances or at other spatiotemporal scale but, may not be relevant for the systems overall dynamics. Obviously, deciding what is relevant and what is not is far from trivial and there is always a risk oversimplification. For instance, in the case of the Cerrado, high atmospheric nitrogen, in part caused by agricultural intensification at global scale, can alter plant community diversity [Jacobson *et al*., 2010]. This could have negative effects to bird species, but was not included on the model. There is a possibility that fertilizer could affect bird species by increasing nitrogen on plants and thus increasing herbivore abundance, which could affect birds positively because many feed on these insects. Because there is no empirical evidence that this could affect communities at landscape scale, it was also not included in the model.

5 Conclusion

Both farming practices had negative impact on bird community of the Cerrado. This shows that numerous and large areas should be conserved without neither land-use management (e.g. parks). On the other hand the two farming practices were very different in their impacts on birds. Intensive agriculture led to the decline non-forest because it acted directly on the matrix leading to instabilities of forest species. This happens because intensive farming affects negatively supplementation (behavior of using the matrix as an extra habitat for feeding and defending territory) and migration through the matrix (because it decreases *Permeability to forest sp*). Traditional management destabilized non forest birds, but had no effect on both forest groups. Hence, concerning bird conservation, Traditional management should be preferable to Intensive farming and decision making about land-use policy should consider these results.

Great part of the world´s biodiversity inhabits agrienvironment or natural patches embedded in a farmed matrix. Therefore, our model could be applied to other patchy landscapes and results should be understood beyond the Cerrado ecoregion. This is possible if basic knowledge, regarding matrix use by species e and management effect on matrix, is available, even if found at low resolution.

Qualitative models has shown to be a powerful tool for building ecological models and modelers should be encouraged to use this technique to explore this type of modeling in their predictive potentialities. Here, we present an example of how qualitative reasoning can indeed be used to predict behaviors of biological systems under different scenarios, offering a causal framework for decision making using sparse and fuzzy data.

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