How agricultural matrix intensification may affect forest understory birds? A qualitative model on stochasticity and immigration

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Abstract

Understanding how different approaches to matrix management affect organisms that inhabit natural patches is crucial for biological conservation. Considering that most of the tropical area is composed by agricultural land and that most of this land is either intensified or on the way to be, a relevant question is: how may agricultural intensification of the landscape matrix of an Atlantic Forest area (a biodiversity hotspot) affect the dynamic of understory endemic passerines of different species populations? This paper describes a qualitative model based on the Qualitative Process Theory, which takes a compositional modeling approach and was implemented in Garp3. The model describes a landscape composed by an extinction-resistant source patch and one target patch where stochastic events occur. If permeability of the matrix exceeds a given species-specific threshold, propagules from coming from the source reach the target patch. Agriculture intensification affects the matrix spatial structure and reduces permeability to forest birds, thus reducing rescue effect. Our results suggest that, if agriculture intensification continues to threat the Atlantic Forest biome, populations that exists in the small forest patches (which is the case of most forest remnants) will be highly susceptible to local extinctions with no further re-colonization.

1.1 General Introduction

Studies concerning the ecological impact of fragmentation have long been stressing the importance of habitat patch characteristics [Perfecto and Vandermeer, 2010]. Despite of this, the matrix in which "natural" forest patches are embedded seems to play an important role in rendering or facilitating the rescue effect (arrival of individuals from another patches affecting positively the population which is suffering from demographic and genetic problems associated with low population numbers [Brown and Kodric-Brown, 1977], having great contribution to species occurrence [Perfect and Vandermeer, 2010]. Matrix is described as major component of landscape and nowadays it is often composed by anthropic agroenvironment (Balmford et al., 2005]. This is a good reason why conservationist projects should be aware of how different agricultural management practices affect biodiversity at the landscape scale. Considering that most of this agroenvironment is either intensified [Benton et al., 2003] or in the way to, the understanding of how land-use intensification will affect species inhabiting patches within this agricultural matrix is a keynote condition to biological conservation. Here we developed a qualitative model, using Garp3 workbench as the simulation engine, to theoretically predict how agricultural matrix intensification will affect five different bird species, with different sensitivities and different dispersal abilities, inhabiting forest patches in an Atlantic Forest landscape.

1.2 Intensification of the agriculture matrix

"Agriculture intensification" is a generic term used to describe changes in farming practices adopted after the Green Revolution switching traditional agricultural practices by modern agriculture, heavily dependent upon industrial inputs. Intensification includes the use of pesticides, irrigation systems, machinery, increase in farm size and productive specialization (loss of cultivated diversity from species to genetic level). Impacts of agricultural intensification on biodiversity are widely recognized and some authors suggest that it is one of most threatening factors to species worldwide [Benton et al., 2003].

Most of the studies on biological impacts of agriculture intensification has focus on specific issues (loss of spatiotemporal heterogeneity and pesticide impact) related to how intensive management affect biodiversity of farmed areas [Benton et al., 2003]. Yet, theoretical considerations point to a deep impact of intensification of the agricultural matrix on species inhabiting patches embedded in this matrix and so farming practices must be understood beyond farm level to landscape scale (Perfecto and Vandermeer, 2010). However, empirical evidences about such impact are not available. When it comes to how intensification might affect matrix permeability to birds and thus to (re)colonization of empty patchy areas, there is, to the best of our knowledge, no studie available in the literature. This is due the technical difficulties in measuring vertebrate dispersal [Holyoak et al., 2008]. In the case of the Neotropical region, this is even more serious, as basic movement ecology is scarce and contradictory [Marini, 2010]. Hence, in the System Dynamic´s jargoon, many variables in ecology can be considered "soft" because they are difficult to measure [definition after Coyle, 2000]. Therefore it presents great quantification risk [Coyle, 2000] because measuring techniques, although aiming highest precision, are greatly affected by environmental noise and measuring/analyses bias. This fact suggests that grain of analyses of ecological systems are coarser than ecologists think, therefore new modelling techniques in ecology that deal with low resolution data, and that deals better with causality are necessary.

1.3 Endemic understory birds of Atlantic Forest: threatened guild of a threatened Biome

The Atlantic Forest biome encompasses the southeastern part of Brazil and parts of Paraguay and Argentina and is considered a world conservation hotspot [Myers et al., 2000]. Deforestation destroyed large part of the forest, so that only 7 % of the original wood-cover remains [Ribeiro et al., 2009]. Most of forest remnants are less than 50 ha [Ribeiro et al., 2009], which causes high level of extinctions on avian species, as expected for this forest size magnitude [Ribon et al., 2003]. Considering that local extinctions can be balanced by colonization from subpopulations of other patches, landscape connectivity (capacity of landscapes to permit biological flux) is a key factor to biodiversity maintenance [Taylor et al., 1993]. This is particularly true for Atlantic Forest birds (Uezu et al., 2005).

Concerning birds from Atlantic Forest, passerines that inhabit the forest understory seem to be especially negatively affected by fragmentation [Stratford and Stouffer 1999]. The cause of this sensitivity lies on the low dispersal ability and their reluctance to cross open habitats. This constrains the immigration on small patches, making populations prone to local extinction without no further recolonization (Şekercioğlu et al., 2002).

We choose five bird species of endemic passerines of the Atlantic Forest: *Conopophaga lineata* (Rufous Gnateater), *Chiroxiphia caudata* (Blue manakin), *Pyriglena leucoptera* (White-shoulder Fire-eye), *Sclerurus scansor* (Rufous-breasted Leaftosser), *Xyphorynchus fuscus* (Lesser Woodcreeper). Except for *C. caudata*, which is understory/medium strata frugivore, all other are understory insectivores. These species were chosen because they share similarities (phylogenetic proximity and small size), as well as differential dispersal ability, natural density, home range and territory sizes. This permits building a single model (although with different initial scenarios) considering that the main forces driving population changes (such as colonization and extinction) could affect all these species, as well as compare how different ecological features (dispersal ability and diet) could affect population dynamics of different species. Put in another words, they are similar enough to be encompassed by the same model but they are different enough enabling to understand how different ecological characteristics will affect the response of agriculture intensification of the matrix.

Finally, these are one of the most well known species in the Atlantic Forest, so that it would be impossible to build this type of models for other species given the actual ornithological data available.

1.4 Stochastic variations and immigration

As well as other groups, birds show great demographic variation caused by deterministic and stochastic factors [Saether et al., 2002]. These factors could be caused by a great variety of human associated factors, such as habitat loss, fragmentation, hunting, and introduction of invasive species [Primack and Rodrigues, 2001]. Also non-human processes, such as lighting fire, storms, flood, predation, disease may also affect population dynamics. Other than these environmental and human factors, intrinsic dynamics of the populations may also lead to variations in population numbers. Demographic stochasticity is caused by chance realizations of individual probabilities of death and reproduction in a finite population. Because independent individual events tend to average out in large population, demographic, as well as environmental stochasticity, is most important in small populations [Lande, 1993]. Despite of this, extinction caused by stochasticity could be balanced by immigration by individuals coming from other areas, characterizing the rescue effect [Brown and Brown-Kodric, 1977]. Hence, connectivity of landscapes (ability to permit biological flux) is a vital element for (re)colonization, and thus biological conservation of species in fragmented landscapes [Taylor et al., 1993]

Concerning colonization, certain human activities such as roads construction. [Develey and Stouffer, 2001], pasture and monoculture forestry [Machado and Lamas, 1996] may hamper forest movements, and thus colonization. As a general rule, landscapes subjected to intensive land-use management, offer low permeability to species flux [Perfecto and Vandermeer, 2010].

1.5 What is and why qualitative reasoning

In order to simulate how intensification of the agricultural matrix could affect forest birds given their sensitivity to stochasticity variations and immigration we used a modeling technique that is appropriated with the data available for the species studied. Therefore we used the Qualitative Reasoning models an area of Artificial Intelligence which creates representations for continuous aspects of the world, such as space and time, quantities, which support reasoning with very little information; see the special issue of *AI Magazine*, 24(4). Theory on Qualitative Reasoning has resulted in a set of dependencies that capture cause-effect relationships between quantities. These dependencies are defined such that, on the one hand they present conceptual notions that closely match human reasoning, while on the other hand they are grounded in mathematical formalisms allowing automated computation [Bredweg et al., 2009].

According to Forbus' Qualitative Process Theory, the behavior of a given system is determined by active processes. They are seen as mechanisms that affect objects' properties, the effects of which propagate to other compartments of the system over time and space. Therefore, the consequences of processes being active may be explained by means of causal relations involving relevant quantities. The software Garp3 workbench (www.garp3.org) simulates systems using the Qualitative Process Theory [Bredeweg et al., 2009]. Given that ecological systems have high complexity levels, low information precision and low replicability, therefore qualitative reasoning have high potential to solve problems in ecology and conservation [Salles and Bredeweg, 2006; see also special issue of *Ecological Informatics*, 4(5-6): 261-412, 2009]. In the case of the species studied, despite of them being one of the most studied species in the Atlantic Forest, many basic aspects their biology still unavailable, so that the scarce information we have about then is inconclusive, contradictory and biased by the data assessment method.

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. 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. The effects of processes are propagated via proportionalities to the rest of the system. For example, 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. Simulations start with initial scenarios that describe the structure of the system and the initial values of some quantities. A space state containing all the possible outcomes of the initial situation is then produced. For each possible state Garp3 automatically generates a *causal model* that shows how causality flows in the system during that time period. All figures in this paper were produced by Garp3

Qualitative reasoning models engines are also designed to exploit causal ambiguities so that the output represents all possible solutions for these ambiguities. For instance, if a variable is receiving two contradictories influences (let say P- and P+), the outcome will be the increase of the target variable in one behavior path, decrease in another or even be kept stable as a third possibility. Hence, this multiple outputs, as opposed to one typical traditional numerical modeling techniques, enhance systems understanding.

2 Objective of the model

We aim at answering the following question: How agricultural intensification of the landscape matrix of an Atlantic Forest region may affect the dynamic of populations of five understory endemic passerines inhabiting small forest patches? More specifically, we built a qualitative model to predict the impact of agricultural matrix intensification on forest species, considering they have different dispersal ability, they use the matrix differently and they have different sensibility to stochastic events that takes place on the forest patch they inhabit. We also aim at comparing our results with other models in the specialized literature.

3 The model

Landscape description

We describe a landscape in which "Source" is a large forest track and "Target" is a small adjoining forest patch with the same habitat quality. Because of its size (<100ha), the Source is assumed to be extinction resistant, as low bird extinction rates occur in patches with this magnitude size in Atlantic Forest [Ribon et al., 2003].

The target patch is a small (from 10 to 20 ha) Atlantic Forest remnants of secondary at advanced stage. Both forest patches are embedded in an agroenvironment, the farmed matrix; and inter-patch distance is between 500m to 1km.

Matrix is composed of non-intensive agricultural systems like agroforestry and home gardens. Agroforestry systems and polycultures are known to have high tree density and vegetation complexity [Moguel and Toledo, 1999]. Contrarily, pastures and annual monocultures have low vertical complexity and low tree diversity and richness, which characterize intensive farming practices.

Model description

The model has nine entities: Agricultural intensification, Agricultural matrix, Species source, Target patch, *Sclerurus scansor*, *Pyriglena leucoptera*, *Conopophaga lineata, Chiroxiphia caudata*, *Xiphorhynchus fuscus.* Two external agents are modeled: Emigration and Stochastic events. Entities and agents are associated to quantities. Matrix has quantities *structural permeability*, *light incidence*, *Heterogeneity among farm-plots*, *Insect abundance*, *Tree richness/diversity*, *Fruit availability*, *Pesticide*. Species entities have quantities *sub-population numbers* and *sub-population variation rate*. Species source has *propagules quantity*; Emigration has *migration rate* and Stochastic events entity has *stochastic event*. *Structural permeability* captures the matrix structure in rendering or facilitating the flux of propagules through it, so different species will respond differently to it. For example, *C. caudata* is a very vagile species, so that propagules from source will always reach the target patch, no matter of the structural permeability value. Differently *S. scansor* was considered here as the less vagile species, so that the *Structural permeability* threshold beyond

which the increase of *Structural permeability* affects positively subpopulation variation rate. The other species are considered to have intermediate response (structural permeability threshold equal to medium value). How migration is affected by matrix permeability is represented in Table 1
The model assumes that demographical and environmental stochasticity occurs in the target patch a variable with exogenous random behavior that goes from zero to maximum, so that, for less sensitive species (*C. caudata, P. leucoptera,*

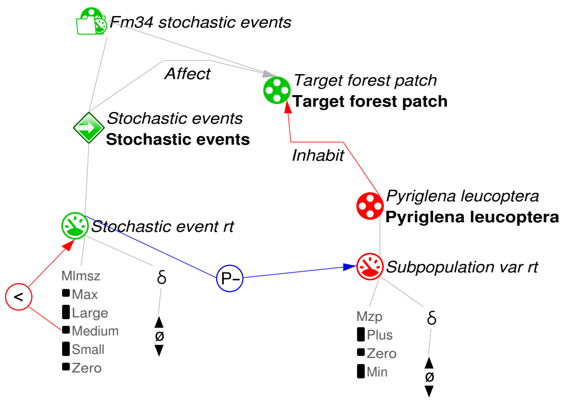

Figure 1: Model fragment representing that is stochastic events is greater or equal to medium, stochastic events affect negatively (I-) subpopulation variation rate of *P. leucoptera* in the Target patch, if stochastic event is greater than medium.

C. lineata), if *stochastic events* are greater than value medium, it affects negatively *Sub-population variation rate*. An example of the affect of *Stochastic events* is shown in figure 1. For moderate sensitive species (*Xiphorhynchus fuscus*), negative influence of stochastic events is active if its value is greater or equal to medium. Finally, *S. scansor*, a very sensitive species, is always negatively affected by stochastic events, no matter the values assumed by this quantity. This differential sensibility to stochastic negative events was assumed considering that the low density typical of *S. scansor* could enhance higher susceptibility to demographic stochasticity (e.g. Allee effect, which is the fact that the population is too small so that individuals tend to have low reproduction rates because low density decrease mating encounters).

3 Simulations

Effects of intensification and non intensification on the Farmed matrix

Figure 2 represents the causal model created by Garp3 in the first state of the simulation of the initial scenario in which Agriculture Intensification affects farmed matrix characteristics. In the model, *Agriculture intensification rate* of Agriculture Intensification, affects matrix influencing negatively *Vertical Complexity*, *Tree density and richness* and *Heterogeneity among farm-plots* and influencing positively *Pesticide*. There is a feedback (used to stabilize the system) between *Heterogeneity among farm-plots* and *Agriculture intensification rate* because heterogeneity is the main characteristic of intensified systems [Benton et al., 2003].

Contrarily, in the scenario in which non intensive practices are kept upon Farmed matrix, *Heterogeneity among farm-plots, Tree density and richness* are kept at maximum and *Pesticides* is kept at zero values. Consequently, in the non intensive scenario, *Structural permeability* is kept at maximum values.

Effects of the intensification of the agricultural matrix on birds inhabiting forest patches

Agricultural intensification affected species differently. For species that feed on the matrix (*C. caudata* and *P. leucoptera*) the decrease of *Insect abundance* and *Fruit availability* has negative influences (P-) on species *Subpopulation variation rates*. For the other species that use the matrix as a conduit, the loss of *Structural permeability* affected recolonization. In many behavioral paths, cyclic behavior were found. Figure 3 shows some of the possible behavior paths created by the simulations of the scenarios in which intensification occurs on the farmed matrix. In this case, *C. lineata* suffers extinction (subpopulation is zero) and recolonization because even though *Stochastic events* is kept at maximum, the species high dispersal abilty enable the propagules from the Source to reach Target forest. This happens even when there is a decrease of *Structural permeability*. *P. leucoptera* subpopulation numbers is kept at maximum values because, in this behavioral path, *Stochastic events* is lower or equal to medium, condition in which, *Stochastic events* doesn't affect

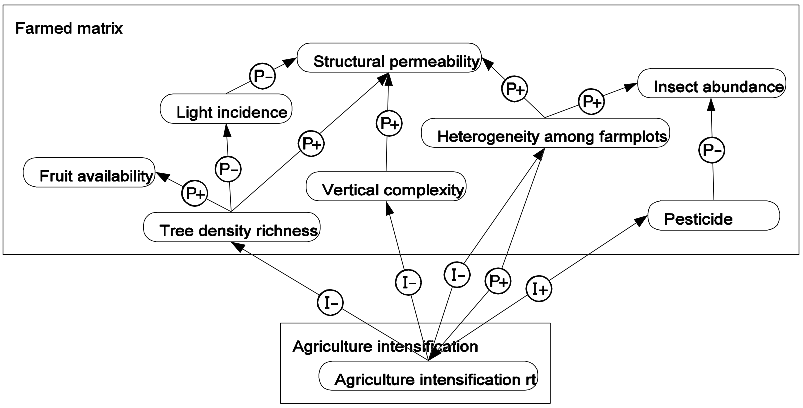

Figure 2: Causal model created in the first state during a simulation starting with the scenario "Agriculture intensification acts upon farmed matrix".

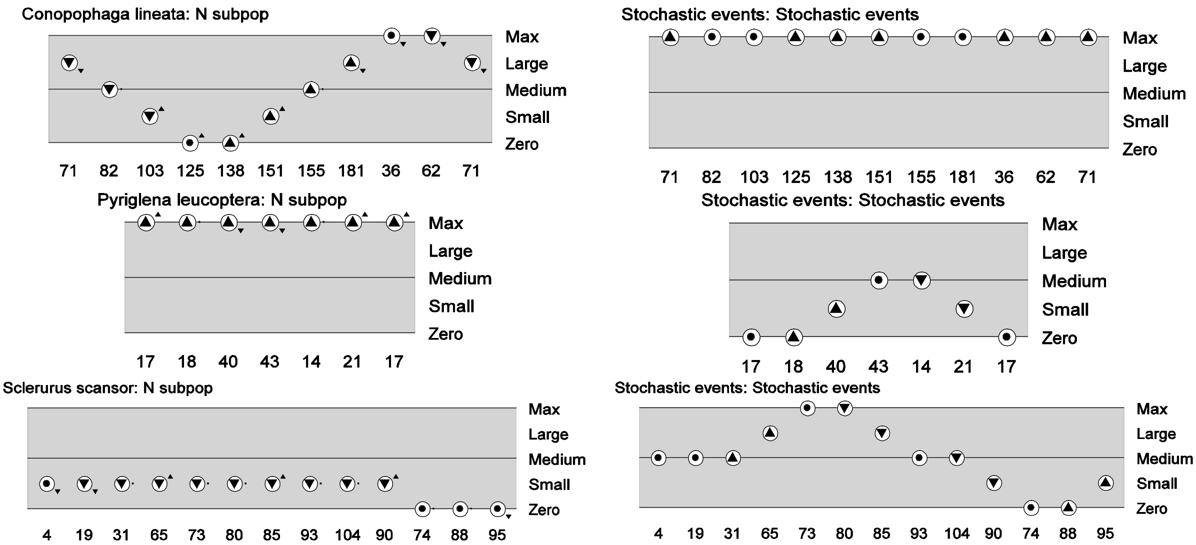

Figure 3: Some possible value history of Subpopulation and Stochastic events created by the simulation of the scenario in which agriculture intensification affects farmed matrix.

subpopulation. Finally *S. scansor* suffered extinction in the behavior path shown in figure 3 because immigration is not possible, given the decrease in *Structural permeability*. Figure 4 shows the value history of some of the possible behavioral paths produced by the simulation of the scenario in which non-intensive practices are kept. In this case, the sub population of *C. lineata* is stabilize at maximum, because high colonization counterbalances the negative effects of *Stochastic events* as a consequence of keeping *Structural permeability* at maximum values. *X. fuscus* suffers extinction and recolonization and *S. scansor* subpopulation is kept at maximum in both showing cyclic behavior.

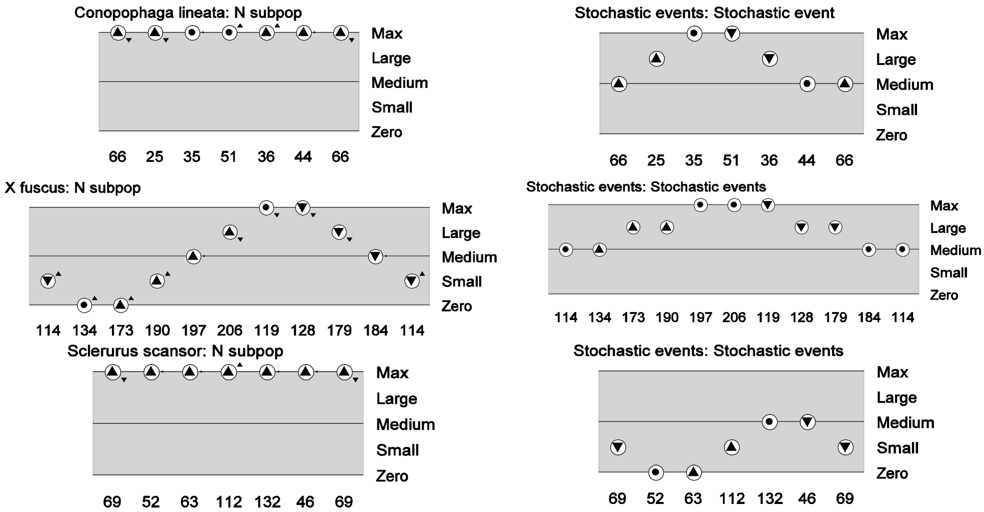

Figure 4: Some possible value history of Subpopulation and Stochastic events created by the simulation of the scenario in which agriculture non intensive practices are kept

3 Discussion

Resuming model outputs

Table 1 represents the general trends of the results of how different species respond to intensive and non-intensive management of the matrix.

C. caudata suffered little effect of agriculture intensification because of the high dispersal ability [Marini, 2001] and its low sensibility to disturbs [Stotz et al., 1996]. Still, agriculture intensification may lead to the instability of *C. caudata* populations, while in the non-intensive scenarios, all behavior paths showed stabilization of *N Subpopulation* at medium values. The fact that *C. caudata* feeds on the matrix may enhance some (although little) sensibility to intensification of the matrix.

P. leucoptera was also little affected by intensification so that in the intensive scenario, subpopulation stabilized in small values, other than the two possible behavior paths in the non-intensive. These results suggest that intensification could reduce subpopulation numbers of *P. leucoptera*, but without offering extra extinction risk. This species also may feeds on the matrix, so that intensification could reduce food availability for the population. The only species that was not affected by agriculture intensification (intensive and non intensive scenarios showed the same results) was *C.lineata*. This happened because this species is not very sensitive [Stotz et al., 1996]. Still, our results are conservative, because it is very probable that this species uses the matrix for feeding, but, as no records are known for this interpretation, we opted not to include such relationship in the model. *Xiphorhynchus fuscus* was deeply affected by intensification so that population suffered extinction and stabilization in small values in the intensive scenario. On the other hand, the worse possibility in the non intensified scenario the population would be stabilization in small values.

Finally, *Sclerurus scansor* was also profoundly affected by intensification, so that the only possibility is that subpopulation go extinct or stabilize at small values. For this species, extinction also happen on the non intensive scenario, but this was only one possibility, so that stabilization at various levels is also possible in other behavior paths.

Concerning model´s validation, it is very important to know if the model meets the performance requirements [Rykiel, 1996]. Mostly, ecological models using QR are validated using expertise knowledge (e.g. Zitek et al., 2009) or comparing it with quantitative data [Araujo, 2009]. Yet, the present model was not validated by any of those methods, but we intend to use expertise knowledge (the presentation on this congress is a part of this validation). Concerning numerical validation, in this case, it is not possible to be done because all the data available in the literature was used in the model´s input. Therefore using these data to validate output would generate an unwanted bias.

Finally, we are aware that the models doesn´t not add any significant contribution to RQ in the way that it doesn´t innovate the technique. On the other hand, we are positive that the present model brings a new approach for ecological modeling using RQ. The explanation for this lies in the fact that most of the ecological literature using qualitative models, explore models in their explanatory abilities, rather than in the predictive ability (e.g. Dynnalearn Project).

The importance of using RQ for scientific communication and education is unquestionable, despite of this, very few of these models have addressed specific question of environmental management, such as the present. For instance, Salles and Bredeweg (2006) developed predictive models on populations and communities. Their results reveal the potential of RQ for addressing ecological questions, but they do not apply to a spatially explicit situation aiming to address a practical conservation problem, such as the present model does. If qualitative reasoning is to be a wide accepted method in ecology and conservation, it must address the need for predictive models using low resolution data.

4 Final remarks

Here we developed a qualitative model to understand and predict the impact of agricultural matrix intensification on the persistence of five understory birds endemic to the Atlantic Forest. The model shows that intensification may cause deep negative effect on populations of the more sensitive species (*X. fuscus* and *S. scansor*) hampering rescue effect and thus re-colonization. In the case of the medium-to-low sensitive species, effects can be low and restricted to species that uses the matrix for feeding (*C. caudata* and *P. leucoptera*). Finally, species that are not much sensitive, have high dispersal abilities and don't use the matrix other than moving through it during dispersal (e.g. *C. lineata*), may be less affected by intensification.

Table 1: General trends of the subpopulation numbers of the different species in the target patch, under intensive and non intensive scenarios.

Species	**Intensive**	**Non intensive**
Chiroxiphia caudata	Extinction/Re-colonization Stabilize in max	Stabilize on medium
Conopophaga lineata	Extinction Extinction/Re-colonization Stabilize in max Stabilize at small	Extinction Extinction/Re-colonization Stabilize at small Stabilize at max
Pyriglena leucoptera	Extinction/Re-colonization Stabilize at max Stabilize at small(no cycle)	Extinction-colonization Stabilize at max
Xyphorynchus fuscus	Extinction Stabilize at small	End in small (no cycle) Stabilize at max Stabilize at medium Stabilize at small Extinction/Re-colonization
Sclerurus scansor	Extinction Stabilize at small	Extinction Stabilize at small Stabilize at max Stabilize at medium Extinction-recolonization

Overall, agriculture intensification may lead to a decline or even local extinction by affecting populations directly (decreasing food resources) and indirectly (reducing rescue effect). We suggest that non intensive farming practices (such as agroforestry, subsistence farming and home-gardens) are done in the Atlantic Forest biome. This would maintain or enhance food availability for forest birds that feed on the matrix, as well as increase permeability of landscape for species that disperse through the matrix.

The qualitative modeling technique was successful so that, very sensitive models that requires high precision input (e.g. Population Viability Models) may fail to predict population behavior because of the lack of basic biological knowledge about the species. Because, modelers can´t wait for field biologist to gather long-term precise numerical data, we suggest that qualitative reasoning should be considered as powerful tool for predicting behavior of populations under different scenarios, fostering biological conservation and management grounded on explicit causality.

Finally, our model was initially designed to address the question of how agricultural intensification of the matrix is affecting forest birds. Therefore, at first we didn´t develop it to be used by others, except ourselves. On the other hand, we hope that these findings are used by the scientific conservation community, so that ecology and biological conservation can conserve and understand biological systems through the light of causality, even with low resolution datum. This doesn't mean that the present model could not be used by undergraduate and graduate students as an educational tool, since it encompasses central concepts in ecology (e.g. matrix permeability, agriculture intensification, predation risk, rescue effect, supplementation on adjacent matrix and stochasticity).

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