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Can rice field management practices contribute to the conservation of species from natural wetlands? Lessons from Brazil

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Abstract

A major goal of worldwide agriculture over the next 30 years will be to feed a burgeoning population of about 9 billion people. This expansion poses a great challenge because crop production is an activity that profoundly affects natural habitats and biodiversity. An interesting perspective for biodiversity conservation is the incorporation of production systems into overall conservation efforts. Rice is one of the world's major crops and Brazil is the leader in the Western Hemisphere with 35% of the cultivated area. Rice fields are sometimes considered man-made wetlands with potential values for many aquatic species. The main goal of this paper is to synthesize results of studies carried out over the past decade in rice fields of southern Brazil to identify management practices that enhance biodiversity levels in agricultural matrices. We also provide direction to environmentally-oriented legislators for implementing general strategies for rice farmers to supplement aquatic diversity of natural wetlands. Major techniques include: 1) keeping some rice fields flooded during the fallow phase; 2) increasing organic rice production to reduce the use of pesticides; 3) encouraging rice farmers to rejuvenate soils by periodically taking fields out of production; and 4) avoid draining new wetlands for rice production. Incentivizing good management practices in rice fields would transfer some of the responsibilities related to the conservation of biodiversity to production systems.

Zusammenfassung

Ein wichtiges Ziel der weltweiten Landwirtschaft für die nächsten 30 Jahre ist, eine wachsende Bevölkerung von rund 9 Milliarden Menschen zu ernähren. Dieser Zuwachs stellt eine große Herausforderung dar, weil die landwirtschaftliche Produktion die natürlichen Lebensräume und die Biodiversität beeinflusst. Eine interessante Perspektive für den Schutz der Biodiversität ist, die Produktionssysteme in die Schutzbemühungen einzubeziehen. Reis ist eine der wichtigsten Feldfrüchte, und Brasilien ist mit 35% der Anbaufläche der führende Produzent in der westlichen Hemisphäre. Reisfelder werden manchmal als menschengemachte Feuchtgebiete mit potentiellem Wert für viele aquatische Arten angesehen. Das Hauptziel dieses Artikels ist, die Ergebnisse von Studien zusammenzuführen, die in der letzten Dekade in Reisfeldern von Süd-Brasilien durchgeführt wurden, um Bewirtschaftungsweisen zu identifizieren, die die Biodiversität in der Agrarlandschaft fördern. Wir geben auch Hinweise an umweltorientierte Gesetzgeber zur Implementierung allgemeiner Strategien, mit denen Reisbauern die aquatische Diversität von natürlichen Feuchtgebieten ergänzen können. Die Hauptmethoden sind: 1) Einige Reisfelder sollten

während der Brachezeit überflutet bleiben. 2) Der biologische Reisanbau sollte verstärkt werden, um den Pestizideinsatz zu verringern. 3) Die Reisbauern sollten ermutigt werden, die Böden durch regelmäßige Nichtbewirtschaftung zu regenerieren. 4) Es sollten keine zusätzlichen Feuchtgebiete für den Reisanbau entwässert werden. Mit dem Anreiz für eine gute Bewirtschaftungspraxis auf den Reisfeldern würde ein Teil der Verantwortung für den Erhalt der Biodiversität auf die Produktionssysteme übertragen.

Keywords: Agricultural policies, Agricultural systems, Agroecosystem, Organic rice, Paddy fields, Sustainable farming.

Introduction

Agriculture in the next 30 years will need to feed a human population that reaches about 9 billion people (Bloom 2011). This poses a great challenge for agriculture (Tilman, Balzer, Hill, & Befort 2011) because crop production has already negatively impacted natural habitats and their resident species (Foley et al. 2005, 2011; Power 2010). Agriculture today covers approximately 38% of the global land surface, of which 12% are croplands (i.e., 1.2 billion ha; FAOSTAT 2013). Any forecast in agricultural expansion is of concern from an environmental perspective. The challenge for modern agriculture lies in assuring food for a burgeoning population, while preserving both natural habitats and biodiversity (Gaba et al. 2015).

Currently, a major strategy to conserve biodiversity is the establishment of protected areas. Butchart et al. (2015) estimated that protected areas across the world currently comprise 14.6% of the land surface, however, this percentage is concentrated in certain regions, not ensuring species conservation in other ecoregions, biomes and key locations. An interesting perspective to consider from the biodiversity conservation point of view is the incorporation of production systems such as agriculture into conservation efforts (Brussaard et al. 2010; Phalan, Onial, Balmford, & Green 2011). Land sharing (to integrate biodiversity conservation and food production on the same land) and land sparing (to separate land for conservation from land for food production) are agricultural strategies (Fischer et al. 2008; Gabriel et al. 2009; Green, Cornell, Scharlemann, & Balmford 2005) to minimize the impact of food production on biodiversity (Phalan et al. 2011). Godfray and Garnett (2014) maintained that the sustainable management of agricultural lands could contribute significantly towards reducing the negative impacts of agriculture on biodiversity and natural ecosystem services.

Rice is the third most cultivated crop in the world, occupying about 13% of the world's cropland area (164 million ha) (FAOSTAT 2013). Asia accounts for 89%, followed by the Western Hemisphere (5%), where Brazil is the leader with 35% of the cultivated area (FAOSTAT 2013). Irrigated rice fields are considered man-made wetlands by many wetland classifications (e.g., Neotropics, Scott & Carbonell 1986; Asia, Scott 1989; global, Ramsar Convention 1990). The most recent Brazilian wetland classification (Junk et al. 2014) also labels rice fields as wetlands. Irrigated rice fields provide habitat for many species of wetland invertebrates, plants, fish, amphibians, and birds (Table 1). Natuhara (2013) suggests that ecosystem services from rice fields may provide many of the same values provided by natural wetlands. Recently, a pioneer project (LEGATO – "Land-use intensity and Ecological enGineering – Assessment Tolls for risks and Opportunities in irrigated rice based production systems") conducted in South-East Asia explored new opportunities to enhance sustainability of irrigated rice fields (Settele et al. 2015), including practices tied to rice cultivation influences on biodiversity. Katayama, Baba, Kusumoto and Tanaka (2015) identified policies to decrease the impacts of rice fields on natural biodiversity (e.g., bans on pesticides and herbicides; decreases in chemical fertilizer application, using more efficient machinery and irrigation processes; and fiscal incentives to farmers who protect fields after abandonment).

In the Americas, Brazil is the largest rice producer accounting for 32% of the production (USDA 2015). Research related to biodiversity conservation in irrigated rice fields in Brazil is still rare (e.g., Guadagnin, Peter, Rolon, Stenert, & Maltchik 2012; Linke et al. 2014; Rolon & Maltchik 2010; Stenert et al. 2009). The southern portions of Brazil contribute almost 50% of the national production of rice (IRGA 2013). Irrigated rice production has been a major contributor to the fragmentation and loss of natural wetlands (Maltchik 2003). Southern Brazil is located in the Pampa biome, which is highly impacted by various human activities; the region has numerous endemic species but very little area under protection (< 1%), with about half of it protecting wetland systems. In view of this, the question arises: Can such a small area adequately protect wetland aquatic biodiversity? Thus, incorporating production systems into biodiversity conservation may be an intriguing way to conserve high levels of species richness in a rice cultivation matrix. This concept is not new for agriculture, and the idea has attracted attention across the world (Brussaard et al. 2010; CEC 1985; Phalan et al. 2011).

This paper synthesizes results of numerous studies conducted over the past decade in irrigated rice fields of southern Brazil to identify management practices that enhance wetland biodiversity levels in an agricultural matrix. Our goal is to reconcile environmental and agricultural interests. We will address three major questions: (1) Does flooding of rice fields after cultivation contribute to species conservation? (2) Can organic rice production contribute to the conservation of biodiversity of natural wetlands? and (3) Does the intensity and history of rice cultivation influence species richness in rice fields?

Rice management practices and wetland species conservation

Does flooding of rice fields after cultivation contribute to species conservation?

Most rice producers in southern Brazil drain their rice fields after harvest. This practice enables farmers to graze livestock during the off-season period. However, many fields adjacent to natural wetlands tend to flood after intense rainfall. This flooding is un-intentional, but the result is that these fields are not used for rice production in the subsequent season; the costs of draining them exceed any production gains. A strategy of keeping rice fields flooded during the off-season period was used by producers outside Brazil. For example, California rice producers usually flood their fields after harvest to accelerate residual straw decomposition. This practice is an important strategy for biodiversity conservation because valuable habitat for waterbirds is created (Brouder & Hill 1995; Elphick & Oring 2003).

In southern Brazil, recent studies compared the species richness of aquatic plants (Rolon & Maltchik 2010), invertebrates (Stenert et al. 2009), amphibians (Machado & Maltchik 2010) and birds (Guadagnin et al. 2012) between rice fields that either flood or are dry during off-season periods. In these studies, high species richness was observed in the rice fields overall: 88 species of aquatic plants, 12 species of amphibians, 71 macroinvertebrate taxa and 59 species of birds (Table 2). But these studies showed that the species compositions of aquatic plants, invertebrates and anuran amphibians differed between flooded and drained rice fields (see Appendix A: Table 1). These results suggest that if rice farmers permitted some rice fields to flood in the off-season, the biodiversity on a landscape or regional level will increase due to the mosaic created by the variation of winter-flooded and winter-drained rice fields. We recommend that rice producers allow 10% to 15% of their fields to flood during the off-season to support increased biodiversity. Feedback from farmers suggests that this level would be acceptable in practice. Additional direct benefits of off-season flooding to future rice production, such as enhanced soil nutrient levels and rice straw decomposition, need to be explored in Brazil.

Can organic rice production contribute to the conservation of biodiversity of natural wetlands?

There are many models of organic rice production around the world, including Brazil (e.g., biodynamic, natural, biological, permaculture, or agroecological), but all are based upon two common principles: 1) non-use of agrochemicals; and 2) incorporation of alternative ways of rice production that minimize environmental impacts. Data of planted area and net production of organic rice on a large scale (country, world) are limited, and information is often by region or sub-region (e.g., county). In southern Brazil, the area of organic rice production is small, less than 0.5% of conventional production, with an annual production of 5 T/ha. In comparison, production rates for conventional farming are typically larger, sometimes reaching 7.5 T/ha (IRGA 2013). Organic agriculture in Brazil is usually not determined by market demands, government policies, or environmental objectives, but instead is a choice made by some families concerned with environmental and health questions.

Several publications suggest that organic agriculture supports greater levels of biodiversity than conventional approaches (Bengtsson, Ahnstrom, & Weibull 2005; Hole et al. 2005; Rundlöf & Smith 2006), including organic rice fields (Rizo-Patrón, Kumar, McCoy, Springer, & Trama 2013; Wilson, Watts, & Stevens 2008; Zhang et al. 2013). Recent studies conducted in southern Brazil reported a total of 36 species of aquatic plants (Linke et al. 2014), 14 species of amphibians (Moreira & Maltchik 2014), and 64 taxa of macroinvertebrates (including 50 genera of aquatic insects) (Dalzochio et al. 2016a,b) in rice fields overall, although species richness in both organic and conventional rice fields was smaller than in natural wetlands (Table 3). These studies suggest that both organic and conventional rice cultivation reduces biodiversity compared to natural wetlands, likely due to the soil preparation, machinery use, and landscape transformation used for crop culture. Species richness and composition of aquatic plants, invertebrates and anurans are similar between organic and conventional rice fields (see Appendix A: Table 2). Thus, the expectation that the biodiversity of organic rice fields would be greater than that of conventional fields was not confirmed in southern Brazil. The lack of difference may in part result because the organic rice farms are small parcels of land often imbedded in a larger matrix of conventional rice fields. However, in terms of species conservation, these results should not necessarily be viewed negatively because a lack of agrochemical application and the use of sustainable farming practices also reduce some stresses on biodiversity associated with rice production. For example, some organic rice producers flood their fields prior to the normal growing period to stimulate germination of the weed seed bank, and these plants subsequently die when the water is drained, eliminating the need for herbicides treatments.

Does the history of rice cultivation influence species richness in rice fields?

Over the long term, a management practice frequently used by rice farmers in southern Brazil is to periodically take the land out of production (i.e. a resting phase). This practice has the goal of minimizing negative impacts of cultivation, such as soil compaction, a decrease in soil microbial activity, and excessive soil and water contamination from agrochemical use (Reis & de Saibro 2004). Prior to 1980, such a resting phase occurred once every three years. However, with the new market demands for rice, most farmers abandoned the use of resting phases, and employed intensive cultivation annually, even including the cultivation of other non-rice crops during the normal off-season. Additionally, new areas were converted to rice cultivation, thus creating rice farms with fields of very different cultivation histories. Godfray and Garnett (2014) contend that increasing or maintaining food production should be not achieved with intensified production, but rather with sustainable production.

Anuran (Moreira & Maltchik 2015), macroinvertebrate (Dalzochio 2013) and macrophyte (Ana Silvia Rolon, unpublished results) richness in rice fields with different cultivation histories (cultivated for 3, 10, or 20 years) was analyzed, and compared with natural wetlands. In these studies, 14 and 35 species of anuran amphibians and aquatic plants, respectively, and 41 taxa of macroinvertebrates were observed in the rice fields (Table 4). However, the composition of macroinvertebrates and anuran amphibians varied among rice cultivation histories (Dalzochio 2013; Moreira & Maltchik 2015) (Table 4, see Appendix A: Table 3). The richness of anuran and aquatic plants were greater in natural wetlands than rice fields, but they did not differ between rice fields with different cultivation histories. This suggests that wetland conversion to rice fields impairs wetland biodiversity and damage occurs almost immediately upon conversion.

After this initial impact, the effects on aquatic plant biodiversity tend to stabilize. Nonetheless, rice fields still supported a plethora of aquatic plant species.

A Brazilian perspective for aquatic biodiversity conservation in rice fields:

Rice fields are clearly not substitutes for natural wetlands in Brazil, because rice fields have lower species richness and different species compositions than natural wetlands. However, the cumulative studies reviewed here indicate that rice fields support a large number of species from diverse groups of organisms. In this sense, depending on the specific management practices used by farmers, rice fields provide habitat for numerous wetland species, and probably play a major role in wetland species conservation in Brazil.

Here we briefly summarize some considerations that could provide direction to environmental legislators to generate policies for rice farmers that should benefit wetland biodiversity. Suggested actions connect production systems to the natural environment, resulting in the conservation of wetland species.

1. We suggest that farmers permit portions of their rice fields to naturally flood during the normal fallow phase. Even if only 15% of rice fields flood, this could provide significant benefits towards maintaining high levels of species diversity for various groups of organisms in an agricultural matrix.
2. While organic rice cultivation still harms the biological diversity of natural wetlands, the practices used by organic farmers likely reduce some stresses on biodiversity associated with rice production. Thus organic techniques should be encouraged in Brazil, especially because today Brazil is such a major consumer of agrochemicals worldwide. An increase of organic rice production in Brazil

would be a positive conservation action to simply reduce the use of pesticides in this country.

3. Rice farmers should be encouraged to periodically rest the land. This practice would reduce the systemic impacts caused by soil compaction and the use of pesticides, and it will also provide significant benefits to biodiversity. If rice farmers left a portion of their rice fields in a resting phase annually, this would contribute significantly to maintaining greater biological diversity in an agricultural matrix.
4. Draining further natural wetlands for rice production should be discouraged. We should instead encourage re-using abandoned rice fields or converting areas previously cultivated for other crops.

The high biological diversity observed in rice fields is a valuable resource in terms of biodiversity conservation, especially if certain management approaches are used (see above). Rewarding farmers for using best management practices in rice fields could result in the positive development of production systems contributing significantly to the goal of conserving wetland biodiversity.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at XXXXX.

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Table 1. List of studies developed in irrigated rice fields showing the diversity of wetland plants, invertebrates, fish, amphibians, and birds in Brazil and other world regions.

Taxonomic group	Brazil	Other world regions
Plants	Linke et al. 2014, Rolon & Maltchik 2010	Luo et al. 2014, Otsuka et al. 2006
Invertebrates	Ávila et al. 2015, Dalzochio et al. 2016a,b, Stenert et al. 2009	Schmidt et al. 2015; Settle et al. 1996.
Fish	-	Bambaradeniya et al. 2004, Fernando et al. 1979
Amphibians	Cunha et al. 2015, Machado & Maltchik 2010, Moreira & Maltchik 2014, 2015	Fernando et al. 1979, Hasegawa 1998, Naito et al. 2010, Tomioka 2000
Birds	Guadagnin et al. 2012	Amano 2009, Amano & Yamanura 2007, Brouder & Hill 1995, Czech & Parsons 2002, Elphick & Oring 1998, 2003, Fujioka et al. 2010, Ibanez et al. 2010

Table 2. Studies showing the richness of aquatic plants, macroinvertebrates, anuran amphibians and birds in drained and flooded rice fields in southern Brazil.

	Rice field management			
Taxonomic group	Drained	Flooded	Total	Reference
Aquatic plants	69 species	56 species	88 species	Rolon & Maltchik (2010)
Macroinvertebrates	50 taxa	51 taxa	71 taxa	Stenert et al. (2009)
Anuran amphibians	11 species	10 species	12 species	Machado & Maltchik (2010)
Birds	59 species	49 species	59 species	Guadagnin et al. (2012)

Table 3. Studies showing the richness of aquatic plants, macroinvertebrates and anuran amphibians in organic and conventional rice fields in southern Brazil.

	Rice management			
Taxonomic group	Organic	Conventional	Total	Reference
Aquatic plants	27 species	23 species	36 species	Linke et al. (2014)
Macroinvertebrates	58 taxa	50 taxa	64 taxa	Dalzochio et al. (2016a,b)
Anuran amphibians	13 species	11 species	14 species	Moreira & Maltchik (2014)

Table 4. Studies showing the richness of aquatic plants, macroinvertebrates and anuran amphibians in rice fields with different cultivation histories (cultivated for 3, 10, or 20 years) in southern Brazil.

	Field age				
Taxonomic group	3 years	10 years	20 years	Total	Reference
Aquatic plants	24 species	23 species	16 species	35 species	Rolon (unpublished results)
Macroinvertebrates	31 taxa	39 taxa	37 taxa	41 taxa	Dalzochio (2013)
Anuran amphibians	-	12 species	12 species	14 species	Moreira & Maltchik (2015)