Agriculture, Ecosystems and Environment 164 (2013) 114–130

Contents lists available at SciVerse ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

How do different agricultural management strategies affect bird communities inhabiting a savanna-forest mosaic? A qualitative reasoning approach

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ARTICLE INFO

Article history:
Received 27 July 2011
Received in revised form
17 September 2012
Accepted 21 September 2012
Available online 23 November 2012

Keywords:
Bird community dynamics
Cerrado
Garp3
Intensive agriculture
Landscape ecology
Qualitative reasoning
Traditional management

ABSTRACT

Most of the world's biodiversity is threatened by agricultural intensification. Agricultural intensification also is considered as major human thread to one of the world's most threatened ecosystems, the Cerrado in Brazil. The Cerrado can be characterized as a natural mosaic of grasslands, woodlands, dry savannas and forests forming a naturally heterogeneous landscape representing the home for an enormous amount of endangered bird species. In this paper, we present a qualitative reasoning model to compare impacts of Intensive farming and traditional management on bird communities inhabiting a mosaic of savanna-forest landscape in the Brazilian Cerrado ecoregion, by using non-numerical knowledge and explicit representation of causal relations. Three groups of bird species were represented, based on their distinct use of the forest-savanna mosaic: forest specialists, forest generalists and non-forest inhabitants. The qualitative model was built in Garp3, a qualitative simulation engine. The qualitative model was successful in representing the impacts of both agricultural systems on the bird groups, addressing advantages and disadvantages of this method. The model shows that intensive agriculture leads to non-forest and forest specialists decline, whereas forest generalists are kept stable. On the other hand, traditional management may lead to either a decline or maintenance of the non-forest and maintenance of both forest groups. Replacement of traditional management by intensive agriculture may negatively affect birds. Heterogeneity is a key process to maintain diversity in agricultural landscapes.

1. General introduction

1.1. Ecological background

The Cerrado is the largest, richest and possibly the most threatened tropical savanna in the world (Silva and Bates, 2002). It is characterized as a mosaic of grasslands, woodlands, dry savannas and forests forming a naturally heterogeneous landscape (Eiten, 1972). Due to this high levels of biodiversity and threats, where almost half of its 12,600 plants species are endemic (Mendonça et al., 2008), the region is considered as a world conservation hotspot (Myers et al., 2000). Despite this fact, the Cerrado has been historically neglected by conservation actions, and treated as a "forgotten ecosystem" (Marris, 2005). The fact that only 6.2% of the biome is maintained by protected areas (Myers et al., 2000) highlights this, and the need of increasing the number and size of the reserves is clear. Despite of it, in places where is not possible to establish parks because of social, political or historical factors, human activities with low impact should be encouraged.

Although the records of agriculture practices in the Cerrado dates around 6 hundred years ago (Ribeiro, 2005), modern intensive agriculture, especially soybeans plantations, is nowadays the main driver of habitat loss (Carvalho et al., 2009). As in other parts of the world, farmlands of the Cerrado have come through significant changes in the last 30 years. Technological advances have deeply impacted farming practices, biodiversity distribution and sociocultural aspects of farming (Shiva et al., 2002; Goulart et al., 2009). Although many regions have changed into high-tech agriculture, many farmers still live in a traditional way, using farming practices not much different than centuries ago (Altieri, 2002). Still, modern agriculture is facing wide expansion and great part of the world farmlands are intensified or on their way to intensification (Balmford et al., 2005).

This is very clear in the Brazilian Cerrado ecoregion, where 556,000 km^2 is composed by intensive pasture and monocultures and 232,000 km^2 is composed by native pasturelands characterized by managements with low technological level, and this area is shrinking under the pressure of Intensive farming expansion (IBGE, 1998; Diniz-Filho et al., 2009). The Cerrado has been also considered a 'strategic' region for the intensive production of soybeans and cattle for exportation, so that agribusiness expansion is predicted in the region for the next years (Klink and Machado, 2005).

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http://dx.doi.org/10.1016/j.agee.2012.09.011

Because a significant part (if not all) of the Cerrado is already altered by humans at some degree, to understand how different farming practices affect biodiversity is keynote to define strategic actions toward to its biodiversity conservation.

We aim at producing a qualitative model comparing the impacts of two farming practices on bird communities inhabiting mosaics of savanna and forest in a naturally patchy Brazilian Cerrado landscape. We also assess the predicted impact of both farming practices on three groups of bird species, classified according to different matrix uses.

1.2. Back ground on qualitative reasoning

Qualitative reasoning (Weld and de Kleer, 1990) is an area of Artificial Intelligence that provides techniques to build simulation models of physical systems and allows reasoning with scarce, imprecise and non-numerical data. This approach was chosen because the understanding of how different farming practices affect bird communities requires comprehension of different species dispersal ability, territory size and sensitivity to disturbances. Information about these topics in the Cerrado region is scarce, sparse and often documented in qualitative ways. Thus, sensitive numerical models cannot be developed based on the available data. Therefore, the present qualitative model focuses on the prediction of effects of different management practices (traditional vs. intensive) on birds using scarce and punctual data.

In qualitative models that adopt the Qualitative Process Theory (Forbus, 1984), continuous properties of the system objects (*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 assumed to be the initial cause of changes in the system and qualitative proportionalities are the effects of process propagation. Like number, a variety of qualitative representations of mathematical relationships have been developed (Forbus, 1996).

In qualitative reasoning models, relationships (both direct influences and proportionalities) have mathematical and causal meanings. Therefore, qualitative models use compositional qualitative mathematics for ordinary differential equations, which means that this technique uses a non-numeric mathematical reasoning. It also formally represents causality of complex systems through state dependent causal models.

2. Farming practices and effects on birds

Agricultural intensification is associated to the Green Revolution, a consequence of the expansion of the capitalist economy based on the replacement of Traditional farming by mono-specific systems heavily dependent on the use of machinery, irrigation systems, fertilizers and pesticides (Altieri, 1999). Although each intensive crop system has a particular structure (e.g. single-species forestry stands are different from annual crop monocultures), most of them are based on the same basic principles: high input and output of energy and matter (Angelsen and Kaimowitz, 2001), and low spatial-temporal heterogeneity (Benton et al., 2003). Impact of agricultural intensification on biodiversity is widely recognized as one of most significant threats to biodiversity worldwide (Benton et al., 2003; Donald and Evans, 2006). Agricultural intensification negatively impacts in-farm biodiversity through use of pesticide, farm size reduction and heterogeneity reduction. Concerning biodiversity that lives in adjacent areas to agricultural systems, agriculture intensification leads to the decrease of landscape permeability to species fluxes (Perfecto and Vandermeer, 2010).

One of the most well documented impacts refers to the consequences of pesticides on birds, described half a century ago (Carson, 1962). At a physiological level, pesticides increase the risk of egg breakage by reducing egg shell thickness (Ratcliffe, 1970; Mellink et al., 2009), as well as causing changes in brain activity (Busby et al., 1983). Consequently, pesticides may not only cause population decline of birds inhabiting the agrienvironment (Fuller et al., 1995; Brickle et al., 2000; Chamberlain et al., 2000), but also negatively affect species inhabiting adjoining forest areas (Cooper et al., 1990). Concerning spatial structure, agricultural intensification reduces heterogeneity at farm level, between farms, regions, and even between countries, leading to a severe biodiversity loss (Benton et al., 2003).

Intensification also tends to increase farm size and reduces crop diversity (Altieri, 1999). Farm management is related to its size, so that small farms mean that each farmer management decision is restricted to a smaller area (smaller farmed grain). In Europe, small farms are known to support more bird richness and bird territories, butterflies, bumblebees and herbaceous plant species in comparison to larger farms (Belfrage et al., 2005). In Brazil, agrarian reform carried out based on agroecological principles replacing large tracks of pasture with small home-gardens has favored forest bird species (Uezu et al., 2008; Goulart et al., 2011).

Finally, intensification leads to the decrease in farmed matrix permeability of organisms that inhabit native fragments in which it is embedded, declining connectivity of agricultural landscapes (Donald and Evans, 2006; Perfecto and Vandermeer, 2010). Nevertheless, empirical studies on how bird dispersion and colonization are affected by agricultural intensification are rare (Donald and Evans, 2006).

Traditional management, in turn, represents a wide range of non-intensive cropping and livestock systems. These systems are very diversified and unique in their structure, so that management is much dependent on biodiversity, local environmental conditions and cultural characteristics. Traditional management encompasses many different practices such as subsistence farming, raising cattle at low density on native grasslands, extractivism, home-gardens, non-tillage farming and agroforestry systems. Management of these systems is known to result in high-habitat heterogeneity, harboring higher levels of biodiversity in comparison to more intensive management practices (Perfecto et al., 1996; Greenberg et al., 1997; Faria et al., 2006; Marsden et al., 2006).

Classifying different management systems (intensive and non-intensive) in terms of an environmental impact gradient is keystone to land-use decision making at landscape scale. The status of bird species is particularly useful to assess ecological impact of different land use management system (Ormerod and Watkinson, 2000), since they provide sufficient data on abundance and richness that allows detailed analysis. Therefore, they can be used as bioindicators representing other groups. Furthermore, they play important ecosystem functions, such as plant dispersal, biological control, pollination (Sekercioglu, 2006).

The work here described aims at presenting a theoretical evaluation of impacts of intensive and traditional agriculture on birds inhabiting a forest-savanna mosaic in the Cerrado ecoregion. It also hypothesizes that qualitative reasoning models are able to capture main system behavior addressing issues of ambiguity and complexity, and could be used to better understand ecological patterns in agricultural landscapes.

Cerrado's bird species were divided in three groups based on their differential use of the forest-savanna mosaic: (a) forest specialist species, that inhabits forest but may migrate through the matrix; (b) forest generalist species, that may feed, breed and migrate through the matrix; and (c) non-forest species, that may