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Impact of oil palm plantations on the structure of the agroforestry mosaic of La Gamba, southern Costa Rica: potential implications for biodiversity

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Abstract Human activities often cause changes and homogenization in landscape structure. To investigate the impact of changing cultivation systems on structural and functional aspects of a tropical agroforestry system, we developed satellite based land cover maps of the La Gamba area in southwestern Costa Rica and refined them by mapping fine-scale linear landscape elements. Performing a landscape pattern analysis, we compared eight sections of the study area by landscape metrics. Furthermore we performed a Morphological spatial pattern analysis (MSPA) for hypothetical non-forest, forest generalist and forest specialist species, and compared the current situation to a possible future scenario with double the area covered by oil palm plantations after a virtual conversion of other agricultural patches. The heterogeneous rural sections clearly differed from the homogeneous forests and especially pasture-dominated rural sections included many diverse, small and elongated patches, many linear landscape elements but few big plantations. According to the scenario with double the area covered by oil palm plantations, non-forest species lost large parts of their habitat, while forest species mainly lost corridors. The protection of natural landscape elements that support wildlife movement between forest areas is of major importance, particularly as the globally increasing cultivation of oil palm is significantly altering many tropical land mosaics, including the countryside of La Gamba. We propose the establishment of eight least cost path corridor routes in the study area to make the agricultural area pervious for wildlife.

Keywords Landscape corridor · Landscape metrics · Land use change · Morphological spatial pattern analysis · MSPA · Oil palms · Piedras Blancas National Park

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Introduction

Today, biodiversity is highly threatened by human activities in most tropical regions of the world (Myers et al. 2000; Kappelle et al. 2003; Brooks et al. 2006; Butchart et al. 2010). Not only natural ecosystems, but also human dominated landscapes are facing increasing biodiversity loss (Chazdon et al. 2009; Fahrig et al. 2011). Loss and fragmentation of tropical forests and rapid changes in land use have a great influence on population dynamics of various native plant and animal species (Rosero-Bixby and Palloni 1998; Sala et al. 2000; Harvey et al. 2008a). Habitat fragmentation has weaker effects on biodiversity than habitat loss (Fahrig 2003), but it leads to a considerable change in habitat quality. Changes in land use and land cover have different effects on particular guilds of species, as species only occurring in forest interior face greater habitat loss through fragmentation than species associated with edge habits or secondary habitats within the human dominated landscape (Bender et al. 1998).

Habitat fragmentation can be alleviated by improving the ecological connectivity between forest patches and natural landscape elements in agricultural areas (Beier and Noss 1998). The presence of natural landscape elements, such as forest patches, gallery forests and live fences, is therefore of great importance for wildlife using cultivated areas (Harvey et al. 2005, 2008b; Fischer et al. 2006; Seaman and Schulze 2010). Biological corridors connect patches of natural vegetation, which facilitates movement of plants and animals and ensures the continued course of ecological processes (Chetkiewicz et al. 2006). This reduces the extinction risk of fragmented populations and favours the recolonization of unpopulated habitats. Interconnected populations whose individuals can disperse between habitat patches are usually less likely to die out and face less fluctuation in population size than isolated populations (Beier and Noss 1998; Burel and Baudry 2003).

The village of La Gamba in Southwestern Costa Rica and its surrounding agricultural area belong to an important zone for wildlife exchange between lowland and mountain areas, but also between different lowland forest areas (Weissenhofer et al. 2008). The economy of the area has undergone several changes, but cattle breeding and rice production has always been important, and up until the 1980s large areas of the countryside were deforested to gain farmland (Klingler 2007). Today, rice cultivation has sharply decreased while the production of oil palm has risen steadily, where oil palm plantations are already the second most area intensive land use type after pastures. The cultivation of oil palm is increasing globally, causing severe problems in many tropical agricultural systems leading to deforestation, loss of biodiversity, destruction of soils and alteration of traditional countryside (Corley and Tinker 2003; Fitzherbert et al. 2008; Koh and Wilcove 2008). It was expected that until 2050, palm oil demand will likely be nearly twice as high as it is today (Corley 2008). In 2008, oil palm plantations covered near 30% of the agricultural portion of our study area and profoundly affected the landscape structure of the agroforestry mosaic (Höbinger 2010). So far they have mainly replaced rice fields and pastures, without causing much new deforestation. Their expansion into forest areas is less likely than in other regions because forests around La Gamba mainly cover steep and rather inaccessible areas. In contrast, more than 80% of pastures and other agricultural land use types and more than 90% of oil palm plantations were to be found in the river plains at inclinations of less than 5° (Höbinger 2010).

This study aims at assessing current and future processes in tropical agroforestry landscapes, using a lowland region in southern Costa Rica as a case study. The study objectives were (1) to analyze the landscape pattern of the agroforestry system (2) to assess the landscape functionality for different species guilds for the current situation and for a future scenario with double the area covered by oil palm plantations (3) to evaluate the effects of fine-scale linear landscape elements on the overall landscape pattern, and (4) to determine potential corridor routes between the forest areas as well as gaps that should be restored with particular priority. Assessing the effects of fine-scale linear landscape elements, which must be mapped in the field, is of a methodological interest, because it provides insight as to whether the additional effort of field mapping indeed pays off. As the analysis 'without linear elements' additionally provides a scenarios of more homogeneous landscapes where linear elements (live fences, forest strips, hedgerows, little streams, drainage ditches, roads, and footpaths) have been eliminated, we could also address the ecological question of their importance for overall connectivity (e.g., Dawson 1994; Beier and Noss 1998; Bennet 2003). The study evaluates the landscape ecological consequences of on-going land use change, especially the spread of oil palm plantations in the region, and forms a basis for further investigations and action plans for biodiversity conservation in this area and in other tropical landscape mosaics.

Methodology

Study area and land cover mapping

The study area, the agroforestry systems and forest areas surrounding the village of La Gamba, is situated at the edge of the Piedras Blancas National Park in the southwest of Costa Rica (Golfo Dulce region). Its range of altitude lies between 60 and 345 m.a.s.l. and it covers a total area of 25.7 km^2 (centered at 8°40′ N and 83°11′ W). Costa Rica is one of the most biodiverse countries in the world (Kappelle et al. 2003), and the Golfo Dulce region has a particularly rich flora and fauna (e.g., 2,369 vascular plant species, Weber et al. 2001) due to a perhumid climate and a high diversity of orographic formations. The Piedras Blancas National Park includes six types of lowland primary forest: forest on plains, forest on hill tops and ridges, forest on inland slopes, forest on coastal slopes, forest in ravines and lowland riverine forest (Weissenhofer et al. 2008). The zone around La Gamba is important for the dispersal and movement of plant and animal species between different lowland forest areas as well as for the connection between lowland and mountain forests (e.g., Piedras Blancas National Park and the Fila Cal, an unprotected zone with pristine mountain forests). To investigate the landscape mosaic, we mapped land cover from satellite images (minimum mapping unit: 600 m^2) as well as fine-scale linear landscape elements in the field (minimum width: 1 m). The thematic resolution was 26 land cover categories plus seven further categories of linear landscape elements (Table 1). The base for mapping of the region was a ‘QuickBird 2’ satellite image with a pixel size of 2.4 m for the multispectral channels (green, blue, red and infrared) and 0.6 m for the panchromatic channel (La Gamba, Costa Rica, QuickBird scene 0520173 30010_01_P001, 6/12/2007 © Digital Globe 2008, Distributed by Euroimage).

Landscape pattern analysis by landscape metrics

To analyze the landscape pattern, the number of land use categories was reduced to eleven: primary forests, secondary forests, shrublands, riparian vegetation, fern-dominated vegetation, pastures, oil palm plantations, live fences and timber plantations, agriculture, settlements and roads, and drainage ditches and rivers (including ponds). We divided the study area into eight sections, each representing homogenous zones with similar land use history (Klingler 2007). Each zone is of a compact shape, comprises mainly either forests or agricultural mosaics, and includes enough single patches for a robust calculation of landscape metrics (Fig. 1).

In a first approach we chose landscape metrics to analyze the landscape pattern (O’Neill et al. 1988; Turner et al. 2001; Uuemaa et al. 2009). A careful choice of metrics is essential if redundancies and misleading results are to be avoided (Li and Wu 2004). In order to find a suitable set of metrics we followed the suggestions of Botequilha Leitão et al. (2006), Cushman et al. (2008) and Schindler et al. (2008) and finally applied a set of eight landscape metrics for our analysis. As the landscape sections differed in size, we preferred metrics that are standardized for area. We computed the metrics patch area (AREA) and perimeter-area fractal dimension (PAFRAC) for both landscape and class level analyses (McGarigal and Marks 1995), the metrics patch density (PD), similarity index (SIMI), contagion (CONTAG) and patch richness density (PRD) for landscape level analysis only, and the metrics Euclidean Nearest Neighbor Distance (ENN) and Edge Contrast (ECON) for class level analysis only. SIMI was used as the area-weighted mean of all single patches. ENN and ECON represent the area-weighted means of the respective land cover classes. We applied the eight neighbor rule to guarantee that linear landscape elements were identified as single patches (McGarigal and Marks 1995; Schindler et al. 2008). For SIMI and ECON, we defined a similarity and contrast matrix, respectively. The values for these matrices were based on characteristics of the land cover categories, such as tree cover, vegetation height, intensity of land use and naturalness.

Morphological spatial pattern analysis (MSPA)

In a second approach of landscape pattern analysis, we performed a Morphological spatial pattern

Table 1 Land cover types and linear landscape elements defined as habitat (including corridors or stepping stones) for forest specialist (*FS*), forest generalist (*FG*), and non-forest species (*NF*) for the MSPA

Land cover	FS	FG	NF
Areal elements			
Primary forest	X		
Old secondary forest	X	X	
Young secondary forest		X	
Charral		X	X
Forest patch	X	X	
Major riparian forest	X	X	
Pioneer riparian forest		X	X
Gynerium sagittatum			X
Fern-dominated veg.			X
Pasture no trees			X
Pasture single trees			X
Pasture arboreal > 50 m			X
Pasture arboreal < 50 m		X	X
Tacotal		X	X
Oil palm pl. > 3 years			
Oil palm pl. < 3 years[a]			X
Timber plantation		X	
Banana plantation			
Corn			X
Rice			X
Cacao		X	
Cleared			
Residential area			
Horticulture			X
River			
Open water			
Linear elements			
Forest strip	X	X	X
Riparian vegetation		X	X
Live fence		X	X
Hedgerow		X	X
Drainage ditch			X
Rivulet	X	X	X
Street			

[a] In the future scenario with double the amount of oil palm plantations, all plantations were assumed to be more than 3 years old

analysis (Vogt et al. 2007; Vogt 2010). For this purpose, we created binary grids classifying all land cover categories and linear landscape elements into habitat and non-habitat (Table 1). We postulated three categories of species (Imbeau et al. 2003; Seaman and Schulze 2010): (1) Forest specialist species (FS) that are associated with the core areas of forest patches, avoiding edge habitats and cultivated areas; (2) Forest generalist species (FG) that use mainly young secondary forests and natural landscapes within the cultivated area, avoiding the interior of old grown forests and open habitats; (3) Non-forest species (NF) that occur at boundaries of two different habitats and in extensive parts of farmland such as pastures, but avoid the forest interior. The land covers assigned to each guild of species (Table 1) were assumed to be preferred habitats, potential corridors or stepping stones for these species. Extreme generalist species were not regarded.

The MSPA (Vogt et al. 2007) produces a classification of the habitat area into the categories: CORE (interior area excluding perimeter), PATCH (too small to contain a core area), EDGE (external patch perimeter with specified edge width), PERFORATION (like edge, but for interior perimeters at non-habitat holes in the habitat), BRIDGE (habitat corridor connecting different core areas), LOOP (habitat corridor ending at the same core area), and BRANCH (connected at one end to a core, corridor or a perforation). For each of the three guilds we defined a value for edge width (i.e. the outermost parts of a habitat, still affected by the bordering non-habitat areas and thus not as suitable as core habitat). It is difficult to state general values for depth of edge influence, because these values depend on the studied habitats, species groups and even individual species guilds (Ries et al. 2004). For the sake of simplicity we defined these distances as the outermost 100 m of habitat for forest specialist species (Brand and George 2001) as the outermost 50 m for forest generalist species, and as the outermost 5 m for non-forest species.

To establish a scenario of future landscape pattern, we assumed that the agricultural landscape will continue to be altered by the conversion of the agricultural mosaic to oil palm plantations. For this scenario we converted all areas (with the exception of small and remote patches) belonging to the land use categories ‘pasture without trees’, ‘pasture with isolated trees’, ‘rice’, ‘corn’, ‘banana’, ‘cacao’, ‘oil palm < 3 years’ and ‘cleared’ into the category ‘oil palm > 3 years’. This conversion resulted in an exact doubling of the current area of oil palm plantations.

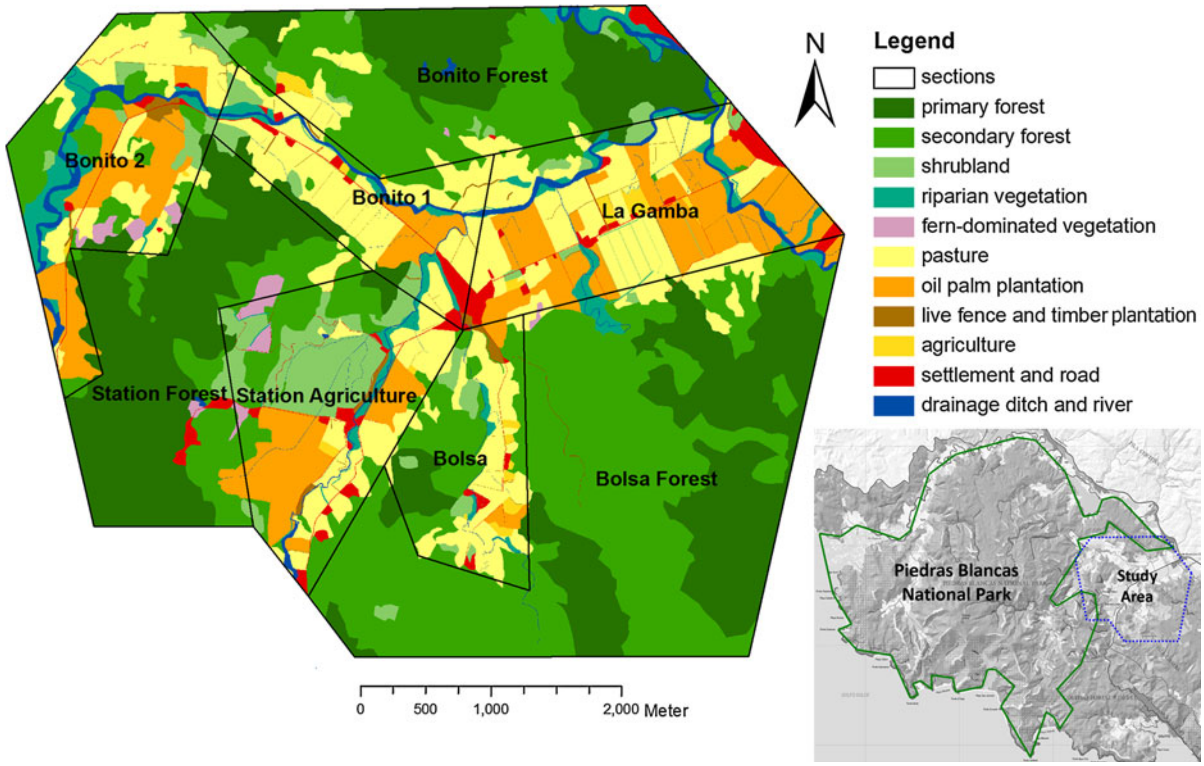

Fig. 1 Land cover map and the landscape sections used for the landscape pattern analysis of the study area "La Gamba" in vicinity of the Piedras Blancas National Park

In this scenario, we also removed all natural linear elements situated within the new plantations.

Impact of linear landscape elements

To assess the impact of linear elements on the overall landscape structure, we conducted the landscape pattern analysis and the MSPA with the original map including linear elements, as well as with a simplified map without such elements.

Computed corridor routes

To evaluate how connectivity between the forests in the region could be improved, including the connectivity of coastal forests and the La Gamba forests with the forests of the Piedras Blancas National Park (Fig. 1), we computed least cost corridors for the study area by means of the ArcGIS tool 'least cost path'. Resistance values, representing the difficulty with which an individual of a theoretical species can move through a grid cell of the landscape (Adriaensen et al. 2003; Beier et al. 2007), were assigned to each land cover category, based on an assessment of naturalness and tree cover of the land cover types. Streams had the highest resistance values, while physiographic and relief variables were not taken into account, as slopes were not regarded to be considerable barriers for the migration of plant and animal species in the study area.

Software for analyses and graphical illustrations

We used the program ArcView® (ESRI, Inc., Redlands, CA) to produce a vector map showing land cover, FRAGSTATS 3.3 (McGarigal and Marks 1995) to compute the landscape metrics, and GUIDOS 1.3 (Vogt et al. 2007; Vogt 2010) for the MSPA. We also used R 2.6.0 (R Development Core Team 2007) to illustrate the results in the form of barplots, and Adobe Illustrator CS3 13.0.2 (Adobe Illustrator Team 2007) for producing and modifying graphics.

Results

Land cover and landscape metrics

Primary vegetation (including riparian forests) covered 29%, secondary vegetation such as secondary forests, charral (very young secondary forest transitioning from abandoned land, more than 5 years out of use) and fern-dominated vegetation covered 35%, anthropogenic ecosystems (including pastures) 34% and water (rivers and ponds) 2% of the study area (Fig. 1). Land use types of the agricultural land mosaic were pastures (61%) and oil palm plantations (31%). Settlements (5%) and other land use types such as rice, cacao and bananas (4% in total) covered only small areas.

All landscape metrics clearly separated forests from rural sections. Generally, forest areas showed lower values of PD, PAFRAC and PRD and higher values of SIMI and CONTAG compared to rural areas (Fig. 2). The differences between forests and rural areas were most evident for traditional pasture-dominated landscapes (sections Bonito 1, Bolsa and parts of Station Agriculture), which typically consisted of many small patches of different types and included many linear landscape elements such as live fences, streets or drainage ditches. Rural sections including few linear landscape elements and large plantations or undivided pastures (sections La Gamba, Bonito 2 and parts of Station Agriculture) were characterized by metric values more similar than those of forest sections.

Most rural sections of the study area had much higher fractal dimensions than forests. Patch types including linear elements showed the smallest patch areas and the highest PD and fractal dimensions (Fig. 3). Patches of primary forest had the biggest AREA and the lowest PD and fractal dimensions. Secondary forests were smaller and had higher PD and fractal dimensions. All other natural patch types, such as riparian vegetation, were of very small extent and more complex shape. Oil palm plantations consisted of larger, but less numerous patches compared to pastures.

Morphological spatial pattern analysis (MSPA)

The MSPA revealed that the total area of habitat was largest for FS and smallest for NF species. For all three guilds, more than 90% of their habitat belonged to the categories CORE and EDGE (Figs. 4 and 5). All other types covered less than 5% of the habitat area. According to the future scenario of continued conversion of traditional agromosaics to oil palm plantations, NF would loose 47.6% of current habitat, FS 4.0% and FG 4.3%. CORE habitat would decrease for NF and FG species, while PATCHES would decrease for FS and FG, but increase for NF. EDGE would increase for NF, but remain the same for FS and FG. Corridors (BRIDGES and LOOPS) and BRANCHES would slightly increase for NF and decrease for FS and FG (Figs. 4 and 5).

Assessing the impact of field mapped linear landscape elements

Excluding linear landscape elements had a significant influence on the metric values. Most obviously, PD was much smaller in each section due to a higher mean patch area of all patch types (Fig. 2). Furthermore, PAFRAC had smaller values in all sections except for Bonito forest and Bonito 2 (Fig. 1). SIMI was much lower in the forest sections compared to the analysis taking linear landscape elements into account. The values of CONTAG were slightly higher and the values of PRD slightly lower when linear elements were neglected. At class level PAFRAC was higher for primary forests, secondary forests, riparian vegetation and oil palm plantations, but much lower for the categories ‘live fence and timber plantation’ and ‘settlement and road’ as these mostly consisted of linear elements (Fig. 3). ENN showed higher values for most categories when linear elements were excluded, while ECON was significantly higher only for primary forests and secondary forests.

The MSPA revealed that by neglecting linear landscape elements, the habitat area of all species categories decreased (Figs. 4 and 5): FS—2.73%, FG—2.22%, and NF—1.98%. The area covered by CORE remained very similar. PATCHES decreased for FS and FG, EDGE for FG and NF. Corridors (LOOPS and BRIDGES) decreased for all three species categories. BRANCHES increased slightly for FS and decreased slightly for FG and NF.

Computed corridor routes

A total of eight least cost paths were defined so as to connect the big forest patches of the study

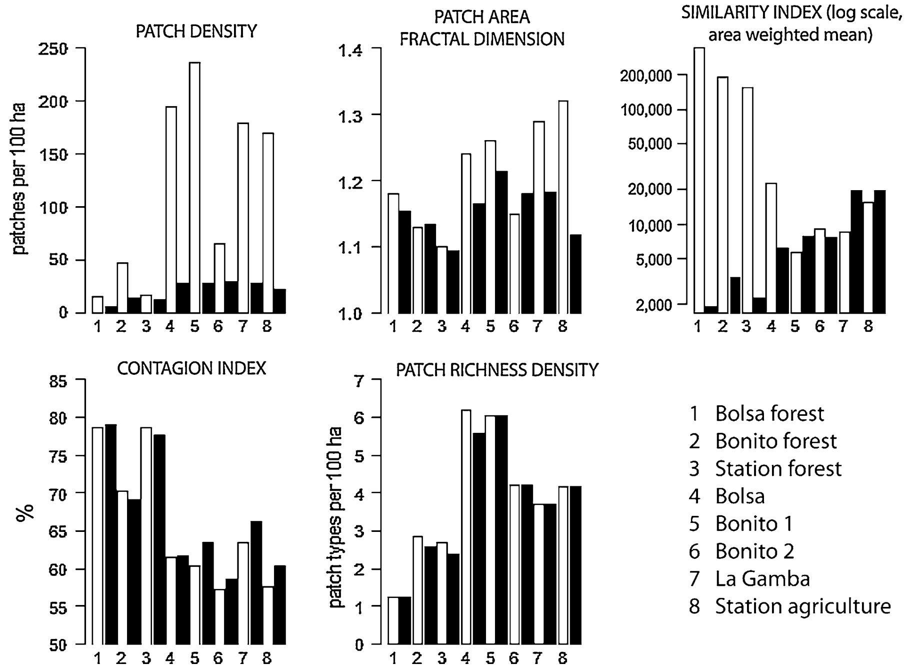

Fig. 2 Landscape level metrics for the eight sections, considering (*white bars*) and neglecting (*black bars*) the information obtained by ground mapping of linear landscape elements

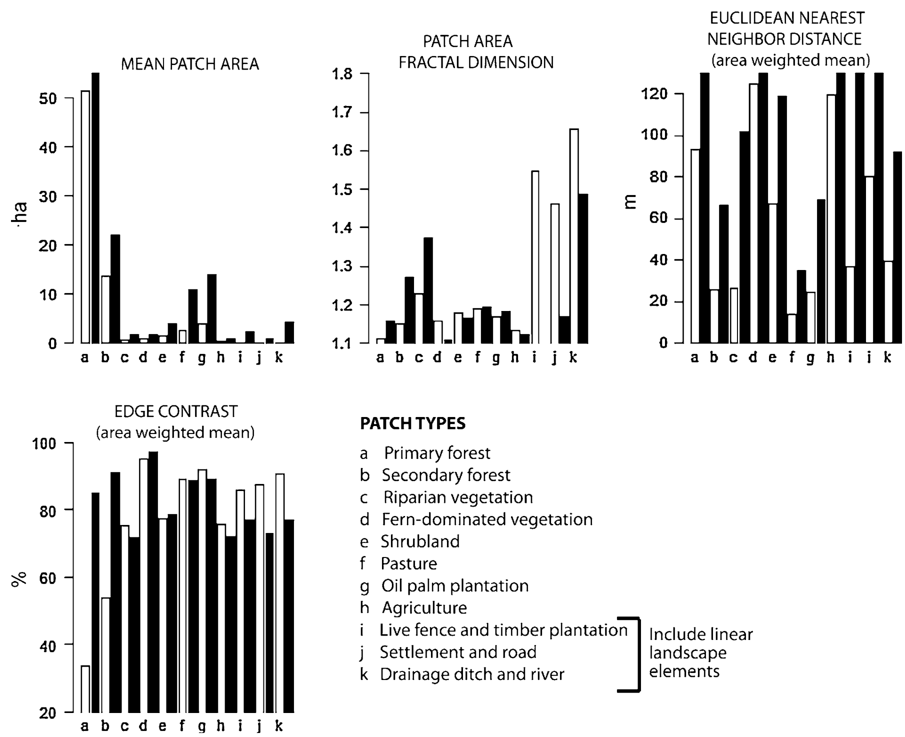

Fig. 3 Class level metrics, considering (*white bars*) and neglecting (*black bars*) the information obtained by ground mapping of linear landscape elements

area and to cross the agricultural area in places where barriers and disturbances were minimal. The corridors C1, C2, and C3 traversed the Valle Bonito, C4 and C5 the section between La Gamba and the Interamericana, C7 the Valle Bolsa, and C6 and C8 the agricultural area near the Tropical Station (Appendix 1). The lengths of the corridors (distances across farmland between the forest areas) ranged from 124 to 1290 m (Appendix 2).

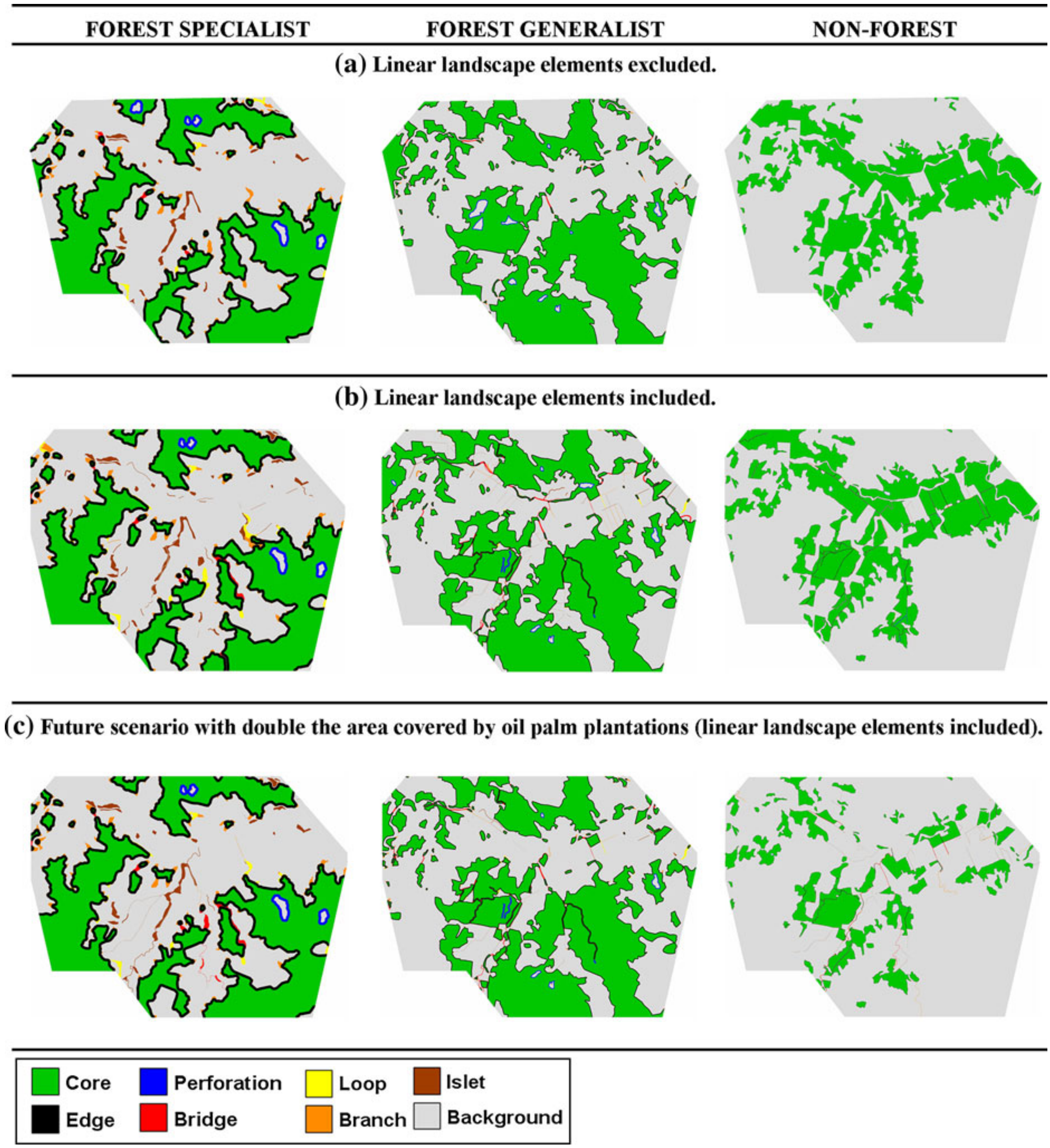

Fig. 4 Habitat spatial pattern for forest specialist, forest generalist, and non-forest species after MSPA. Current situation, neglecting (**a**) and considering linear elements (**b**), and scenario with double the area covered by oil palm plantations (**c**)

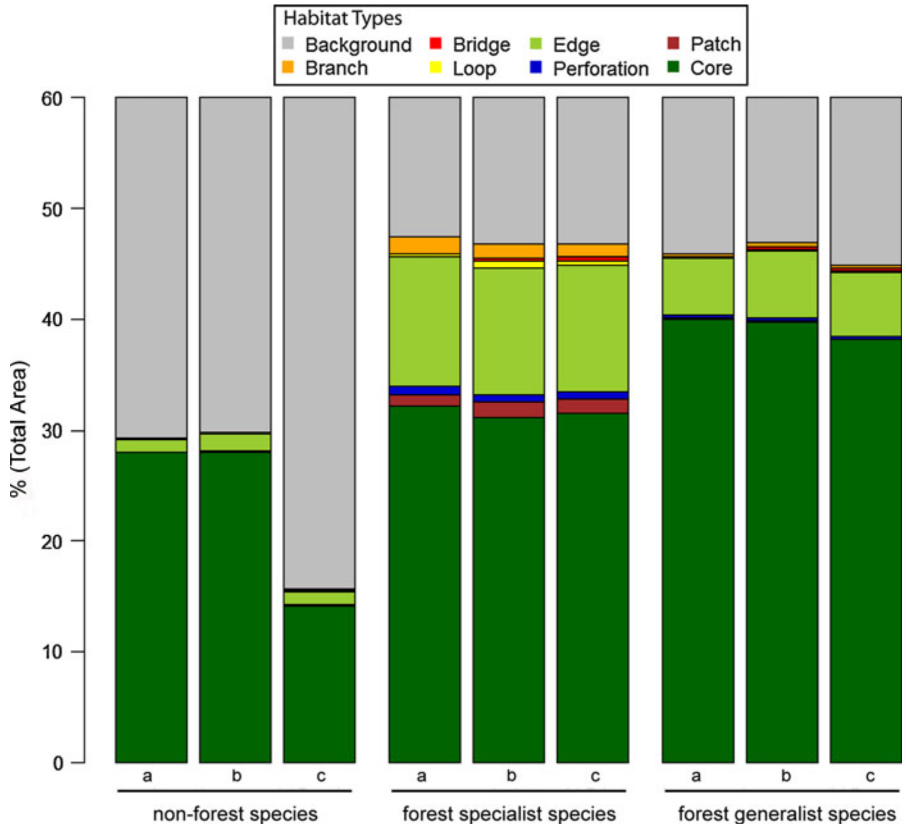

Fig. 5 Percentage of habitat categories for non-forest, forest specialist and forest generalist species for the current situation, neglecting (**a**) and considering linear landscape elements (**b**), and the scenario with double the amount of oil palm plantations (**c**)

Discussion

Comparative landscape structure analysis and the importance of linear elements

In agricultural areas, ecological heterogeneity and complex patch shapes, as measured by landscape metrics, are often related to naturalness and increased species richness (Moser et al. 2002; Kati et al. 2010; Renetzeder et al. 2010, Schindler 2010). In our study, rural areas were particularly heterogeneous, being diverse, of a high fractal dimension and including many small patches. This heterogeneity was partly caused by the field mapped fine-scale linear landscape elements. Fewer large and isolated patches would be the consequence of eliminating these small landscape elements within the rural areas. Shape complexity was also much smaller in agricultural landscapes without live fences, drainage ditches and field roads. According to the MSPA, the fine-scale linear elements also provide important corridor routes across rural areas especially for FS and FG species. The inclusion of linear landscape elements might also be a reason why the results of this study (e.g., most rural sections had higher fractal dimensions than forests) are not consistent with several classic studies of landscape pattern analysis, where agricultural areas were shown to be related to simple and compact shaped patches (e.g., O'Neill et al. 1988; Griffith et al. 2000). Combining information of different scales is recommended for the formulation and implementation of land use policies (Renetzeder et al. 2010), and fine-scale assessments are often needed to uncover the landscape pattern of landscapes with agroforestry mosaics (Schindler et al. 2008; Wrbka et al. 2008).

Effects of conversion to oil palm plantations

A strong effect was encountered under the scenario of spreading oil palm plantations. Globally, oil palm is a rapidly expanding crop which has already replaced large areas of natural forest in many tropical countries such as Malaysia or Indonesia, and this process still continues (Basiron 2007; Corley 2008). These plantations cause many other problems such as habitat fragmentation, pollution, biodiversity loss and soil degradation (Corley and Tinker 2003; Fitzherbert et al. 2008; Koh and Wilcove 2008). In our study, habitat loss and fragmentation for all three species guilds was the consequence of the future scenario with double the area covered by oil palm plantations. NF species lost large parts of their habitat, while FS and FG species lost mainly corridors and stepping stones across the agricultural landscape. Oil palm plantations are labor-intensive permanent cultures of a large extent. Unlike the pastures in our study area, these plantations were not divided or bordered by live fences (Fig. 1). Mainly ecologically futile elements such as roads and drainage ditches dominated within and along oil palm plantations, while pasture-dominated parts were richer in ecologically valuable elements such as live fences and riparian vegetation. Oil palm plantations are an unsuitable habitat for most forest species and act as severe barriers to animal movement (Fitzherbert et al. 2008). The expansion of these plantations involves the risk of a simplification of the landscape and an increasing barrier effect of agricultural areas for the dispersal of animal and plant species. Bender et al. (1998) found that habitat loss and fragmentation caused a decline in population size which was greater than predicted for forest specialist species, while being weaker than predicted for non-forest species. Hence, the habitat loss encountered in this study, which was most severe for non-forest species, may not lead to an equivalent reduction in population sizes, but could lead to a significant reduction or shift in biodiversity.

When comparing the two applied methods of landscape analysis, the advantages and disadvantages of each method soon became quite obvious. When calculating landscape metrics, a thematic resolution of eleven land cover classes can easily be handled, while the MSPA allows only for two classes (suitable; non-suitable), and for this reason all land cover classes had to be transformed into these two categories. On the other hand, calculating landscape metrics implies a rather high number of patches per section, and several pitfalls, including difficulties with the interpretation of the results (Wu et al. 2002; Li and Wu 2004; Wu 2004). The MSPA on the other hand provides the possibility of zooming into the landscape from the perspective of a certain target group of species. The downside is that the researcher needs to define how this target group of species perceives the landscape, which can be a very difficult task, especially if the target group is rather broadly chosen (e.g., 'vertebrates'). As both types of analyses are low-cost in terms of time or money (GUIDOS and FRAGSTATS are both freeware, fast and user-friendly), we recommend the application of both approaches for applied purposes, the MSPA being indispensable for fine-scale spatial explicit output and the calculation of landscape metrics for the numerical comparison of landscape attributes.

Corridor routes and conservation recommendations

Today, maintaining biodiversity in human dominated landscapes has become increasingly important, and agri-environment policy should aim at enhancing biodiversity while providing sufficient agricultural products for human consumption (Fahrig et al. 2011). The computed corridor routes illustrated that remnants of riparian forests were especially valuable landscape elements, as some of these extended from the forests into the farmland, significantly decreasing the distance across agricultural areas. Furthermore, patches of natural riparian vegetation and forests were also valuable stepping stones. Continuous corridors connecting the forest areas are, however, very rare.

To maintain the exchange of plants and animals between the forest areas surrounding the village of La Gamba, the conservation of natural habitats is of great importance. We suggest further improvement to the situation by elongating existing corridors such as riparian vegetation and live fences and by planting additional live fences and forest patches, especially along the areas of the computed corridor routes. As the mean patch area of pastures was relatively large (2.5 ha) and the density of live fences was rather low (20.0 m per ha farmland) compared to other areas (Harvey et al. 2005; Chacón León and Harvey 2007), the number of live fences could easily be increased (Höbinger 2010). Harvey et al. (2005) propose that live fences should be integrated into conservation planning in agricultural landscapes, e.g., by converting 'dead' fences into live fences and by dividing pastures into smaller paddocks (e.g., for rotational grazing, which might also increase cattle production). More tree and shrub species should be used for live fences, and they should be planted and elongated in a way that connects forests and other natural habitats, in order to enhance overall landscape connectivity for wildlife. Further conservation-friendly management practices such as staggered or partial pollarding (instead of complete pollarding) and keeping trees at a taller height and wider crown width would lessen the grade of disturbance and allow the colonization of live fences by epiphytes, vines and lianas (Harvey et al. 2005). These measures would provide a higher conservation value to the agricultural landscape mosaic, improve the connectivity of forest patches, and increase the tree cover within farmland. The higher tree cover would provide additional habitat for several species, but would also have a positive effect on plant and animal movement. Seaman and Schulze (2010) ascribed great conservation value to gallery forests in our study area, as they provide valuable corridors and stepping stones for forest specialist bird species and, at the same time, constitute an important habitat for generalist and non-forest birds.

It is crucial to bridge the gap between science and action by implementing and evaluating research based conservation recommendations (Schindler et al. 2011). In Costa Rica there is a national interest in promoting and financing nature conservation and sustainable land use, which is a great help in realizing concrete action plans. Federal institutions such as 'Sistema Nacional de Áreas de Conservación' (SINAC) are working on the conservation of biodiversity and natural resources and have set up a national program for conserving biodiversity by restoring ecological connectivity between large forest areas. Furthermore, it intends to enhance the surrounding areas and improve the collaboration of local actors and the relevant national institutions (Jimenez and Gonzales 2007; SINAC 2009). Another institution, 'Fondo Nacional de Financiamiento Forestal' (FONAFIFO) provides funds for compensation payments to the local actors for the financial losses they may incur through implementing nature conservation measures such as live fences. This study provides argumentation for further conservation measures, and also offers the necessary methodological insight.

Conclusion

Remote sensing data and field mapping complement each other for fine-scale landscape assessments of tropical agroforestry mosaics, as do landscape metrics and MSPA when analyzing landscape pattern. The agromosaic around La Gamba is of importance for the connectivity of natural areas in this biodiverse region. This study illustrates the heterogeneity of the agromosaic, which is partly related to fine-scale linear landscape elements such as live fences, tree lines and hedgerows. This heterogeneity is endangered by the conversion of the traditional land uses into larger oil palm plantations. If the current trend of land conversion is not reversed, non-forest species will lose large parts of their habitat and forest species will lose important corridors through the agricultural land. The protection and restoration of natural landscape elements that support wildlife movement between forest areas should be an integral part of conservation strategies. Additionally, we propose eight corridor routes that should be established through the study area to increase the overall connectivity.

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Appendix 1

See Fig. 6.

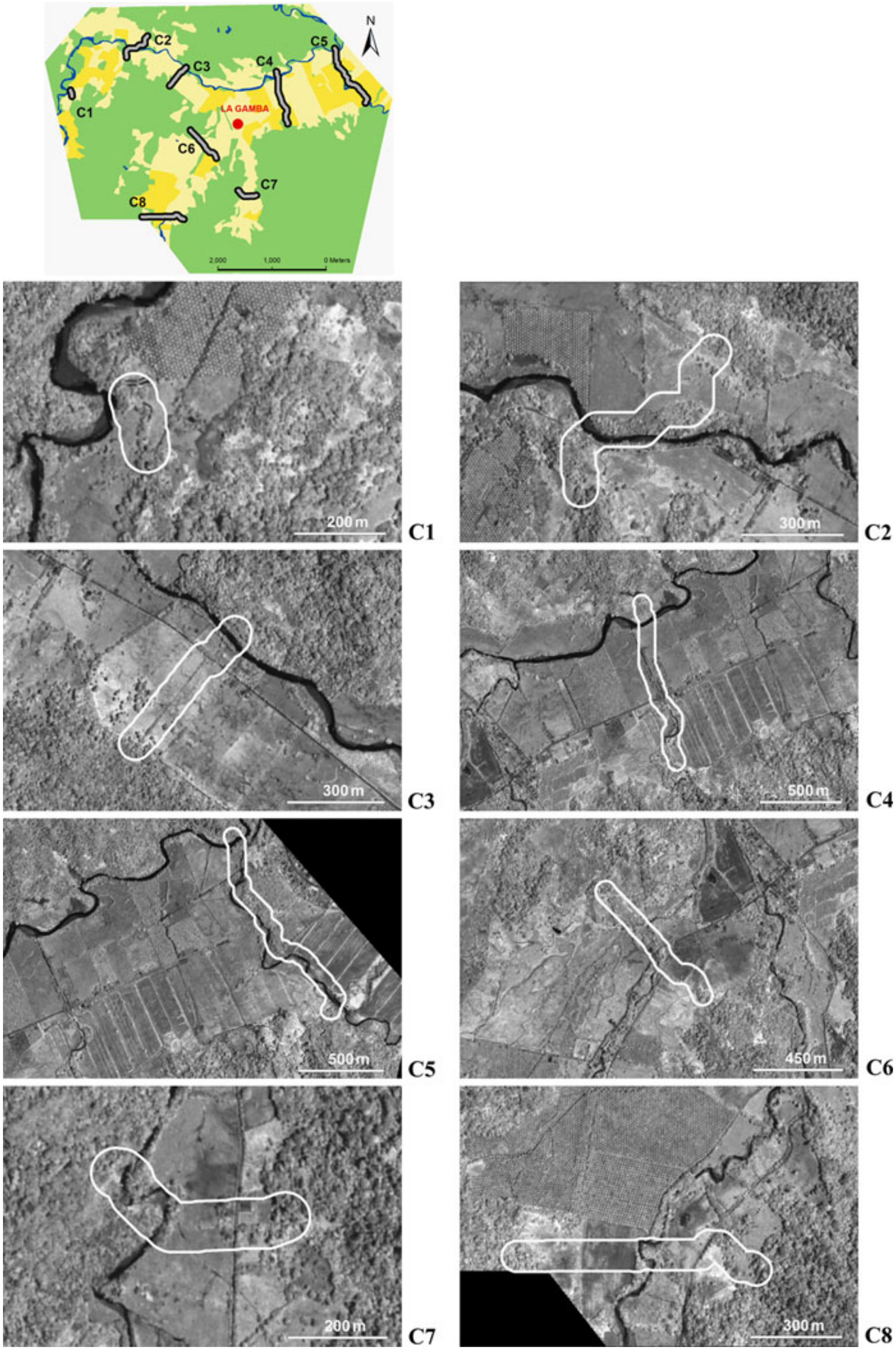

Fig. 6 Illustration of the eight computed least cost corridor routes (corridor width = 100 m)

Appendix 2

See Table 2.

Table 2 Lengths and coordinates of the start and endpoints of the corridor routes

Corridor	Length (m)	Start		End	
		X (m)	Y (m)	X (m)	Y (m)
C1	124	256,521	963,959	256,544	963,843
C2	683	257,968	964,981	257,558	964,568
C3	456	258,654	964,379	258,350	964,042
C4	1,035	260,329	964,302	260,545	963,344
C5	1,290	261,414	964,728	261,981	963,723
C6	733	258,738	963,221	259,219	962,698
C7	390	259,617	962,106	259,956	962,016
C8	813	258,606	961,617	258,606	961,583

WGS 1984, UTM Zone 17 N, False easting: 500,000, False northing: 0, Central meridian: −81, Scale factor: 0.9996

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