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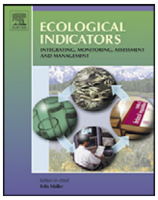

Case study

Exploring effective conservation networks based on multi-scale planning unit analysis. A case study of the Balsas sub-basin, Maranhão State, Brazil

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ABSTRACT

Nature conservation and restoration activities require delineation of effective conservation networks. This paper presents a methodology which allows a quick evaluation of different planning options for extensive areas. We analyzed the spatial structure of remaining patches of the natural Cerrado vegetation in the Balsaǐs sub-basin, South of Maranhão State of Brazil (about 25,590 km^2) in order to understand how the remaining habitats are distributed and spatially configured. Conservation area network scenarios are based on hexagonal cells, referred to as analysis unit (AU) cells. A multi-scale analysis of 10,000 ha and 50,000 ha AU cells was set up to represent local and regional scales, respectively. For each AU at both local and regional scales we computed landscape metrics of native vegetation: NATIVE VEGETATION COVER: percentage of native vegetation cover; (NV-NP): number of patches; (NV-MSI): mean shape index. Subsequently, five different conservation and restoration strategies were defined: (a) only enforce nature conservation within legally established units; (b) target nature conservation only within the local AU landscape; (c) target regional management by combining neighboring AU; (d) management of both local landscape and region; (e) protect the legal conservation areas and promote local and regional conservation. We also generated scenarios of habitat capacity for mammals and matched these results with the different vegetation conservation scenarios. Results indicate that only 12% of the study area is well conserved and that 43% of the region is in a very critical condition. The percentage of AU cells where native vegetation conservation actions are required differ for the five conservation strategies: These results allow policy makers and other stakeholders to target the locations and extent of conservation units required. We suggest that about 45% of the sub-basin could be managed at local, regional or both scales. Regarding a mammal species diversity scenario an even higher percentage of the average habitat capacity of the selected species occurs in open cerrado and valleys areas that coincide with critical areas. The proposed multi-scale analysis unit cell approach can support the planning process of extensive areas as necessary in Brazil.

1. Introduction

Recent studies indicate that multi-scale land use and land cover change dynamics are relevant for targeting effective areas for conservation and restoration of natural ecosystems (e.g. Veldkamp et al., 2001; Kangalawe et al., 2008; Ribeiro et al., 2009). In many areas land cover data is often used as a proxy for ecological data, despite the fact that it cannot express the whole complexity of real ecosystems (Walsh et al., 2008). Nowadays, with the availability of abundant GIS tools and with the growing knowledge of landscape ecology, new promising methods are becoming available to improve the identification of effective conservation networks. Since environmental planning is an interactive, transdisciplinary activity (but see Metzger, 2008), the scientific community can use simple images and environmental indicators to explain to politicians and stakeholders the dynamics of land cover change and their impacts (Opdam et al., 2003; Schindler et al., 2008).

Many studies have proposed planning for sustainable management of basins, forests, landscapes and biodiversity for nature conservation in a context of integrated ecological tools and habitat networks, combining modeling of biological data with political and economic development scenarios (e.g. Vos et al., 2001; Verboom et al., 2001, 2006; Opdam et al., 2003; Fahrig, 2003; Lindenmayer et al., 2006; Oliveira filho and Metzger, 2006). For planning purposes,

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local and regional strategies and actions need to be developed for conservation and environmental restoration (see Jongman and Pungetti, 2004). The conversion of primary vegetation to extensive monoculture, intensive farming and urban areas implies significant impacts on biodiversity, as it leads to partial or – sometimes – total loss of unique natural habitats (Oliveira filho and Metzger, 2006; see also Ribeiro et al., 2009). For this reason, biodiversity conservation is a growing concern in landscape planning and management. A possible sustainable conservation strategy is to establish networks of intact natural areas to counter the effects of fragmentation (Vos et al., 2001; Ribeiro et al., 2009). Many methods have been developed to integrate habitat network requirements with species' responses to landscape pattern change (Vos et al., 2001; Opdam et al., 2003). Fahrig (2003) listed several definitions about habitat fragmentation to better understand its effects on biodiversity. The fragmentation results in an increase of the number of patches, decrease in patch sizes and, increase in isolation of patches (nearest neighbor distance). According to the author habitat amount influences the above cited landscape metrics and highlight that regions where patches are large often correspond to regions where there is more habitat.

Multi-scale landscape analyses can help build understanding of the role of regional scale change on local scale processes (Wagner and Fortin, 2005; Boscolo and Metzger, 2009; Lyra-Jorge et al., 2009; Fortin and Dale, 2005, 2009). Recently this journal dedicated a special issue on "Ecological Indicators at multiple scales", edited by Zurlini and Girardin (2008), who highlight the relevance of multi-scaled analysis contributions on the improvement of better knowledge regarding socio-ecological systems, and providing good ecological indicators for ecosystems management. Multi-scale approach have been applied to several ecological studies: understanding aquatic system responses (Cassandra et al., 2008); selection of ecological indicators to understand ecological changes in Georgia pine forests (Dale et al., 2008); quality-of-life indicators (Malina-Pykh and Pykh, 2008), landscape change dynamic (Walz, 2008); assessment impacts on preserved areas (Zaccarelli et al., 2008); bird incidence function at fragmented landscapes of Atlantic forests (Boscolo and Metzger, 2009); influence of habitat amount and edge density on medium and large-sized mammals of a savanna dominated landscape of southeastern of Brazil (Lyra-Jorge et al., 2009); and insect taxa association across local, regional and macro-regional scales of Neotropical streams (Roque et al., 2010).

In this paper, we describe a methodology for identifying effective conservation strategies for large areas (>50,000 ha). Our objective is to demonstrate that a combined multiple metrics and multi-scale approach is a promising technique to facilitate identification of concrete actions for effective ecological conservation, mainly when macro-regional strategies need to be addressed (see Ribeiro et al., 2009).

2. Methods

2.1. Study area

Agriculture first appeared in the Southern Maranhão region in the 1970s, with expansion particularly during the 1990's. Balsas' region (see Fig. 1) was the target area for the implementation of various agro-industrial projects such as 'Batavo' and 'Nova Holanda' that caused environmental degradation due to over exploitation of soils (Sematur, 1991; Barreto, 2007). As a consequence of arable land expansion, natural habitats were replaced and remaining areas were fragmented, which had a significant impact on the diversity of regional flora and fauna (Barreto, 2007). The *Cerrado* originally covered about 60% of Maranhão State, and is the more representative vegetation physiognomy of the State (MMA, 1999). Because of the scattered natural remnants, the remaining areas serve as ecological pathways and stepping stones, consequently controlling current species distribution and dynamics. Apart from that, the southern region is the area where three important biomes (Amazon, Cerrado and Caatinga) meet and interact resulting in high species diversity and environmental heterogeneity (Barreto, 2007). Given the large land changes in the Balsas region, we explore effective conserva-

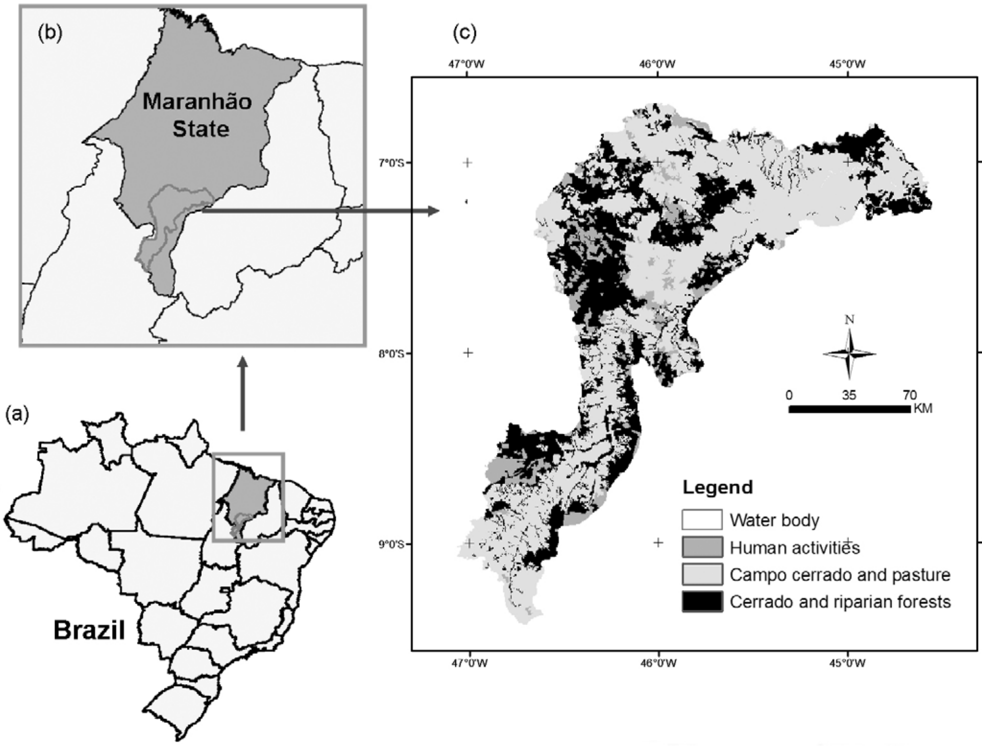

Fig. 1. Location of the study region. (a) Brazilian states; (b) Maranhão State and Balsasĩs basin in red; (c) Land cover for Balsaĩs basin. Source: Lansat Lab, State University of Maranhão, 2007.

Table 1
Land cover summary for Balsasĩs basin, Maranhão State, Brazil, 2000 year.

Cover class	Area	
	km^2	%
Human activities (crop fields and buildings)	2423	9.5%
Water body	16	0.1%
Brazilian savanna (cerrado) and Riparian Forests	8337	32.6%
Open fields (campo cerrado) and pasture	14,814	57.9%
Total	25,590	100%

tion networks using a multi-scale analysis. The spatial structure of remaining native vegetation patches of Balsa's sub-basin are analyzed using landscape metrics at different scales in order to understand how the remaining habitats are fragmented and connected.

We analyzed the spatial structure of remaining patches of native vegetation in Balsa's sub-basin comprising 25,590 km^2, south of Maranhão State of Brazil (S09°29′30″/S06°35′19″ and W47°13′30″/W44°28′00). The land cover map (see Fig. 1 for spatial patterns and Table 1 for area coverage of the most important cover types) was derived from Landsat/TM 5 images acquired for the year 2000. Thirteen cover classes were reclassified into four general classes, to better match the scales of this study: (a) cerrado (Brazilian savanna) and riparian forests; (b) open fields (campo cerrado) and pasture; (c) human activities (crop fields and building) and (d) water bodies.

2.2. Analysis units and multi-scale analysis

Measuring or quantifying vegetation fragmentation is not a straightforward task (Fahrig, 2003). One landscape metric which has often been used to characterize the fragmentation level is the number of habitat patches (henceforth, NV-NP). Such metrics, when used alone, are of limited use (Corry and Nassauer, 2005). In previous studies, the sampled or analyzed units (i.e. landscape of analysis) differ in size and their accuracy is often not well known. To overcome this limitation we subdivided the study area into equally sized cells hereafter called analysis units or AU—of about 10,000 ha. In the literature, there are three commonly shape types of analysis units that are neutral with respect to land ownership: rectangular, hexagonal or natural environment division (sub-basin of 5th order, for example). Hexagons and rectangular cells have been used to measure spatial and temporal landscape heterogeneity (Griffith et al., 2000; Jurasinski and Beierkuhnlein, 2006; Schindler et al., 2008). Recently Birch et al. (2007) evaluated the pros and cons of using rectangular (or quadratic) and hexagonal shaped cells for ecological modeling. They found that when the target of analysis is landscape structure characterization like spatial arrangement (configuration) or connectivity of habitat patches, the hexagonal shaped cells provided better results compared to rectangular cells. Based on the findings of Birch et al. (2007), we chose hexagonal cells as analysis units.

Our study region was subdivided into 325 hexagonal cells, each comprising 10,000 ha. We chose this size for three reasons. Firstly, it is a manageable dimension for designing coordinated conservation and restoration actions, at local scales at implementation (Opdam et al., 2003). It also corresponds to the average actual size of conservation units in the study area. Secondly, for our purpose we considered this size allows computation and analysis of land cover and habitat patch configurations computationally fast for large number of AUs (Gardner et al., 1989). Thirdly, this size is consistent with other studies of landscape structure and configuration (Radford et al., 2005; Uezu et al., 2005; Martensen et al., 2008; Umetsu et al., 2008; Hansbauer et al., 2008; Metzger et al., 2009; Boscolo and Metzger, 2009). However, considering also that the responses of different taxa change across scales (Wagner and Fortin, 2005; Fortin and Dale, 2005, 2009) and, that analysis of only one scale level provides a partial diagnostic of the overall 'status' of habitat cover and spatial arrangement for biodiversity, we decided to compute the landscape metrics on an additional scale. For each original AU, we defined a second layer of larger AU cells of about 50,000 ha, as nested AUs. The 10,000 and 50,000 ha AU cells were treated as local and regional scales, respectively. Our rationale for in a regional context (50,000 ha) is the potential to capture the influence of regional on local scale processes of relevance to Brazil (Boscolo et al., 2008; Boscolo and Metzger, 2009; Lyra-Jorge et al., 2009; Roque et al., 2010).

2.3. Landscape metrics and data analysis

For each AU and for both scales we computed the three landscape metrics for extant native vegetation (NV) (Cerrado and riparian forest, see Fig. 1): percentage of cover, number of patches and mean shape index. These metrics were computed using the software Fragstats version (Mcgarigal and Marks, 1995), which can be run using the Patch Analyst 3.1 extension (Rempel, 1999) of ArcView 3.2 (ESRI, 1999). These landscape metrics were selected because they are commonly used on conservation planning and for biodiversity assessment, as well as it is easily computed (e.g. Riitters et al., 1995; Hargis et al., 1998; Neel et al., 2004; see also Schindler et al., 2008; Cushman et al., 2008).

The native vegetation cover index is a useful metric at the local landscape level, because it provides general information about threshold values for percolation and fragmentation (Stauffer, 1985; Fahrig, 2003). The number of patches of native vegetation is a metric that can be used to estimate the fragmentation level of a region of interest. However, the same values can be observed on landscapes with low, median and high vegetation cover. Therefore, we combined this metric with other metrics, such as vegetation cover. Verboom et al. (2001) suggested an approach that classifies networks of native vegetation according to the presence or absence of one or several relatively large patches to distil the variety of potential landscape patterns into a few simple measures that have a more direct ecological interpretation.

The mean shape index quantifies the shape of all native vegetation patches inside an AU. The more circular the patches the closer the index value is to one. If the patches are irregular the AU will have shape index values greater than one. For biodiversity conservation purposes, a circular-shaped patch is generally considered to be more desirable because irregular-shaped patches potentially have more edge effects, which affect patch properties (e.g. microclimate and population dynamics) and favor invader, opportunist and generalist species, often at the expense of locally adapted species (Murcia, 1995). It is also important to consider that in the case of large patches the edge effects have less impact.

The frequency distribution of classes of each landscape metric within the AUs, for both scales, was computed. Chi-square statistics were used where applicable (Zar, 1999) to test for differences in metric values between the local and regional scales. The statistical tests were done to demonstrate if the distribution of cells across number of patches is non-uniform. In the case of vegetation cover, we incorporated threshold values based on the literature for percolation in relation to animal movement (Stauffer, 1985; Gardner et al., 1989) and fragmentation (Andrén, 1994; McIntyre and Hobbs, 1999; Fahrig, 2003). The Pearson correlation coefficient was calculated for vegetation cover to test for significant differences in the metric values between local and regional scales.

All statistics were computed using R language (R Development Core Team, 2008). Two-dimensional scatter plots between the three landscape metrics were generated for visual comparison.

Table 2
Frequency for NATIVE VEGETATION COVER classes, at local (index 10) and regional scales (index 50). Freq = Number of cells, Pct = percentage, Cum = cumulative percentage.

NATIVE VEGETATION COVER class	Freq10	Pct10	Cum10	Freq50	Pct50	Cum50
(0–10%]	98	30.2%	30.2%	54	16.6%	16.6%
(10–20%]	42	12.9%	43.1%	51	15.7%	32.3%
(20–30%]	35	10.8%	53.8%	62	19.1%	51.4%
(30–40%]	22	6.8%	60.6%	38	11.7%	63.1%
(40–50%]	32	9.8%	70.5%	48	14.8%	77.8%
(50–60%]	23	7.1%	77.5%	29	8.9%	86.8%
(60–70%]	23	7.1%	84.6%	20	6.2%	92.9%
(70–80%]	11	3.4%	88.0%	10	3.1%	96.0%
(80–90%]	19	5.8%	93.8%	13	4.0%	100.0%
(90–100%]	20	6.2%	100.0%	0	0.0%	100.0%
Total	325	100.0%		325	100.0%	

Finally, landscape metrics across the two scales were combined to identify locations for native vegetation conservation strategies and actions including protection and restoration. These locations were compared with an independently created map identifying potential conservation areas for mammal species. In this map the potential habitat capacity was summed up for a series of mammal species following expert knowledge rules (Eupen et al., 2003). The potential suitable habitat areas were extracted by relating spatial landscape characteristics with species characteristics. Landscape characterization was done by extracting and combining abiotic and biotic information such as soil, topography, and vegetation species information consist of estimations of densities in different habitat types and known home range and dispersal distances. Results of this relation are maps with potential connected habitat areas for which the total dispersal capacity per species was calculated.

The final joined map can be seen as an indicator for mammal habitat quality since it is summing up the capacity of all selected species. By creating this map independently from the landscape metric approach it could be used to check if correspondence between both maps and methods exist.

3. Results

We were unable to identify natural open fields in a consistent way–such as campo cerrado–on Landsat/TM images, and consequently the cover classes campo cerrado (open fields) had to be combined with pasture and the area of each class computed (Table 1). Open fields and pasture are the most extensive at 57.9%, followed by native forest (cerrado and riparian forest), which covers about 32.6% of the study area.

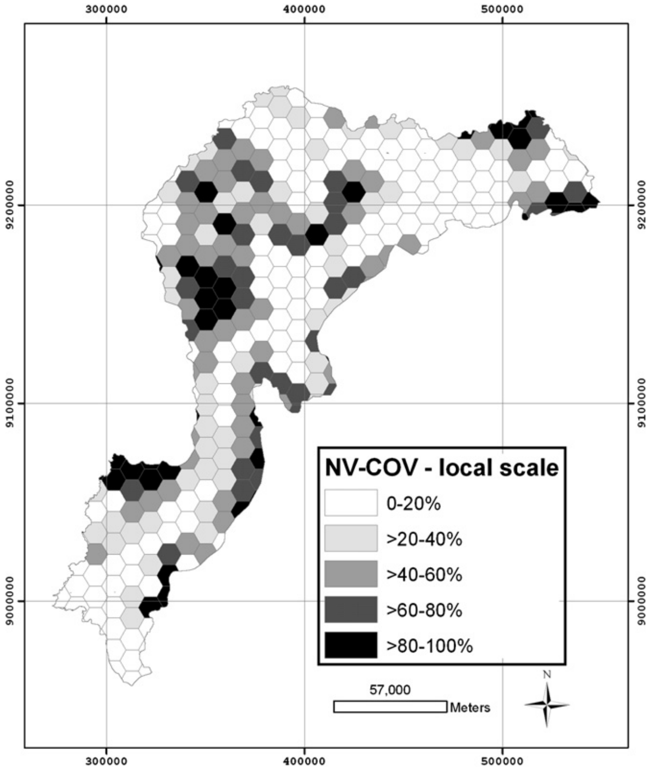

Fig. 2. Classes of NATIVE VEGETATION COVER values attrib to each AU of 10,000 ha, estimated at local scale.

3.1. Native habitat pattern analysis

Our analysis of vegetation cover at the local scale (Table 2) shows that 53.8% of AUs have a percentage of cover <30% The frequencies for the first three native vegetation cover classes (0-30% of total cover) did not differ significantly ($X^2 = 0.963$; $n = 325$; df = 1; $p = 0.3488$) when compared to frequency of other native vegetation cover classes (31–100%). A probable cause for this observation is that the cell quantities below the fragmentation threshold are statistically similar the cell quantities above the fragmentation threshold.

At the local landscape scale, the native vegetation cover of 0–10% and 10–20% showed 30.2% and 12.9% of the total number of cells (Table 2). This means that more than one third of the study region is critically fragmented. Considering the native vegetation cover values for each AU, and for each landscape scale, we grouped these values into five general classes (Figs. 2 and 3). The 80–100% class with native vegetation cover has relatively few landscapes represented at the 50,000 ha scale, whereas the 0–20% class with patchy or removed nature vegetation cover is well represented, at the local scale.

3.2. Number of patches as a measure of fragmentation

About 10% of AU cells at the local scale have no vegetation cover and therefore no native vegetation patches (Fig. 4) compared with <1% at the regional scale. Also, at the regional scale we recorded 63% of AU with 1–4 patches, with a peak frequency at 1 patch (26% of AUs). The Chi-square test demonstrated the NV-NP was statistically high ($X^2 = 10.7741$; $n = 325$, df = 1; $p = 0.0019$) when comparing NV-NP between 1 and 4 against other classes of NV-NP (NV-NP = 0 and NV-NP ≥ 5). About 7% ($n = 22$) of AU showed NV-NP > 8 and only one AU exhibited 15 patches.

The number of vegetation patches as metric is difficult to interpret alone because one can have low values on landscapes with low or high native vegetation cover amount (see Fahrig, 2003 for details). Therefore we decided to combine these two metrics. We grouped native vegetation cover into values into 25 classes of 5%

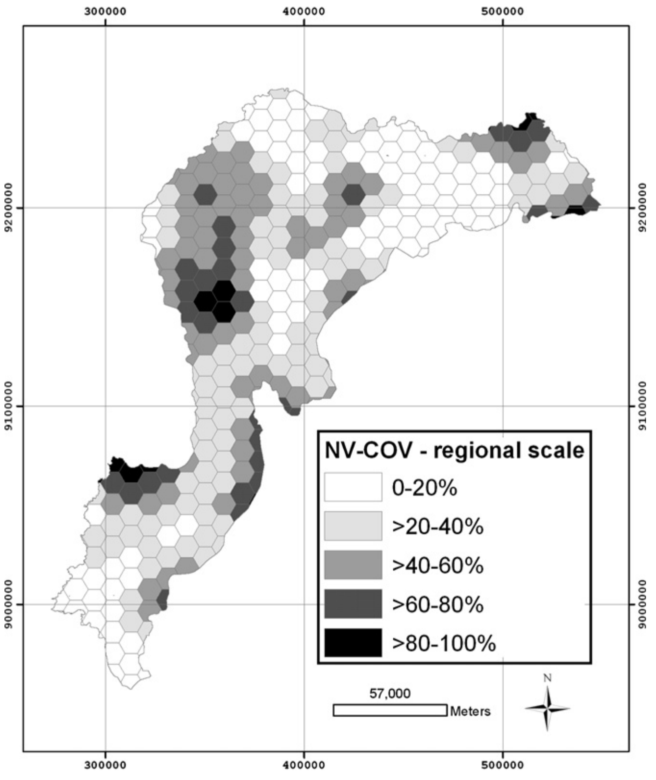

Fig. 3. Classes of NATIVE VEGETATION COVER values for each AU of 10,000 ha, but estimated at regional scale (50,000 ha around the midpoint of AU).

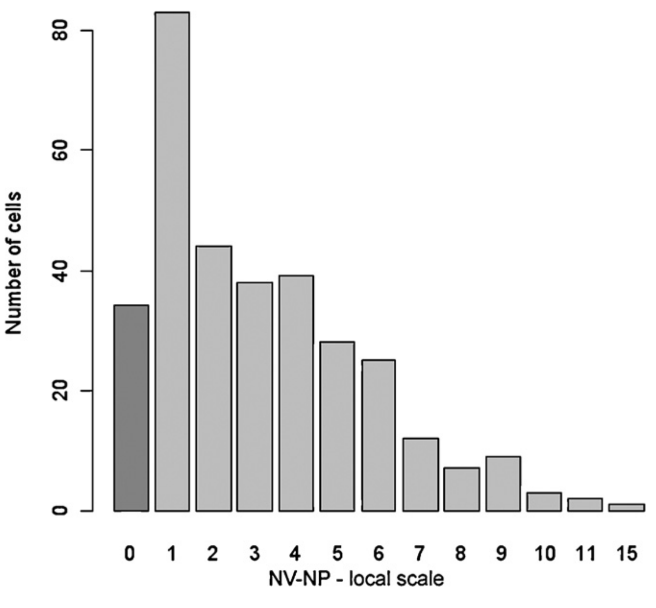

Fig. 4. Frequency of AU (cells) for the levels of number of patch (NV-NP), at local scale.

ranging from 0 to 100%, and computed the frequency of number of native vegetation patches (from 1 to 15), at the local scale (Fig. 5). The largest frequency was observed for native vegetation cover values < 20%.

Analyzing Pearson's correlation, we observed a slightly negative relationship between the number of native vegetation patches and native vegetation cover ($r = -0.10$; $p > 0.05$). This result could suggest that when native vegetation cover increases, fragmentation tends to decrease. We also observed that low levels of native vegetation patches (i.e. 1–4) are represented by native vegetation cover across its entire range. On the other hand, relatively high native vegetation patches (≥5–15 patches) tends to be related to low habitat amounts (native vegetation cover = 24 ± 17%; $n = 59$).

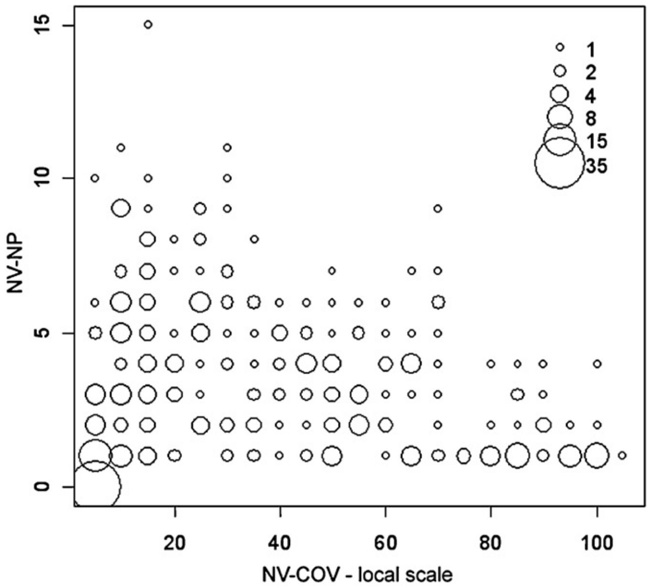

Fig. 5. Frequency of AU (cells) for the combination of levels of number of patch (NV-NP) and levels of NATIVE VEGETATION COVER (from 0 to 100%, step by 5%), at local scale. The size of circles is proportional to the frequency.

3.3. *Mean shape index landscape metric*

We analyzed mean patch shape index at the local scale for those cells with native vegetation cover present ($n = 291$ of 325 AU; Fig. 6). We observed 8.6% with compact or circular-shaped patches (values in the range 1–1.5); 53.6% with moderately regular-shapes (values: 1.6–2.5); 32.6% are of irregular or dendritic shape (values: 2.5–4.0) and 5.2% are critically irregular (values >4.0). These differences were statistically significant ($X^2 = 94.58$; $p < 0.001$ $n = 291$; df = 3). From the perspective of ecological condition, we estab-

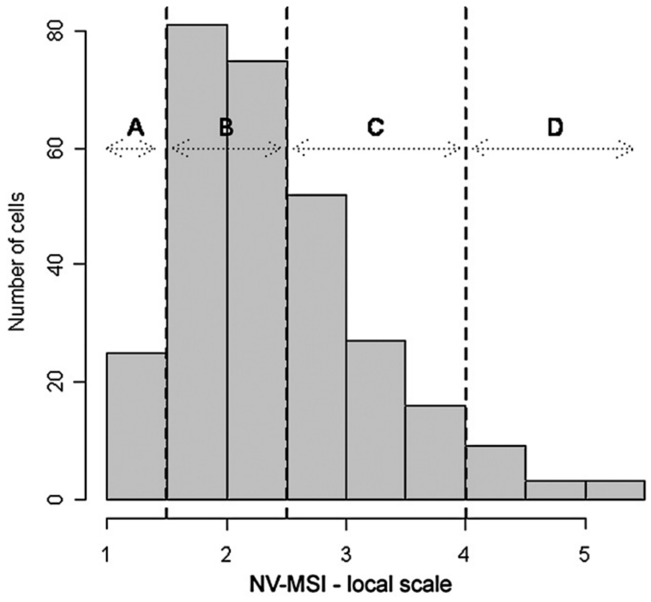

Fig. 6. Frequency of AU (cells) for Mean Shape Index (NV-MSI) classes. A = circular/compact shape; B = moderately regular shape; C = irregular or dendritic shape; D = critically irregular shape.

Table 3
Percentage of number of cells combining NATIVE VEGETATION COVER classes values at local and regional scales. Marginal row subtotal refer to the percentage of cells for local scale NATIVE VEGETATION COVER classes. Marginal columns subtotal refer to the percentage of cells for regional NATIVE VEGETATION COVER classes. The total sum of internal matrix is 100%.

NATIVE VEGETATION COVER at local scale	NATIVE VEGETATION COVER at regional scale					Row subtotal
	(0–20%]	(20–40%]	(40–60%]	(60–80%]	(80–100%]	
(0–20%]	29.2	11.7	2.2	0.0	0.0	43.0
(20–40%]	2.2	11.4	3.7	0.3	0.0	17.6
(40–60%]	0.3	6.2	9.5	0.9	0.0	16.9
(60–80%]	0.3	1.2	5.5	3.1	0.3	10.5
(80–100%]	0.3	0.3	2.8	4.9	3.7	12.0
Col subtotal	32.3	30.8	23.7	9.2	4.0	

Table 4
Conservation actions and management strategies delineated at multi-scale. The actions were based on NATIVE VEGETATION COVER values. CS-LEG: only follow protection CS-LEGislation; CS-LOC: management of landscape (i.e. the interior of AU cells); CS-REG: management of region (i.e. the neighbor of AU cells); CS-LOC&REG: management of both landscape and region; CONS: protect the areas and promote local and regional conservation.

NATIVE VEGETATION COVER at local scale	NATIVE VEGETATION COVER at regional scale				
	(0–20%]	(20–40%]	(40–60%]	(60–80%]	(80–100%]
(0–20%]	CS-LEG	CS-LEG	CS-LOC	CS-LOC	CS-LOC
(20–40%]	CS-LEG	CS-LOC&REG	CS-LOC	CS-LOC	CS-LOC
(40–60%]	CS-REG	CS-LOC&REG	CS-LOC&REG	CS-LOC&REG	CONS
(60–80%]	CS-REG	CS-REG	CS-REG	CONS	CONS
(80–100%]	CS-REG	CS-REG	CS-REG	CONS	CONS

lished that the mean shape of patches within AU can be considered an intermediate situation, with only few cells having an excellent (compact or circular mean shape) or critical (very irregular) shapes.

3.4. Analyzing native vegetation cover at multi-scale

In Table 3 we present a synthesis of the results obtained when considering a multi-scale approach. The native vegetation cover metrics were reclassified into five classes: 0–20%; 20–40%; 40–60%; 60–80% and 80–100%. We counted the percentage of cells belonging to the combination of native vegetation cover classes at both scales. Marginal row subtotal showed in Table 3 refers to the percentage of AU which represents the habitat amount class at local scale. The marginal column subtotal refers to regional scale for that specified habitat amount class.

In general we observe that the class with the highest number of AUs (29.2%) is covered by less than 20% of native vegetation cover at local and regional scales, followed by local = 0–20% and 20–40%, with 20–40% at regional scales (∼11% on each case). None of the cells were recorded with high regional (>80%) native vegetation cover and with low to moderate (0–60%) native vegetation cover at local scale. We also observed that about 41% of cells belong to native vegetation cover between 40 and 80% at both scales.

3.5. Defining conservation strategies for the analysis units

The results at both local and regional scales allow us to propose a multi-scale criteria approach to define conservation strategies based mainly on native vegetation cover values. The conservation actions suggested are: (1) only follow protection legislation; (2) management of landscape (i.e. the interior of AU cells); (3) management of region (i.e. the neighbor of AU cells); (4) management of both landscape and region; (5) protect the areas and promote local and regional conservation. Table 4 shows these actions assigned to the native vegetation cover classes in multi-scale categories. These actions are stated in a comparative way, and could help to define macro-regional strategies for conservation. Of course, if one is interested in one particular cell, these results would be contested, and the scale of analysis would be changed, as would the scope of conservation targets and actions. Rather, our results are designed to inform macro-regional conservation policies and strategies. A detailed description of the actions is shown below:

- CS-LEG: the cells are in a critical condition (<40% of habitat amount) on local and regional scales and in this case if funding is dedicated to this management strategy, this could result in a lower contribution of macro-regional conservation. So we strongly recommend that management here is followed by conservation legislation;
- CS-LOC: As the regional scale presents good conservation status (>40–100% of the habitat amount), we suggest to provide conservation strategies at the landscape (local) scale;

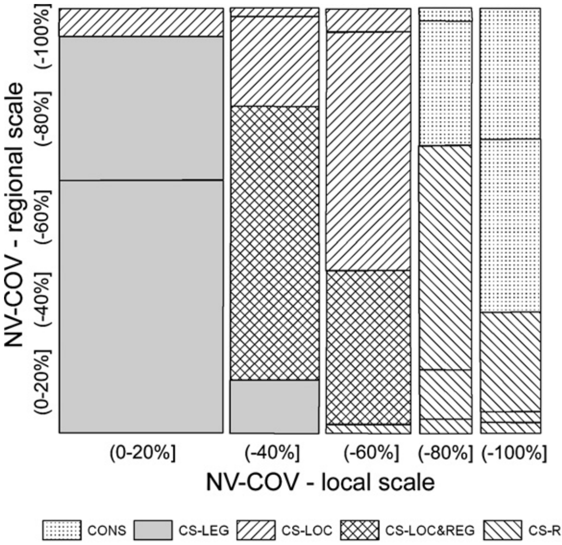

Fig. 7. Proportion of conservation strategies in a multi-scale approach. The actions suggested where: CS-LEG: only follow protection legislation; CS-LOC: management of local landscape (i.e. the interior of 10,000 ha AU cells); CS-REG: management of region (i.e. the neighbour of AU cells); CS-LOC&REG: management of both landscape and region; CONS: protect the areas and promote local and regional conservation.

- CS-REG: As the local scale present good conservation status (>40–100% of the habitat amount), we suggest to provide conservation strategies at the regional (neighbor of target cell) scale;
- CS-LOC&REG: It concerns cells in which the habitat amount are in an intermediate conservation situation (habitat amount of >20–80% at local scale and >20–60% at regional scale). We suggest to define conservation strategies that take in account both the landscape (local scale) and the neighbor (regional scale) of the target cell;
- CS-CONS: Improve conservation strategies, without management needs. We consider that these regions could be defined as the main regions to be defined at integral protected areas. Regional scale metrics helps on the definition of a conservation area network.

We classified our 325 AU into one of the five management strategies described above. The following percentage of cells was assigned to each action: CS-LEG = 43% (*n* = 140 cells); CS-LOC = 6.2% (*n* = 20); MRE = 28% (*n* = 91); CS-LOC&REG = 10.8% (*n* = 35) and CS-CONS = 12% (*n* = 39). In Fig. 7 we illustrate the proportion of actions and management strategies across the scales analyzed in this study.

3.6. Comparing multi-scale landscape metrics and habitat capacity scenarios for mammals

The simple visual comparison of the combinational map of the landscape metrics (showing locations for native vegetation conservation strategies) with the map indicating potential mammal species habitat quality, shows that a higher percentage of average habitat capacity for the selected species occurs in open cerrado and valley areas (compare Figs. 1 and 8). This result is relevant because it allows targeting of combined vegetation and mammal conservation measures.

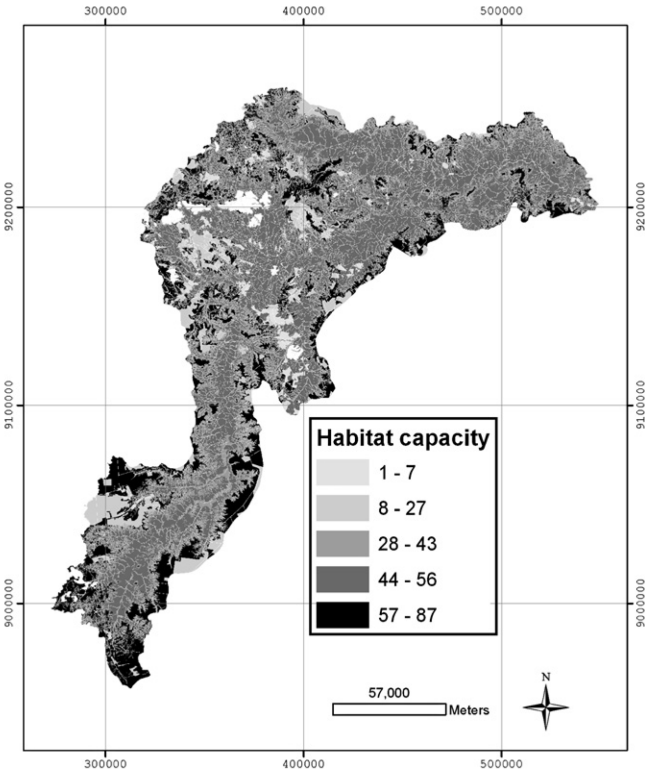

Fig. 8. Average habitat capacity for all selected mammal species in the Balsasĩs region, south of Maranhão State, Brazil.

4. Discussion

When a region has only about less 30% of its original native vegetation remaining, it is considered to be at a fragmentation threshold below which there is increasing evidence of impacts on population persistence (Fahrig, 2001, 2003; Huggett, 2005). In fact, the study area presents a heavily degraded area with few large (>1000 ha), and many small (<100 ha) and isolated patches. Landscapes with low natural habitat coverage (<30%) are considered to have a low connectivity. According to Taylor et al. (1993) connectivity is a measurement of how much an organism of interest uses landscape features (i.e. habitat patches, corridors, matrix), or alternatively what the probability of movement of this organism is across the study landscape. It has been suggested that connectivity is related to colonization probability (Fahrig and Merriam, 1985; Hanski and Simberloff, 1997) and the rescue effect, as key processes determining population maintenance in fragmented landscapes (Hanski and Simberloff, 1997). As the study region in 2000 is at a critical fragmentation threshold, we consider biodiversity to be at risk if no conservation actions are implemented, and ecosystem diversity may collapse in the nearby future.

4.1. Native habitat pattern analysis

Our analysis of vegetation cover at the local scale (Table 2) shows that 53.4% of AUs have a percentage of cover <30%. This suggests that about half of AU cells are below the critical fragmentation threshold (of <30% of total cover) (Andrén, 1994; Fahrig, 2003) and that much of the rest of the landscape is in marginally better condition. When the AU is below the fragmentation threshold, the population's maintenance capability for species a high habitat area requirement is expected to be low.

As the regional native vegetation cover can be linked to landscape connectivity and fragmentation, we can deduct that connectivity within the study region is low. Of course connectivity will depend on the target species or taxonomic group. For example, if one considers a large-sized mammal, the region may be considered relatively well connected. However, if a small mammal species (<5 kg) were the target species, and its ability to cross gaps (i.e. move between patches, through inhospitable matrix) is relatively low (e.g. <100 m; see Boscolo et al., 2008; Awade and Metzger, 2008; Martensen et al., 2008; Metzger et al., 2009), the whole region may be considered poorly connected.

Considering that many AUs have native vegetation cover values below 30% at both scales the future perspectives of maintaining biodiversity at the same level is low. Therefore, it is important to relate the amount of habitat with different fragmentation measures in order to identify actions for the majority of species that occur in a region of interest. For example, as the native vegetation cover increases though restoration actions, the relative size of the largest patch (i.e. source areas) also increases. This pattern can be observed in an ascendant manner up to ~50% of habitat amount; when the cover is greater than 50%, the number of patches tend to decrease (Fahrig, 2003). In one of these cases, one species could be favored and others will not. It is also relevant to consider that in order to maintain biodiversity large patch areas with a large interior are required. Large patches buffer edge effects and tend to be more heterogeneous than small patches due to greater-within patch variation in biophysical factors such as slope, attitude and substrate type (Verboom et al., 2006).

In conclusion our results suggest that half of the region could be said to be in a critical degree of conservation, with low habitat amount at both scales. The other half of the region shows a transition between low (<20%) and slightly high (60–80%) natural habitat coverage.

4.2. Number of patches as a measure of fragmentation

As Fahrig (2003) commented, the number of vegetation patches is difficult to interpret alone because one can have low values (1–4 patches, for example) on landscapes with low or high native vegetation cover amount. Frohn and Hao (2006), listed 16 landscape metrics calculated and evaluated with respect to the effects of changing spatial resolution. The patch density metric showed the most predictable behaviour among the patch metrics decreasing with increasing spatial resolution. They considered that metrics may behave differently to aggregation in areas with different spatial patterns, a result commonly found in analyzing land cover patterns (Veldkamp et al., 2001). Therefore, for this, we decided to combine native vegetation and number of patches metrics. Castellon and Sieving (2007) applied the criteria in three real-world demonstration landscapes, first, to predict numbers of breeding territories of endemic birds potentially accommodated within patch configurations and, second, to evaluate increases that might be achieved if landscape connections among isolated patches were restored (e.g., using corridors). Because it is important to distinguish changes in habitat configuration from changes in habitat area in assessing the potential impacts of fragmentation, Ferrari et al. (2007) investigated two metrics that measured these different influences on connectivity. The combination of the two metrics provided a means for targeting sites most at risk of suffering low potential connectivity as a result of habitat fragmentation. Peng et al. (2006) indicate that increasingly more investigations suggest that not only scale effects and the precision of remote sensed data had significant influence on landscape metrics, but also the difference of land use classification affects change of landscape metrics.

4.3. Mean shape index landscape metric

In the study area, the mean shape of patches within AU can be considered an intermediate situation, with only few cells having an excellent (compact or circular mean shape) or critical (very irregular) shapes. This allows us to conclude that the whole region area is dominated by moderately regular to irregular or dendritic shaped patches. In fact, only few compact and large patches can be found on the landscapes, and many of native vegetation are found as small irregular-shaped patches near riparian condition. Ohman and Lamas (2005) showed that it is possible to use the shape index metric in large long-term planning problems for decreasing fragmentation. Therefore, we considered it is a metric useful when used in conservation issues and much of the focus in studies of spatial modelling.

4.4. Comparing multi-scale landscape metrics and habitat capacity scenarios for mammals

We are convinced that our results can be used to support the creation of a future Natural Park in the Balsas region. The mapping of native vegetation cover values and metrics has indicated hotspots that require conservation action. Ideally this should be combined with land use/cover change projections based on modeling (Verburg et al., 2004). These studies can identify where the conservation hotspots and management zones (Verburg and Veldkamp, 2004) occur and where immediate action is needed most. Once the landscape metrics are calculated and analyzed sessions with all stakeholders are required to come to a feasible solution.

5. Conclusion

The definition of required management actions and selection of priority sites are important steps towards effective local and regional biodiversity conservation plans. Historically the selection of areas for integral protection have been done by taking in account scenic beauty, cultural reasons, areas dedicated to install visiting parks and charismatic species. Furthermore, attention was focused on the last remaining native vegetation areas, which are usually in the less accessible places (Veldkamp and Fresco, 1997). As a consequence, many areas protected by law were established in regions of high elevation, where soil is poor compared with lower elevation plains and where economic interest is low (Rouget et al., 2003).

Lindenmayer et al. (2006) suggested a management checklist as a short-cut to improve conservation of natural ecosystems. The authors highlight the importance of landscape features such as connectivity and heterogeneity. Our work exploited several features of landscape patterns and connectivity in a multi-scale way. When only analyzing one feature and at one scale level, the results could mask the real conservation status of the AU cells as demonstrated by the different results at the two scales, a result which is also found in land use pattern description (Kok and Veldkamp, 2001). This also links to the dilemma pointed out by Vos et al. (2001) and Opdam et al. (2003) that because species differ greatly in their response to landscape features and spatial scale there is no optimal solution for biodiversity conservation. Choices have to be made, and the method outlined here can help making these choices more informed.

Finally, we wish to emphasize that the suggested methodology needs to be evaluated and adjusted considering the real needs of each region. If the entire study area comprises less than 50,000 ha, we suggest another approach should be evaluated, for example, compute patch-level functional connectivity and minimum patch size. Yet, if the study area is larger than 50,000 ha, we consider a multi-scale approach based on ecologically relevant landscape metrics will help inform macro-regional conservation actions.

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