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Thematic Review

Biodiversity Management and Research in Multifunctional Landscapes

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Abstract*:* Despite their negative environmental impacts, human-modified environments such as agricultural and urban landscapes can have a relevant role on biodiversity conservation as complements of protected areas. Such anthropized landscapes may have endangered, valuable, and nuisance species, although most of them do not fit in any of these categories. Therefore, in such environments we must deal with the same decision-making process concerning the same possible interventions proposed by Caughley (1994) to wildlife management, which are related to biological conservation, sustainable use, control/coexistence, and monitoring. Such decision-making process should be based on good science and good governance. On such context, the first step should be to implement multifunctional landscapes, which keep their primary mission of human use, but incorporate a second but fundamental mission of biological conservation. In this study we present a summary of the research carried out at the Biota Program of Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP) in this field since the late 1990's and propose priorities for biodiversity research and governance in multifunctional landscapes for the near future.
Keywords: *Wildlife management; agricultural landscapes; governance; biodiversity monitoring.*

Gestão e pesquisa da biodiversidade em paisagens multifuncionais

Resumo*:* Apesar de seus impactos ambientais negativos, ambientes modificados pelo homem, como paisagens agrícolas e urbanas, podem ter um papel relevante na conservação da biodiversidade como complementos de áreas protegidas. Tais paisagens antropizadas podem ter espécies ameaçadas, valiosas e incômodas, embora a maioria delas não se enquadre em nenhuma dessas categorias. Portanto, em tais ambientes devemos lidar com o mesmo processo de tomada de decisão sobre as mesmas possíveis intervenções propostas por Caughley (1994) para o manejo da vida selvagem, que estão relacionadas à conservação biológica, uso sustentável, controle/coexistência e monitoramento. Esse processo de tomada de decisão deve ser baseado em boa ciência e boa governança. Neste contexto, o primeiro passo deverá ser a implementação de paisagens multifuncionais, que mantenham a sua missão primordial de uso humano, mas que incorporem uma segunda, mas fundamental missão de conservação biológica. Neste estudo apresentamos um resumo das pesquisas realizadas no Programa Biota da Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP) neste campo desde o final da década de 1990 e propomos prioridades para pesquisa e governança da biodiversidade em paisagens multifuncionais para o futuro próximo.
Palavras-chaves: *Gestão da fauna; paisagens agrícolas; governança; monitoramento da biodiversidade.*

Introduction: Land Use and Biodiversity

Despite its relatively short geological time, the interaction between natural history and human history molded most of the current patterns of biodiversity on Earth, as well as humans current socioeconomic and cultural diversity (Balée 2014). From the expansion of hunting process during the Pleistocene to the recent expansion of agriculture, humans respectively promoted a surprisingly well documented mass extinction (Barnosky et al. 2004) and a surprisingly unknown change on the evolutionary processes of the surviving species (Hendry et al. 2008, Sullivan et al. 2017, Davis et al. 2018). As a result, we currently have missing species in pristine ecosystems (e.g., the "empty forest", as suggested by Redford 1992) and colonizing species in agroecosystems (e.g., Dotta & Verdade 2011, Gheler-Costa et al. 2012, Penteado et al. 2014). At least in part, such pattern can be seen as a result of a "negentropy" (as suggested by Jost 2007), or simply a homogenization process of anthropogenic causes (Magnusson 2006).

There is a consistent increase in spatial scale of anthropogenic impacts from the Pleistocene overkill (caused by hunters) to the 20th Century Green Revolution (caused by farmers). Both led to evolutionary-ecological impacts. However, the former referred to regional mass extinctions of the megafauna (i.e., large-bodied mammals), whereas the later led to huge changes in resources availability to most species of animals and plants as well as microorganisms, globally (Kumar 2007). Therefore, an intrinsic conflict between biological production (i.e., agriculture *lato sensu*) and biological conservation (i.e., the still emerging "crisis discipline", as proposed by Soulè 1985) in terms of land use as planet Earth is finite. However, not even the countries with the best infrastructure in protected areas (e.g., USA and India) are able to provide integral conservation for their biodiversity, even if their existing protected areas worked perfectly, which they do not (DeFries et al. 2005, Possingham et al. 2006). For this reason, the part of biodiversity that still dwells on – or is colonizing – agricultural landscapes and even their matrices (i.e., their dominant agroecosystems), despite their many and complex anthropogenic impacts (e.g., contamination and invasive species), merit conservation efforts. On the other hand, the wild races and varieties of the domesticated species of animals and plants used in agriculture are among the most endangered taxa of the world as they depend on the wilderness to thrive. These wild lineages are fundamental to provide genetic responses to environmental changes like the introduction of novel pathogens and parasites, or climatic changes (Corlett 2020). In other words, in the real-world wild species depend on agricultural landscapes to be fully conserved, whereas agriculture needs the wilderness to be sustainable (Verdade et al. 2014a, 2016). In this debate, for a successful conservation it is suggested that we need to promote what has been claimed in ecology reconciliation and figure out how to reconcile the needs of all biodiversity levels with economic activities and human needs (Rosenzweig, 2003).

Additionally, for the agricultural landscape to sustain the wild species, it is necessary to maintain a variety of conditions such as higher proportion of natural habitats, large habitat remnants spread in the landscape (Uezu and Metzger 2011), and high landscape connectivity provided by the presence of ecological corridors (Uezu et al. 2005), stepping-stones (Uezu et al. 2008) and a permeable matrix. These same conditions also have been shown to favor agricultural production as it contributes to crop pollination (Klein et al. 2007), provide biological control against plagues, produce higher amount of biomass and organic matter which help in soil formation and protection, and contribute to the water cycle regulation (Stosch et al. 2017), helping in the water supply in a perennial form. In a larger scale, this multifunctional landscape also absorbs higher amounts of carbon (Gonçalves et al. 2021), which favor the climate change mitigation.

Such an argument reveals an actual interdependence instead of the assumed conflict between biological production and biological conservation (Verdade et al. 2014a). Such interdependence demands two basic tasks: the existence of a functional conservation system and the establishment of multifunctional agricultural landscapes (Verdade et al. 2016). Although not perfect, functional conservation systems should provide effective conservation for all ecosystems and species, even if not spatially connected (Soulé & Simberloff 1986). Complementarily, multifunctional agricultural landscapes should provide sustainable biological production as its primary mission, but also provide relevant biological conservation as a secondary, but fundamental, mission (Martinelli et al. 2010).

Two distinct strategies have been proposed to mediate the conflict between biological production and biological conservation: land-sharing and land-sparing (Green et al. 2005). Although their distinction is a matter of spatial scale, the former is based on the interspersion of protected areas on a matrix of agriculture, whereas the latter is based on the agriculture intensification and its (idealistic, but practically questionable) limited expansion, with maintenance of (once again idealistic, but practically questionable) large protected areas (Verdade et al. 2014a).

There was a rich debate about it (Vandermeer & Perfecto 2005, Green et al. 2007), but multifunctional agricultural landscapes are effective examples of the land-sharing approach. In Brazil, the Forest Code has been also based on such an approach, even though it has been established decades before such a debate (Metzger et al. 2010). However, the coexistence between human and wildlife in multifunctional agricultural landscapes demand the existence of an effective Wildlife Service to improve the decision-making process concerning biological conservation, sustainable use, control, and monitoring (Sutherland et al. 2004, Verdade et al. 2014b). Such an institution would demand good science and good governance to be effective, as follows.

Biodiversity Management and Governance

According to Graeme Caughley, there are basically four possible human interventions on wildlife management: increase a depleted population, decrease an excessive population, reach the maximum sustainable yield (MSY), or "do nothing but keep an eye on it" (Caughley 1994). Generally, Caughley's vision may apply to the concept of biodiversity as a whole and it is splendid for two reasons. First because it works at the population level. In fact, distinct populations of the same species may have distinct conservation status (e.g., capybaras are considered as a plague in Southeast Brazil, but it is considered endangered in some areas of its Northeast region, Verdade & Ferraz 2013). In addition, because population is the most relevant evolutionary unit (Mayr 1991), which assures the maintenance of the evolutionary process itself. Selfish genes (Dawkins 1969) and group selection (Williams 1966) can be considered as minor exceptions for such a rule. This is particularly relevant as life on planet would collapse if the evolutionary process collapsed (Mayr 1991). Second, because the possible interventions proposed by Caughley cover the main disciplines related to biodiversity management: biological conservation, sustainable yield, control/coexistence, and monitoring (Verdade et al. 2014b)

Research teams associated with the Biota Program of *Fundação de Amparo à Pesquisa do Estado de São Paulo* (FAPESP) showed that agricultural landscapes in the state of São Paulo, Southeast Brazil, have approximately 70% of the species of medium to large mammals (e.g., Dotta & Verdade 2011), 20% of the species of small mammals (e.g., Gheler-Costa et al. 2012), and 60% of the bird species (e.g., Penteado et al. 2016), compared with relatively pristine local environments. Endangered (e.g., giant anteater, *Myrmecophaga tridactyla*), valuable (e.g., Brazilian tiger fish, *Pseudoplatystoma corruscans*), and invasive (e.g., wild boar, *Sus scrofa*) species are found among them. Therefore, the wildlife management demanded by multifunctional agricultural landscapes include biological conservation, sustainable use, control/coexistence, and monitoring. (Verdade et al. 2016). The decision-making process related to the possible actions concerning such disciplines over lands devoted primarily to biological production require a well-established Wildlife Service, which can dialogue with institutions devoted to agriculture and livestock production (Verdade 2004, 2014a). Its *modus operandi* would need a long-term crossing scale monitoring program able to identify possible discrepancies, propose interventions as well as measuring procedures to evaluate their effectiveness (Figure 1). Such a program is likely the most important component of biodiversity management on agricultural landscapes, as well as in protected areas. In fact, in Brazil we have a few thousand endangered, a few hundred valuables, and a few dozen nuisance species. However, we have a few million species (many yet to be described) that are neither of such categories but can become (Verdade et al. 2014a). It is just necessary to remind, though, that such a program should necessarily be based on good science, as follows.

Research

Research on biodiversity management on multifunctional agricultural landscapes should help society to perceive and solve problems on a cost-effective way. The best way to do so would be possibly based on pursuing the factors that limit our knowledge. These factors can be didactically divided into three levels: conceptual basis, technological/methodological innovation, and societal constraints. In colloquial language we can say that we have conceptual limitations when we do not know what to do. On the other hand, we can say that we have technological limitations when we do know what to do, but do not know how. Finally, we have societal constraints when we know what and how to do, but do not know who, where, and when things should be done. Examples of research of these limitations that have dealt with at the Biota Program / FAPESP are shown at Table 1.

In the technological/methodological innovation level, genetic tools used to assess DNA from fecal samples have been shown very helpful and important in supporting to traditional methodologies, for instance, to assess demography in cougar *Puma concolor* (Miotto et al. 2007; 2014) and its monitoring in fragmented landscapes (Miotto et al. 2012). In another example, the jaguar *Panthera onca* believed locally extinct in an Atlantic Forest remaining was re-discovered through molecular feces analyses (Souza et al. 2017). Fecal DNA has been useful to infer about gene flow, animal movement and population connectivity, and population genetics of maned-wolf *Chrysocyon brachyurus* (Ramalho et al. 2014) and ocelot *Leopardus pardalis* (Figueiredo et al. 2015), besides cougar (Miotto et al. 2011; Saranholi et al. 2017). The presence of the invasive European hare *Lepus europaeus* and its potential damage to the native tapiti *Sylvilagus brasiliensis* can be now investigated using DNA mini-barcodes and fecal samples (Rodrigues et al. 2020).

Spatial ecology data are fundamental for conservation decisions, especially in human-dominated landscapes. These data reveal how individuals use the habitat, how they organize in space, and which components are key resources for the species. Technological limitations have been overcome over the last few years. For example, we used GPS transmitters to track anteaters (*Myrmecophaga tridactyla*) in the wild in the first time in state of São Paulo. This type of information provides data robustness and demonstrated which resources are necessary for the species (Bertassoni et al. 2020).

In relation to societal constraints, agroforest woodlots were studied in the Pontal do Paranapanema region, considering different aspects.

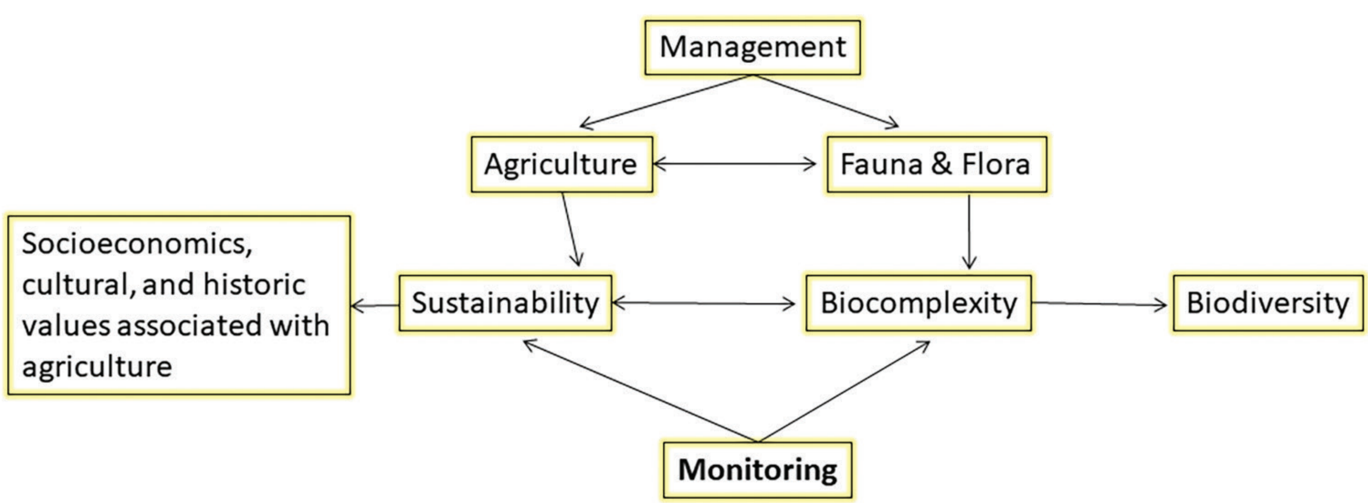

Figure 1. Rational for a long-term crossing scale biodiversity monitoring program on multifunctional agricultural landscapes.

Table 1. Research on biodiversity management in multifunctional agricultural landscapes at the Biota Program / FAPESP.

Limitation level	Theme	Results	References
Conceptual basis	Diversity of patterns	Diversity of medium to large mammals in agricultural landscapes	Dotta & Verdade 2011 Lyra-Jorge et al. 2008a, 2010
		Diversity of small rodents and marsupial in agricultural landscapes	Gheler-Costa et al. 2012
		Diversity of birds in agricultural landscapes	Penteado et al. 2016
		Plant assemblages and habitat connectivity	Jesus et al. 2012
	Complexity of processes	Trophic ecology of mammals in agroecosystems	Dotta & Verdade 2007
		Temporal dynamics of small mammals in *Eucalyptus* plantations	Verdade et al. 2020a
		Relationship between agricultural management and wildlife ecology	Gheler-Costa et al. 2013, Millan et al. 2015
		The impacts of global climatic changes on biodiversity	Karp et al. 2015
		Caiman ecology in silvicultural landscapes	Marques et al. 2016, 2020
		Fresh water turtles' trophic niche	Marques et al. 2017
		Space use by giant anteaters (*Myrmecophaga tridactyla*) in a protected area within human-modified landscape	Bertassoni et al. 2020
		Dog activity in protected areas: behavioral effects on mesocarnivores and the impacts of a top predator	Bianchi et al. 2020
		Tayra (*Eira barbara*) landscape use as a function of cover types, forest protection, and the presence of puma and free-ranging dogs	Bianchi et al. 2021
		Agroforest woodlots working as stepping stones for birds in the Atlantic forest region	Uezu et al. 2008
		Potential economic impact of carbon sequestration in coffee agroforestry systems	Gonçalves et al. 2021
Technological/ methodological innovation	Molecular markers	Use of genetic tools on management and governance of crocodilians	Verdade et al. 2020b
		Use of genetic tools for demographic approach of large carnivores	Miotto et al. 2007; 2014 Ramalho et al. 2014 Souza et al. 2017
		Genetic tools for monitoring felids in fragmented landscapes	Miotto et al. 2012
		Assessing gene flow of large mammals in fragmented landscapes	Miotto et al. 2011 Figueiredo et al. 2015 Saranholi et al. 2017
		Use of genetic tools for assessing invasive species	Rodrigues et al. 2020
		Environmental DNA for assessing vertebrate diversity	Carvalho et al. 2021
	Isotopic analyses	Stable isotope analyses on wildlife studies	Marques et al. 2014
	Survey methodology	Wildlife counting techniques	Ferraz et al. 2010, Lyra-Jorge et al. 2008b, 2014, Verdade et al. 2013, Islas et al. 2022
Societal dimensions	Governance	Characterization of multifunctional agricultural landscapes	Martinelli et al. 2010
		Instruments of environmental and productive intervention from the perspective of the nexus water, energy and food	Chiodi et al. 2022
	Public policy	The impacts of biofuels' expansion on biodiversity	Joly et al. 2015, Verdade et al. 2015

Table 2. Levels of governance, intervention, and population status at biodiversity management.

Level of governance	Level of intervention	Population status
Federal	Biological conservation	Endangered
	Monitoring	Indicator
State	Sustainable use	Valuable
	Control/Coexistence	Nuisance

First, it was studied their capacity to increase landscape connectivity for forest birds (Uezu et al. 2008), second, their potential to sequestrate carbon from atmosphere was quantified, contributing to Climate Change mitigation, and third, their economic viability was evaluated as an option to income increase for rural settlers (Gonçalves et al. 2021). As results we can conclude that agricultural production (agroecological in this case) can compose a tool for biodiversity and ecosystem service conservation, providing multiple benefits for people and wild species.

What Next?

In general, the focus of the research on biodiversity tends to trade from the diversity of patterns to the complexity of processes as the later molds the former (Verdade et al. 2014b). Innovation, on its turn, tends to thrive on the way to non-invasive methods that allow us to learn about species behavioral ecology (e.g., mating systems and dispersal), demography (e.g., population density, sex ratio and age distribution), and evolution (e.g., rapid evolution in response to anthropogenic pressures).

Environmental DNA, for instance, has emerged as a powerful tool for species surveying when associated to metabarcoding or for a target species monitoring, as invasive species, when qPCR is preferentially used (Carvalho et al. 2021). Non-invasive methods such as fecal and environmental DNA should be prioritized in future studies of wildlife.

Finally, studies on the societal dimensions related to biodiversity tend to focus on the improvement of governance and public policy, as well as on the enhancement of our knowledge on the relationship between socioeconomics and human culture, and biodiversity management. It is noteworthy that this claim for linking innovation to biodiversity monitoring has also been extended to urban environments as a way to create nature awareness among city dwellers (Nunes & Nisi 2018, Nisi et al. 2020). In this regard, we could also incorporate the urban environment as part of a multifunctional landscape where biodiversity needs to be protected and integrated into people's life.

At this point, we can propose that the priority for biodiversity governance would be its political structuring through government from local to federal taking into consideration the possible interventions proposed by Caughley (1994) (Table 2). This way, the states would oversee the management programs of sustainable use and control/coexistence, whereas the federal government would oversee the management of endangered species and a long-term crossing scale monitoring program of biodiversity. The mission of such a program would be to detect possibly significant changes in populations' status, discrepancies, and potential problems soon enough to understand them and take effective decisions to solve them. Although a considerable effort has been taken to the technological and methodological development of similar programs (e.g., Lindenmayer & Likens 2010, Proença et al. 2017), it is necessary to keep in mind that there is still a huge conceptual gap about their conceptual basis. In other words, although we are mainly focusing on how to measure biodiversity, we still do not know what exactly should be measured (Siddig et al. 2016). A possible reason for such a pattern is that the selection of indicator species in monitoring programs tend to be specialist-specific or biased to the specialists in question. This is possibly the reason that suggested indicator species include from frogs (Amarasinghe et al. 2021) to birds (Gregory et al. 2003), and "charismatic" mammals, whatever a "charismatic" mammal is or does (Ducarme et al. 2013).

Considering that monitoring is the basis of biodiversity management, this would be possibly the most relevant discover on the near future concerning biodiversity. Quoting Caughley, we should keep an eye on it!

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Associate Editor

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Conflicts of Interest

The authors have no conflict of interest concerning this manuscript.

Ethics

This manuscript is conceptual with no capture and/or handling of animals and plants or their parts. No ethics license is therefore required.

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