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METHODS

Getting fourteen for the price of one! Understanding the factors that influence land value and how they affect biodiversity conservation in central Brazil

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ABSTRACT

Biodiversity policies are suffering an implementation crisis; the roots are deeply entrenched in the unfair competition between the public and private interests for suitable *versus* available land. In this article we propose a value-based equivalence method for compensation for the 20% compulsory reserves in the Taquari River sub-catchments, as legally required for central savannas of Brazil. Using regression techniques we analyzed 106 land deals in the Pantanal's watershed and identified the most significant variables influencing land value. We argue that the commonly used area-for-area, compensation mechanism, where 1 ha of compulsory reserve is missing, requires another hectare protected in the same catchments, instead of counteract habitat loss, is in fact harmful to biodiversity, stimulating progressive habitat destruction. We identified the economic forces behind deforestation and habitat fragmentation in the central savannahs of Brazil and proposed a market-based approach to counteract these forces using tools already available in environmental economics. We suggest that a dollar-for-dollar reference to determine land equivalence and compensation can better counter-balance the incremental losses from habitat destruction, while providing objectivity and transparency for trading alternatives.

1. Introduction

A major challenge in biodiversity conservation is to develop strategies to protect biological resources that simultaneously take into account, and are compatible with, marketplace mechanisms and other societal interests. The ability of conservationists to implement and sustain conservation actions depends on the value society places on biodiversity

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relative to other human needs, such as food production, shelter and non-essential needs such as wealth (Fearnside, 1999; Costanza, 2000a; Geoghegan, 2002; Luck et al., 2004).

Land suitable for agriculture is at a premium, particularly in developing countries. Conflicts between production and biodiversity protection have led to reserves being created only in areas that have limited use for other purposes. These *ad hoc* decisions, based on conflict minimization, have proved to be inefficient at protecting biodiversity (Pressey, 1994; Luck et al., 2004), diverting scarce conservation resources into areas where biodiversity returns are suboptimal (Brandon and Wells, 1992; Pressey et al., 1993). In addition, creating protected areas based on *ad hoc* decisions may be perceived as being non-transparent authoritarian encroachments into local affairs, particularly unpalatable in politicized rural communities.

In developing nations conservation budgets are very limited if they exist at all (Bruner et al., 2004), and when they do, allocation decisions seem to be as *ad hoc* as the reserves they aim to support (Kiss et al., 2002; Balmford and Whitten, 2003; Sarkar et al., 2006). Systematic conservation budgeting should include elements of economics and a deep understanding of the long term impact economic processes have on biodiversity protection (Fausold and Lilieholm, 1999; Drechsler et al., 2006). Nevertheless, only recently has conservation budgeting became an area of investigation in conservation science (Naidoo et al., 2006), which is still far away from being broadly implemented in developing nations (Cantrell, 1980; Bruner et al., 2004). Implementing conservation plans at any level requires an understanding of the market-based mechanisms that control the dynamics of land value and should be an intrinsic part of systematic conservation planning (Machado et al., 2004; Harris et al., 2005). Previous studies have demonstrated that not taking into account market-based responses to conservation actions can jeopardize conservation plans at all scales, from local to international (Seidl, 2001; Armsworth et al., 2006; Knight et al., 2006; Wilson et al., 2006).

In order for conservation policies to be viewed as being effective and efficient they must have explicit objectives, a transparent costing structure, and most importantly be based on arguments that are defensible (Pressey et al., 1993). A key strategy in conservation planning is to use tools which enable decision makers to get cost efficient return (Farber et al., 2002; Nalle et al., 2002; Baxter et al., 2006; Naidoo et al., 2006; Wilson et al., 2006). Costing biodiversity policies appropriately includes not only land-purchasing but also an array of additional activities (e.g. predator control, public awareness, etc.) which increase efficiency of outcomes and facilitate the dialog between conservationists and society (Knight et al., 2006; Wilson et al., 2006).

The best methods to quantitatively include non-tangible values of biodiversity into a conservation strategy are still under discussion in the scientific literature (Costanza 1996; Costanza et al., 1997; Costanza, 2000b,c; Possingham 2001; Hajkowicz et al., 2005; Armsworth et al., 2006). However, within the framework of what is called the Conservation Resource Allocation Problem land value is identified as one of the most important pieces of information needed to implement reserve systems pragmatically (Main et al., 1999). Nevertheless very few articles in the conservation planning literature deal with real-world land prices and/or the other costs associated with conservation actions (Bedward et al., 1992; Main et al., 1999; Faith and Walker, 2002). Many authors argue that this reflects an "implementation crisis" in systematic conservation (Pressey and Cowling, 2001; Costello and Polasky, 2004; Knight et al., 2006).

Lobbying to reduce the size of protected areas, or change management regimes, is becoming more frequent (Fearnside, 2003). Recently the Cristalino State Park in Mato Grosso State, Brazil, suffered a harsh attack from regional politicians in response to conflicts between the parks development and soybean producers. The region is still under threat of losing 25,000 ha (13.5%) of its area (Fearnside, 1999). These clashes of interests often occur because *ad hoc* protection tends to be argument deficient, non-consensual and politically weak when compared to traditional developmental forces.

Conflict between agricultural development and conservation is also occurring in and around the Pantanal floodplain (Fig. 1). Previous studies have presumed that most threats to the Pantanal originate from outside the floodplain in the central savannahs of Brazil (e.g. (Alho et al., 1988; Mittermeier et al., 1990; Ratter et al., 1997; Harris et al., 2005; Junk and da Cunha, 2005)). It has been demonstrated that these threats to the eastern tributaries of the Paraguay river such as loss of native vegetation, fragmentation and erosion (Harris et al., 2005), are positively correlated with recent fluctuations in commodity demand, either nationally or globally (Hamilton, 2002). While processes threatening biodiversity in the floodplain are complex and have many historical determinants (Myrup, 2001), the expansion of agribusiness in the region has become a major driver of biodiversity loss and is predicted to increase with the push for biofuel production. Agribusiness not only displaces traditional ranching and subsistence agriculture into more remote areas, but also pushes deforestation further into the Pantanal floodplain (Fearnside, 2001; Metzger, 2002; Etter et al., 2006).

Implementing a watershed-based reserve network as mandatory by the current forestry code (Ministério do Meio Ambiente, 1989) requires substantial financial commitment from both the public and the private sector (Forman, 1983; Naiman et al., 1993; Beier and Noss, 1998). Landowners in the region are legally mandated to set aside 20% of their properties as compulsory reserves. If that is not feasible the landowners may compensate the amount lacking in compulsory reserves by protecting land of equivalent ecological value within the same watershed. To comply with compulsory reserves legislation landowners will have to protect roughly 3.04 million hectares in the Pantanal. Governments on the other hand, to conform with international agreements such as the CBD (Convention on Biological Diversity, 2004), should be protecting at least 10% of their territories with representative reserve systems. According to recent recommendations to comply with the CBD (Ministério do Meio Ambiente, 2007) 45 new areas are needed to be incorporated into the public conservation portfolio to protect the 168 selected features, totaling 7.9 million hectares (52.24% of the Pantanal). Recent reviews have shown that less than 2.92% of the watershed is under IUCN reserve categories I to III (Harris et al., 2005; Lourival et al., 2008). The gap between what should be protected and what is in fact protected by governments, discounting private protection, is around 4.9 million hectares. Therefore, a long and resource intensive implementation process is expected before governments and landowners comply with their respective biodiversity conservation duties.

In this article we built a statistical hedonic model to understand the behavior of the variables associated with land

Fig. 1 – Map of Brazil and state boundaries. The grid shows the Upper Paraguay River basin, while the grey area shows the Pantanal floodplain and its subregions. The rectangle highlights the study area in the Taquari river watershed.

value. We used regression techniques to analyze 106 land transactions that occurred between 2000 and 2003 in the Upper Paraguay River Basin (UPRB) in Brazil. Our aim is to suggest quantitative arguments to offset conservation deficits from both, governments and the farming community. These suggestions are based on a series of scenarios where the trade-offs between agricultural development, land acquisition and stewardship policies can be used to support the implementation of a more realistic conservation agenda. It is our belief that market-based methods used to determine land equivalence have the advantage of being transparent and easily understood by the rural community. More importantly, their use can counter-balance the existing conditions that support incremental habitat destruction, reducing the possibility of conflicts between stakeholders (Luck et al., 2004).

2. Methods

We considered the influences of current drivers in the agribusiness sector (e.g. soy and beef production) on property prices and their effects on land-use policies. We identified 16 independent variables positively correlated with land value in the Taquari watershed (Table 1). We evaluated them using linear multiple regression models in order to identify the factors influencing land value and the root-causes of habitat fragmentation (Reydon, 1992; Ribeiro et al., 2006). The models included a mixture of categorical and continuous variables. The variables were analyzed at three spatial scales (topographic sections, economic zones, whole watershed) in order to determine which scale best describes the data.

2.1. *Study region*

The Taquari River is a tributary of the upper Paraguay basin (Fig. 1). supplying the water and sediments which formed half of the world's largest wetland, the Pantanal (Por, 1995). The Taquari watershed encompasses 19 municipalities (Veneziani et al., 1998; Assine, 2005). We used municipalities as the administrative units where land deals occurred therefore their boundaries were used to define the study region. However the extension of some municipalities can be go beyond the Taquari river catchments. These administrative units can be

Table 1 – Parameters included in the regression model as explanatory variables for land values in the Taquari watershed

Continuous variables	Scale	Categorical variables	Categories
Size of the property	Hectare	Location (municipality)	Name
Vegetation cover — 5 classes	%	Available infrastructure	Type
Current land use	%	Electricity wiring	Presence/absence
– Soybean area	%	Water availability	Presence/absence
– Cultivated grass	%	Accessibility	Good/average/poor
– Area of reserve	%	Title conformity	Yes/no/undergoing
Non-floodable area	%	Soil fertility	Very good/good/ average/poor
Topography — 3 classes	%	Soil type	Type
Native vegetation —timber	%	Tourism potential	Presence/absence
		Distance from cities	Close/medium/far

Adapted from Reydon (1992) and Aronsoon and Carlen (2000).

stratified into five landforms types (i.e. topographic zones), described as follows:

- Higher plateau — (topographic section 1) is a tableland varying between 800 and 1200 m above sea level. The area is highly suitable for intensive agriculture (soy, corn, and cotton), dairy and meat production (feed-lots, poultry and piggeries). The fraction of land covered by natural vegetation and fringing wetlands is small.
- First transition — (topographic section 2) has altitude varying between 600 and 800 m. The area is hilly and is used for semi-extensive ranching. However, soils are poor and highly erodible. Native vegetation is found in the steeper terrain and is protected by the forestry code . In these reserves secondary growth and invasive species have spread in the meadows. Endangered species such as jaguars, giant armadillos and maned-wolves (*Panthera onca*, *Priodontes maximus* and *Chrysocyon brachyurus*) use riverine corridors, gallery forests, cliffs and caves as refuges in moving between the Emas National Park (in section 1) and the Pantanal lowlands.
- Lower plateau — (topographic section 3) lies at an altitude between 400 and 700 m and is used for semi-intensive ranching and agriculture. The area is known for very erodable soils which have generated serious siltation problems in the Pantanal floodplain (Veneziani et al., 1998; Assine and Soares, 2004; Assine, 2005). This section has suffered a high degree of fragmentation but still has some blocks of native savannahs and gallery forests.
- Second transition — (topographic section 5) lies at an altitude between 250 and 600 m. The terrain is characterized by sharp cliffs on the border of the Pantanal wetland. The area has been used as a stock staging area in ranching and, when cleared, is used as a fattening ground. However, it still has reasonable natural cover which is protected formally by the forestry code. This area contains populations of rare birds of prey such as the king vulture and ornate hawk-eagle (*Sarcoramphus papa* and *Spizaetus ornatus*).
- Pantanal floodplain — (topographic section 5) is the most intact section (Padovani et al., 2004), with an altitudinal gradient between 80 and 250 m above the sea level. It only includes the Taquari river alluvial fan and the subregions of Paiaguás, Nhecolândia and Abobral. These Pantanal sub regions have healthy populations of endangered species such as the giant river otter, jaguar and hyacinth macaw (*Pteronura brasiliensis*, *Panthera onca palustris* and *Anodorhynchus hyacinthinus*).

2.2. *Regional economy*

Since the implementation of large scale agriculture in central Brazil during the seventies, monocultures of soy, corn, cotton and pastureland started to dominate rural landscapes (Ratter et al., 1997). As a result, habitat loss and fragmentation became the biggest threat to the biodiversity of the Cerrado savanna (Ratter et al., 1997; Mittermeier et al., 1998).

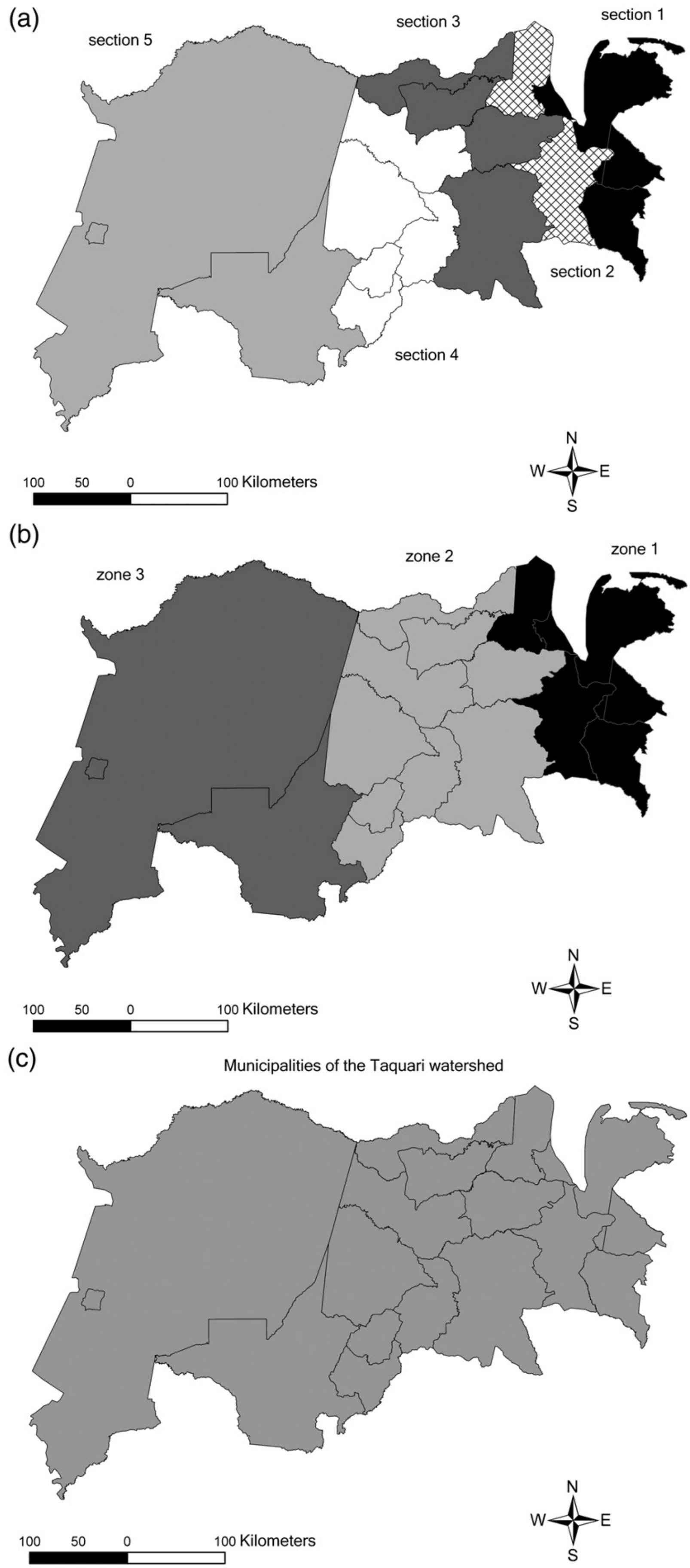
To further understand the behavior and reliability of our variables as predictors of land value, we secondarily grouped the municipalities along the Taquari watershed into three economic zones (Fig. 2b). We characterized these three agricultural production profiles (i.e. economic zones), starting with an agribusiness dominated landscape, then a transition between agriculture and semi-extensive ranching, and for last the extensive ranching of the floodplain (Reydon, 1992), as described below:

- Economic zone 1 — agribusiness dominated (encompassing landforms in sections 1 and 2). With a total of 59 land deals represented in the sample, properties in section (2) are often purchased by landowners from section (1).
- Economic zone 2 — transition between cattle-ranching and agriculture (encompassing landform sections 3 and 4). We sampled 27 land deals, most negotiated by landowners of zones (1 or 3) depending the behavior of commodity prices.
- Economic zone 3 — encompass the Pantanal floodplain, with 20 land deals evaluated. Properties have been disaggregated along family inheritance lines and bought by capitalized neighbors (within-zone transactions) or by outsiders.

2.3. *Data and variables associated to land value*

We carried out 106 interviews with farmers and rural real-estate agents which provided the information on the value of land for deals that occurred between the years 2000 and 2003 (inclusive), within the boundaries of the Taquari watershed. Because there are biases in cadastral data (e.g. due to tax evasion) the information acquired from the questionnaires was verified by consultations with other local real-estate agents and our team's expert consultant. Land values were converted into American dollars at a rate of R$2.92 for each US$1.00 (https://www.cia.gov/cia/publications/factbook/print/br.html, 2006).

We developed a questionnaire to gather information about the perception of regional landowners and professional real-


(a)
section 5
section 3
section 1
section 2
section 4
100 50 0 100 Kilometers
N
W
E
S
(b)
zone 3
zone 2
zone 1
100 50 0 100 Kilometers
N
W
E
S
(c)
Municipalities of the Taquari watershed
100 50 0 100 Kilometers
N
W
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estate agents of the factors determining land price in the region. A multidisciplinary group formed by biologists, social scientists and rural economists was involved in formulating the questions and conduct field surveys, which occurred throughout 2003. Each questionnaire provided information about 95 variables (i.e. continuous and categorical).

From these 106 questionnaires and 95 variables commonly identified in the literature were scrutinized (Aronsoon and Carlen, 2000), we identified 16 of them (Table 1) for their potential to independently influence, determine or explain current and future land value(Awokuse and Duke, 2006). Some of the variables were selected from previous studies in Brazil (Reydon, 1992), others were developed to allow us to understand the influence of environmental conditions on land deals For each possible explanatory variable we gathered data on its occurrence, quantity, quality and the proportion of the area covered by that variable.

2.4. *Statistical model development*

We evaluated the existence of correlations between land values and these variables at three spatial scales: by landform sections, by economic zones, and for the entire watershed (Fig. 2). To construct our models, we extracted the variables whose correlation coefficients were statistically significant ($p<0.05$) described in Table 1. We excluded variables that displayed colinearity, autocorrelations and heterocedasticity to avoid biasing the results obtained by the least squares method (Reydon, 1992). Nevertheless, regression analyses are known to be robust enough to allow predictions, even if some of the assumptions are not met (Borhrnstedt and Carter, 1971). We used the package ECSTAT in our regression analyses, the Fisher coefficient of 95% certainty was used as the threshold based on a *t*-test, while *r*-squared (r^2) was used to measure the model fit. We also used the Durbin–Watson test to verify the absence of autocorrelation and the Spearman's coefficient to account for heterocedasticity; all these statistics are summarized in Table 3.

The order used to describe our findings follows the previously described scales of analysis; starting with topographic sections then focusing on economic zones, and at last analyzing the entire watershed. In our models prices were composed of two fractions, one independent of explanatory variables represented by the intercept (θ) and the other composed of positive or negative influences on independent explanatory variables (Table 3). We used a linear regression model for its robustness and ability to deal with a suite of variables as summarized by the equation below. In our case, the number of terms varies according to the number of variables influencing the model:

$$\lambda = \theta + a_1x_1 + a_2x_2 \ldots + a_nx_n \tag{1}$$

where, λ is the final land value, θ is the independent fraction of realized price (intercept), $x_1 \ldots x_n$ are explanatory variables affecting price, and $a_1 \ldots a_n$ are the proportion/value of variation (i.e. area or quality) of explanatory variables.

2.5. *Conservation opportunities*

Areas available for reserve implementation in the upper Taquari River and in the plateaus around the Pantanal are becoming scarce. The levels of landscape fragmentation and the speed of habitat erosion are dramatic. From the three zones we analyzed, more than 80% of the native vegetation in zone-1 has vanished, while zone-2 has lost more than 50% (Machado et al., 2004), and zone-3 is undergoing rapid habitat conversion where it transitions from wetland to higher ground (Padovani et al., 2004).

Conservation mechanisms capable of preventing further degradation of key habitats and biodiversity in this region are urgently needed. A common mechanism for providing solution to such habitat loss is based on area-for-area compensation whereby the degradation of habitat in one area is offset by protecting an equivalent area in another region. Area-for-area compensation is embedded into different pieces of legislation in Brazil such as: The Forestry code and in resolutions of the National Environmental Council (Ministério do Meio Ambiente, 1989). Nevertheless none of the indicators showed that habitat destruction have slowed down since their inception (Padovani et al., 2004). There are several possible explanations for the apparent ineffectiveness, most related to the weaknesses of enforcement apparatus. Our aim in this paper is to examine the behavior of the variables that influence land value and propose an alternative method to determine land equivalence for compensation purposes.

3. Results

We found that sample size, scale of analysis and land-use practices all significantly influence the capacity of the models to explain changes in land values (Tables 2 and 3). We present our results following the same scales order used in the methods (topographic sections, economic zones, whole watershed).

When the analysis was conducted by economic zone, the modeled results were more reliable than when done by topographic sections. The models explained a large amount of the variation in land value ($0.53>r^2<0.98$ — Table 3), with topographic section 2 being the exception with an r^2 value of only 0.24. The explanatory variables that were included in the largest number of models were the area planted with soybean and the area of cultivated grass, indicating that agricultural commodities were a major indicator of land value in many areas.

3.1. *Topographic section models*

In topographic section (1), higher plateau, the average land value was US$1011.31 while the intercept, represented by the independent fraction of the price was just $278.17. Land value is therefore highly dependent on the percent of area producing soybean, with a percent increase in area producing soybean adding $15.3 to the value of a hectare. In

Fig. 2 – Municipal boundaries in the Taquari watershed represented in our 106 questionnaires. In (a) municipalities are grouped according to topographic sections, in (b) the same municipalities are grouped by economic zones, while in (c) the entire watershed scale is represented by the external municipal boundaries.

Table 2 – Summary information of the land deals surveyed within the Taquari watershed between 2000 and 2003

Scenarios	Total area (ha) 19 municipalities	Supposed 20% of legal reserves	Number of properties negotiated	Maximum property size (ha)	Minimum property size(ha)	Average property size(ha)	Standard deviation	Average value/ha (in US$)	Value of the supposed legal reserve system
Section 1	1,594,351.0	318,870.2	22	4651.0	144.0	976.3	1236.43	1011.31	322,476,621.96
Section 2	1,099,759.6	219,951.9	37	1250.0	151.3	440.8	584.1	1171.36	257,642,881.01
Section 3	2,237,706.5	447,541.3	8	765.0	121.0	394.4	224.0	674.10	301,687,590.33
Section 4	2,239,673.4	447,934.6	19	3370.0	31.0	981.0	1040.1	360.09	161,296,798.92
Section 5	8,056,739.0	1,611,347.8	20	32,528.8	300.0	9302.2	11,259.3	73.19	117,934,546.21
Zone 1	2,154,180.7	430,836.1	59	4651.0	31.7	765.8	889.9	949.00	408,863,496.86
Zone 2	5,017,309.8	1,003,461.9	27	3370.0	31.0	820.9	929.9	398.62	400,000,006.50
Zone 3	8,056,739.0	1,611,347.8	20	32,528.8	300.0	9302.2	11,259.3	73.19	117,934,546.21
Entire watershed	15,228,229.5	3,045,645.9	106	32,528.8	31.0	2386.9	5900.1	258.23	786,477,143.34

Information is grouped by section, zone and the entire watersheds. The calculated value of required legal reserves (20% of area), based on average land value, is also shown (Ministério do Meio Ambiente, 1989).

topographic section (2), first transition, the intercept was higher (US$1245.09) than the actual average land value. Here, areas covered by cultivated grass imposed a negative impact on prices, reducing the value of each hectare by $8.07. In topographic section (3), second plateau, the area of cultivated pasture and the presence of reserves worked to decrease property value. In the model for topographic section (4), second transition, the presence of a negative intercept indicates that a minimum accessibility/infrastructure is required in order for the property to be considered by the market. We verified that value per hectare increased up to US $80 when accessibility and other infrastructure are enhanced. In topographic section (5), Pantanal floodplain, there was also a negative intercept, indicating that properties must have a minimum area that is not subjected to flooding and a minimum area of cultivated grass in order to be negotiable in the market.

3.2. *Economic zone models*

In economic zone (1) agricultural commodities was the major driver of land value. Area of soybean cultivation increased land value while the existence of native timber drove land value down. In the model for economic zone (2), transition — agriculture and ranching, the value for the intercept (θ) was larger than the average realized price, indicating that the predictive variables are driving land value down. The results of this model indicate that infrastructure played a decisive and positive role on land value in zone (2), while areas of reserves depreciated property value. The results for zone (3), extensive ranching, are the same as those presented for section (5), Pantanal floodplain. The model indicates that farms should have a minimum amount of non-floodable area even to be considered by the market, while the value per hectare increases up to 10% when properties have cultivated pasture.

Table 3 – Explanatory land value models for the Upper Paraguay basin

Scale	Explanatory variables (effect)	Code	Model specification	*t*-test	r^2	*p*-value	D_{DW}
Section 1	Soybean planted area (+)	X4c	$\lambda = 278.17 + 15.32(X4c)$	7.86	0.7553	61.72	2.03
					0.7430		
Section 2	Cultivated grass area (–)	X4a	$\lambda = 1245.09 - 8.07(X4a)$	−3.36	0.2440	11.29	1.65
					0.2224		
Section 3	Cultivated grass area (–)	X4a	$\lambda = 2391.18 - 17.30(X4a) - 34.25(X4e)$	−13.51	0.9894	233.12	2.84
	Area of reserve (–)	X4e		−8.19	0.9851		
Section 4	Infrastructure quality (+)	X6b	$\lambda = -50.52 + 41.25(X6b) + 38.61(X8)$	3.26	0.5396	9.96	1.91
	Access quality (+)	X8		3.21	0.4855		
Section 5	Non-floodable area (+)	X5	$\lambda = -104.66 + 2.85(X5) + 3.48(X4a)$	5.05	0.7766	29.55	2.05
	Cultivated grass area (+)	X4a		4.59	0.7500		
Zone 1	Soybean planted area(+)	X4c	$\lambda = 722.92 + 10.01(X4c) - 178(X15a)$	6.40	0.5587	3599	1.92
	Native vegetation-timber (–)	X15a		−4.40	0.5429		
Zone 2	Area of reserve (–)	X4e	$\lambda = 453.53 - 13.84(X4e) + 33.63(X6b)$	−4.03	0.5374	13.94	2.69
	Infrastructure quality (+)	X6b		3.46	0.4988		
Zone 3	Non-floodable area (+)	X5	$\lambda = 104.66 + 2.85(X5) + 3.48(X4a)$	5.05	0.7766	29.55	2.05
	Cultivated grass area (+)	X4a		4.59	0.7500		
Watershed	Soybean planted area (+)	X4c	$\lambda = 620.05 + 11.40(X4c) - 141.15(X15a)$	10.51	0.6576	99.88	2.02
	Native vegetation-timber (–)	X15a		−5.64	0.6510		

Models are grouped according to the scale at which they are applied The two r^2 values represent the actual value (top) and adjusted value (bottom) which takes into account the number of explanatory terms in the model.

3.3. Watershed model

Our last scale of analysis involved all 106 properties and encompassed all 19 municipalities in the watershed. The average negotiated value at this scale was US$258.23. Here again the value of the intercept (θ) was larger than the average realized price, with native vegetation-timber reducing land value by US$414.15 /ha. Land value was significantly influenced by the soy-planted area which increased land value by US$11.4/ha.

3.4. Possible scenarios

In order to verify the usefulness and limitations of our models for conservation we tested how land value is predicted to change using scenarios for future modification in land-use and reserve implementation (Table 4a). We chose to use the economic-zones scale because it represented a good compromise between sample size and robustness in predictive power. We examined five different scenarios in each zone (Table 4a). We manipulated values of explanatory variables in each model to represent five circumstances, with the objective of verifying their impacts on land prices as shown in Table 4a. Based on these results we were able to propose equivalence values between zones (Table 4b), which can be used as guidelines for conservation agreements and land acquisition policies.

In agribusiness dominated zone (1) the value of land increases greatly when it is converted to soybean production. When 100% of the property is under soybean production (i.e. lacking 20% of compulsory reserves), land value reaches its peak at US$1724.55/ha. On the other hand, from 59 properties in zone (1) 19 properties sold had 100% of their area covered with native vegetation, such acquisitions were made to fulfill the need of other title holder to comply with the 20% compulsory legal reserve.

In transition — agriculture and ranching zone (2), the model only works for properties that have small areas in any form of natural reserves. When reserves are larger than 32.7% of the property their effect on prices drove modeled values to negative results (i.e. an artifact of linear models). On the other hand, the current legislation determines that 20% of all properties should be set aside as compulsory reserved areas. These two conditions constrain the reliability of model predictions to a very narrow range. Nevertheless the value of land that contains poor infrastructure is US$176.65/ha, while good infrastructure and absence of reserves can augment value to US$789.87/ha.

In Pantanal zone (3) increasing the percentage of reliable pasture land, land that is not susceptible to flooding and contains cultivated grass, increases property value. In an extreme scenario where 100% of the area is converted to pasture the land value increased five fold, reaching US$528.93/ha.

Table 4a – Variations in land values resulting from manipulations of the models proposed for the three zones in Table 3

Zone 1 scenario	Soybean (Δ %)	Native timber (pres/abs) [a]	Land value US$
1	0	1	202.21
2	50	1	703.03
3	0	0	722.93
4	50	0	1223.74
5	100	0	1724.56
Zone 2 scenario	**Reserve (Δ %)**	**Infrastructure (0–10)**	**Land value**
1	32.76	0	0.00
2	20	0	176.66
3	0	0	453.54
4	0	5	621.70
5	0	10	789.88
Zone 3 scenario	**Non-floodable (Δ %)**	**Pasture (Δ %)**	**Land value**
1	37	0	0.00
2	0	30	0.00
3	50	20	107.60
4	80	0	123.47
5	100	100	528.93

Each scenario presents different combinations (quantity and quality) of the explanatory variables. The symbols and abbreviations between parentheses are: means variation in percentages of the specified land area (Δ %) and presence and absence of features (pres/abs) are shown.

[a] For the purpose of the scenario simulation the variable was transformed into presence/absence, since in zone 1, properties either have native timber or they do not.

Table 4b – Reference values for possible equivalence ratios between zones considering explanatory variables

Zone	Scenario	Zone 3	Zone 2	Zone 2
		Scenario 4	Scenario 4	Scenario 5
1	4–50% area of soy No timber	9.91	1.97	1.55
1	5–100% area of soy No timber	13.97	2.77	2.18
2	4 — no reserve Average infrastructure	5.04	–	–
2	5 — no reserve Good infrastructure	6.40	–	–

Values are calculated by dividing the land value of a scenario in a particular zone by another.

4. Discussion

In this paper we show that land values in the Taquari watershed in Brazil are driven by biodiversity unfriendly activities. This result holds at each of the scales we analyzed. Currently, activities that degrade biodiversity, such as agricultural intensification, substantially increase the value of rural properties. Meanwhile all biodiversity friendly variables (e.g. presence of reserves) functioned to diminish the market value of a property.

All variables which were correlated with land value, despite the perception of them being friendly or unfriendly, favor landholders continue with deforestation and land-use intensification due to their effect on land value (Tocantins et al., 2006). The clearest signal of this effect, can be detected in current and past deforestation rates (Da Silva et al., 1998; Seidl et al., 2001). Regulatory mechanisms, such as the opportunity for compulsory reserve compensation elsewhere (Ministério do Meio Ambiente, 1989), were not capable of holding back the processes that stimulate habitat destruction. Improving the understanding on how such parameters influence can provide great improvement on such legislation.

Property values in rural areas of Brazil tend to dynamically fluctuate with national and international commodity prices, often responding promptly to changes in monetary and regulatory policies (Seidl, 2001; Armijo, 2005; Tocantins et al., 2006). Conversely, conservation budgets rarely are adjusted in response to market dynamics. We demonstrated that modeling techniques can be used to identify variables that significantly impact land value (Drechsler et al., 2006; Wilson et al., 2006). We suggest that managers and environmentalists make use of these models to understand the behavior of land value. This information can then be incorporated into regional conservation strategies, in order to improve their efficiency (Smith et al., 2003; Bruner et al., 2004).

In the case of the Taquari watershed, our results suggest that land value is best predicted when the models are evaluated at the scale of economic zones, rather then by topography or the entire watershed. Analysis at the level of economic zones reflected the spatial variability and the dynamics of land-use practices in the Taquari watershed, offering the best compromise between sample size, robustness and model predictive power.

Our analysis also emphasizes that perceptions of the marketplace can significantly influence the dynamic behavior of land value and therefore the behavior of predictive variables. For example, areas devoted to soybean production are considered fertile and valuable by the agribusiness community. This perception had the effect of increasing land value in and around the Pantanal. Future shifts in agribusiness strategies may also alter these relationships very fast. For example changes in demand for biofuel may push this sector to diversify into sugarcane cultivation in less fertile soils, with an inevitable carry-on effects in the upper terrains of the Pantanal (i.e. economic zone 3), with the potential for accelerated deforestation rates and a disruption of the local social context even further (Padovani et al., 2004; Armsworth et al., 2006).

The impact of particular land use and its influence on land price depended on the region in which the development occurred. For instance, the extension of cultivated pasture in topographic sections 2 and 3 decreased land value, while the same variable in topographic section 5 and economic zone 3 had a positive influence on land value. However, until recently the presence of pasture in topographic section 3 and economic zone 2 was a highly desirable feature because ranchers of the Pantanal invested their profits by expanding their activities into the dryer savannas (Seidl et al., 2001). This trend has changed after massive investments in savanna agriculture (e.g. plant selection, credit lines and infrastructure). The impact of such policies reached the Taquari watershed in the late seventies causing well documented damage to this watershed (Godoy et al., 2002). These studies highlight the dynamic nature of land value and its correlation with the economic drivers of a region.

Recent discussions in the literature have identified a potential negative impact of land acquisitions on biodiversity. For instance, Armsworth et al. (2006) note that land acquisitions can generate undermining feedbacks to conservation goals. Our results demonstrated that variables connected to biodiversity protection (e.g. presence of native vegetation reserves, presence of native timber stands), do have a negative effect on land value, driving prices significantly down at all scales of analysis. The negative influence of biodiversity protection on land value is also demonstrated by the negative intercepts in the models of topographic sections 4 and 5 and economic zone 3. The negative intercept can be interpreted as the minimum value of predictive variables (i.e. available infrastructure, accessibility, floodability and cultivated grasslands) for a property to have any commercial value.

The value of land in the Pantanal (i.e. economic zone (3) and topographic section (5)) relied on the extent of land that is not at risk of being permanently flooded. Properties in this region must have a sufficient area of land that stays above water and a sufficient area of land covered by cultivated pasture, in order to be economically valuable. The negative relationship between flooding and land value found in the Pantanal has historically minimized development and promoted the areas wilderness status. In wetlands flooding is a force that supports ecosystem productivity (Junk, 1992; Mitsch and Gosslink, 1993), and this is acknowledged by traditional farmers. Nevertheless, while low intensity floods in the Pantanal increase fertility and create a disturbance regime that maintains grasslands, high intensity flooding have associated costs as well. For example, to a landowner flooding can result in substantial increases in transportation cost, increased delays and costs associated with infrastructure development and the periodic loss of animals and crops. Land value in this region reflects the balance between landscape composition and moderate flooding that is required to providing enough forage such that ranch productivity is maintained (Seidl et al., 2001).

Another interesting result related to the Pantanal floodplain is that there are dramatic disparities in property size and average land value when compared to other sections/zones. Therefore, the volume of capital needed for land acquisition in the Pantanal is proportional to property size. Historically economic viability using traditional production methods demanded areas bigger than 7000 ha (Garcia, 1984; Seidl, 2001). Properties are rarely sliced in smaller units, imposing to buyers large financial commitments. This fact may explain dominance of intra-zone and out-of-state investments, diverting short term speculators and neighboring agriculturalists that are driving land value up on the surrounding plateaus.

4.1. *Market-based land equivalence valuation*

Recent changes in the Brazilian forestry code act reinforce requirements for farmers to protect 20% of their property; these changes allowed agriculturalists to compensate for the lack of compulsory reserves in their original title on lands outside properties. Nevertheless, compensation should be within the same watershed and assessed by environmental agencies for habitat quality, this process has not been clearly defined and standard indicators are still missing. As a result compensation mechanisms are hectare-based despite the need for ecological equivalence between these areas.

Land equivalence and biodiversity equivalence by extension are thorny subjects, requiring the understanding of complex interfaces between ecology and economics (Bruggeman et al., 2005). Although there are some experimental examples of biodiversity equivalence from Australia and the United States (McCarthy et al., 2004; Wilcove and Lee, 2004) they have not been used in developing nations.

Our results demonstrate that a habitat conservation strategies based on area-for-area compensation as prescribed in the Brazilian legislation (Ministério do Meio Ambiente, 1989), are having unintended results in facilitating development in areas of high conservation importance. Under current legislation developers can purchase cheaper land in adjacent regions to compensate for the destruction of habitat in a region with higher agricultural potential and consequently higher land value. Our data shows that price-wise, within the Taquari watershed, 1 ha of fully developed property in economic zone (1) has an equivalence value of up to 14 ha in the Pantanal floodplain, economic zone (3). This equivalence is based on a scenario that assumes extensive ranching usage of the property (i.e. 20% of floodable area and no cultivated pasture — Table 4b).

We argue that compensation for properties under intensive agriculture but lacking of compulsory reserves (i.e. economic zone 1), can be used as trade advantage in another zone, if there are no possibility for compensation in the same zone. We advocate that intra-watersheds compensation mechanisms should be based on asymmetric land value equivalence (Wu and Babcock, 1996; Von Ziehlberg, 2000; Dobbs and Pretty, 2004) rather than the symmetric area-for-area defined in the legislation (Ministério do Meio Ambiente, 1989). We believe that asymmetric land value equivalence based on modeling can inhibit the effect of variables that drive-up land value at the expenses of habitat loss. Such change can also promote the maintenance of areas of high biodiversity value elsewhere via positive feedback mechanisms.

Our results indicate that land price feedback mechanisms need to be incorporated into conservation budgeting in order to counteract current fragmentation trends (Padovani et al., 2004). Land value models that incorporate feedback dynamics can be used to design economic incentives and penalties that will promote the conservation of biodiversity. Both incentives and penalties must have significant impact over land value, so that they offset undesirable price drivers (Dobbs and Pretty, 2004). Another alternative is the development of land-value-based resource conservation agreements or stewardship mechanisms as used in Florida with the purpose of providing habitat to the Florida panther (*Puma concolor coryi*) (Main et al., 1999). In this scenario financial benefits are transferred between landowner's in different zones of the same watershed. Social contracts such as these engage rural communities in protecting biodiversity and facilitate the achievement biodiversity conservation goals for species and processes. In addition, these contracts engage landowners and the broader society into conservation by sharing costs and responsibilities of protection (Thorbjarnarson and Velasco, 1999; Kremen et al., 2000; Elmendorf 2003; Chomitz et al., 2006).

To illustrate the potential of conservation in private lands in the Taquari watershed, we used the 20% determined by the forestry code as a reference. In this case compulsory reserves should cover at least 3 million hectares for the entire watershed. Based on the average acquisition value of US $258/ha, the compulsory reserves of the Taquari watershed are worth US$786 million in protection (Table 2). If we use the average values for the other two scales (i.e. economic zones and topographic sections) the contribution of an eventual compulsory reserve network alone could be worth respectively US$926 million and US$1.2 billion.

While some authors argue that spatially explicit equivalence methods, such as the habitat-hectare method (e.g. used in Australia) can be the appropriate approach for land equivalence and compensation, Such mechanisms are still under scrutiny of scientists (McCarthy et al., 2004).

Although highly portable, the habitat-hectare method is also data hungry. Therefore it will take a long time, for widening their use in data poor countries, a time that conservationists might not have, considering the pressure of current threats. We believe that land value equivalence is one of the most pragmatic tool to conduct such assessments, until habitat based models become accessible (Maddock, 1999; McCarthy et al., 2004; Gibbons and Freudenberger, 2006).

5. Conclusions

We argue that budgetary decisions need to be based on the actual costs of the conservation activities planned (i.e. from environmental education to reserve implementation). Almost inevitably land acquisitions will be required for implementation of effective reserve networks. However, the costs associated with conservation plans can be minimized via strategic approaches to regulatory mechanisms such as taxation, stewardship mechanisms or even by strengthening enforcement (Faith and Walker, 2002). Land value equivalence models are particularly useful when combined with the above tactics.

Society as a whole is bearing a cost for the inaction of governments and from the rural sector. The Taquari watershed alone is worth up to 1.2 billion dollars in compulsory reserves. Until more sophisticated methods such as habitat-hectare equivalence became available, conservation planning should incorporate state-dependent decisions (premised on land value models that incorporate current land use, existing infrastructure, etc.), which can be evaluated on an annual basis. The use of step-wise state-dependent process would allow appropriate implementation and monitoring of conservation actions. Nevertheless, it is very important that carefully designed baseline studies are conducted, so that investments can actually be correlated with conservation success (Ferraro and Pattanayak, 2006).

Unless the biodiversity agenda incorporates economic arguments and convert them into mechanisms to counteract, or at least balance the effects of developmental forces into land value, the ability of conservationist to compete for land in the marketplace will always be jeopardized.

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