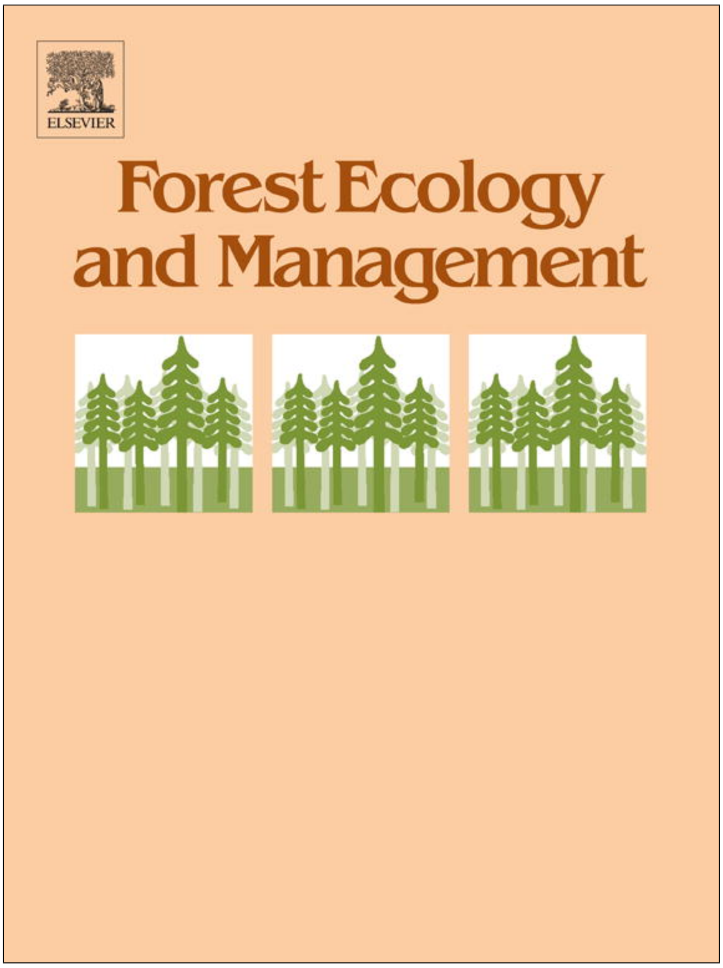
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Land-use and land-cover change in Atlantic Forest landscapes

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ABSTRACT

The Atlantic Forest is one of the most threatened tropical biomes, with much of the standing forest in small (less than 50 ha), disturbed and isolated patches. The pattern of land-use and land-cover change (LULCC) which has resulted in this critical scenario has not yet been fully investigated. Here, we describe the LULCC in three Atlantic Forest fragmented landscapes (São Paulo, Brazil) between 1960–1980s and 1980–2000s. The three studied landscapes differ in the current proportion of forest cover, having 10%, 30% and 50% respectively. Between the 1960s and 1980s, forest cover of two landscapes was reduced while the forest cover in the third landscape increased slightly. The opposite trend was observed between the 1980s and 2000s; forest regeneration was greater than deforestation at the landscapes with 10% and 50% of forest cover and, as a consequence, forest cover increased. By contrast, the percentage of forest cover at the landscape with 30% of forest cover was drastically reduced between the 1980s and 2000s. LULCC deviated from a random trajectory, were not constant through time in two study landscapes and were not constant across space in a given time period. This landscape dynamism in single locations over small temporal scales is a key factor to be considered in models of LULCC to accurately simulate future changes for the Atlantic Forest. In general, forest patches became more isolated when deforestation was greater than forest regeneration and became more connected when forest regeneration was greater than deforestation. As a result of the dynamic experienced by the study landscapes, individual forest patches currently consist of a mosaic of different forest age classes which is likely to impact biodiversity. Furthermore, landscape dynamics suggests the beginning of a forest transition in some Atlantic Forest regions, what could be of great importance for biodiversity conservation due to the potential effects of young secondary forests in reducing forest isolation and maintaining a significant amount of the original biodiversity.

1. Introduction

The Brazilian Atlantic Forest supports one of the highest degrees of species richness and rates of endemism on the planet (Mittermeier et al., 2005; Myers et al., 2000). Nonetheless, a recent broad-scale study (Ribeiro et al., 2009) revealed a serious situation about the spatial structure of Atlantic Forest remnants: more than 80% of the Atlantic Forest patches are less than 50 ha, almost half the remaining forest is less than 100 m from a forest edge and the average distance between forest patches is 1440 m. In addition, much of the standing Atlantic Forest is secondary rather than primary forest (Ribeiro et al., 2009).

This critical scenario of the Atlantic Forest with small, disturbed and isolated forest patches is a consequence of five centuries of intense human occupation (Dean, 1996). The pattern of land-use and land-cover change (LULCC) which has directly resulted in this critical scenario for the Atlantic Forest has not yet been fully investigated (but see Teixeira et al., 2009), contrary to the large number of studies on landscape dynamics for the Brazilian Amazon (e.g. Ewers and Laurance, 2006; Ewers et al., 2008; Michalski et al., 2008; Soares-Filho et al., 2004, 2006). The understanding of how LULCC varies both temporally and spatially and how it affects landscape structure and forest age is extremely important for managing ecosystem services and species conservation in new human-dominated landscapes, and thus to prevent or minimize undesirable ecological impacts (Barlow et al., 2007a,b; Echeverria et al., 2006; Etter et al., 2005).

LULCC in a given landscape can be a random process if transitions among land-use/cover classes are proportional to the size of classes but can also be a systematic process if transitions among classes are not dictated by their sizes (Pontius et al., 2004). Knowing if LULCC is a random or a systematic process is the first step towards the understanding of how land-use will affect land-cover and thus to guide conservation actions (Braimoh, 2006; Pontius et al., 2004). Additionally, it is also important to understand how LULCC varies temporally and spatially to accurately simulate future

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changes in land-cover and thus on biodiversity conservation and ecosystem services.

The effects of the LULCC on landscape structure are also important. It is well known that changes on size, shape and degree of connectivity of forest patches are likely to impact species distribution in fragmented landscapes (Ewers and Didham, 2006). But the ecological consequences of LULCC depend not only on the resulting landscape structure and on how this varies both temporally and spatially (Echeverria et al., 2006), but also on the resulting proportion of forest with different ages of regeneration (Barlow et al., 2007a,b; Etter et al., 2005). Secondary forests patches can sustain a significant amount of biodiversity, but many species need more pristine forest patches to survive (Barlow et al., 2007b; Laurance, 2005). Consequently, population of many species are now thought to be on a deterministic path to extinction in Atlantic Forest landscapes (Brooks et al., 1999; Brooks and Balmford, 1996; Metzger et al., 2009). Both landscape structure and the age structure of forest are important determinants of the maintenance of species in human-modified landscapes (Gardner et al., 2009), and therefore important components of land-cover to consider when assessing landscape conditions.

In this context, this study aimed to describe the LULCC of three Atlantic Forest fragmented landscapes (São Paulo, Brazil) between 1960–1980s and 1980–2000s in order to: (1) evaluate if LULCC deviate from a random trajectory; (2) determine if trajectories of LULCC are constant through time and across space; (3) investigate the effects of the LULCC on landscape structure in terms of size, shape and degree of isolation of forest patches; and (4) verify the effects of LULCC on the current proportion and distribution of forest stands with different regeneration ages.

2. Materials and methods

2.1. Study area

This study was conducted in three 10,000-ha Atlantic Forest fragmented landscapes located in the Atlantic Plateau of São Paulo, Brazil. The whole region of the Atlantic Plateau was once covered with Atlantic Forest classified as Lower Montane Atlantic Rain Forest (Oliveira-Filho and Fontes, 2000), but nowadays much of the region is reduced to secondary forest patches in different stages of regeneration (Ribeiro et al., 2009; Teixeira et al., 2009). The altitude in the Atlantic Plateau of São Paulo varies between 700 and 1100 m above sea level with steep hillslopes, mountain with moderate to gentle hillslopes, and alluvial plains (Poçano et al., 1981);

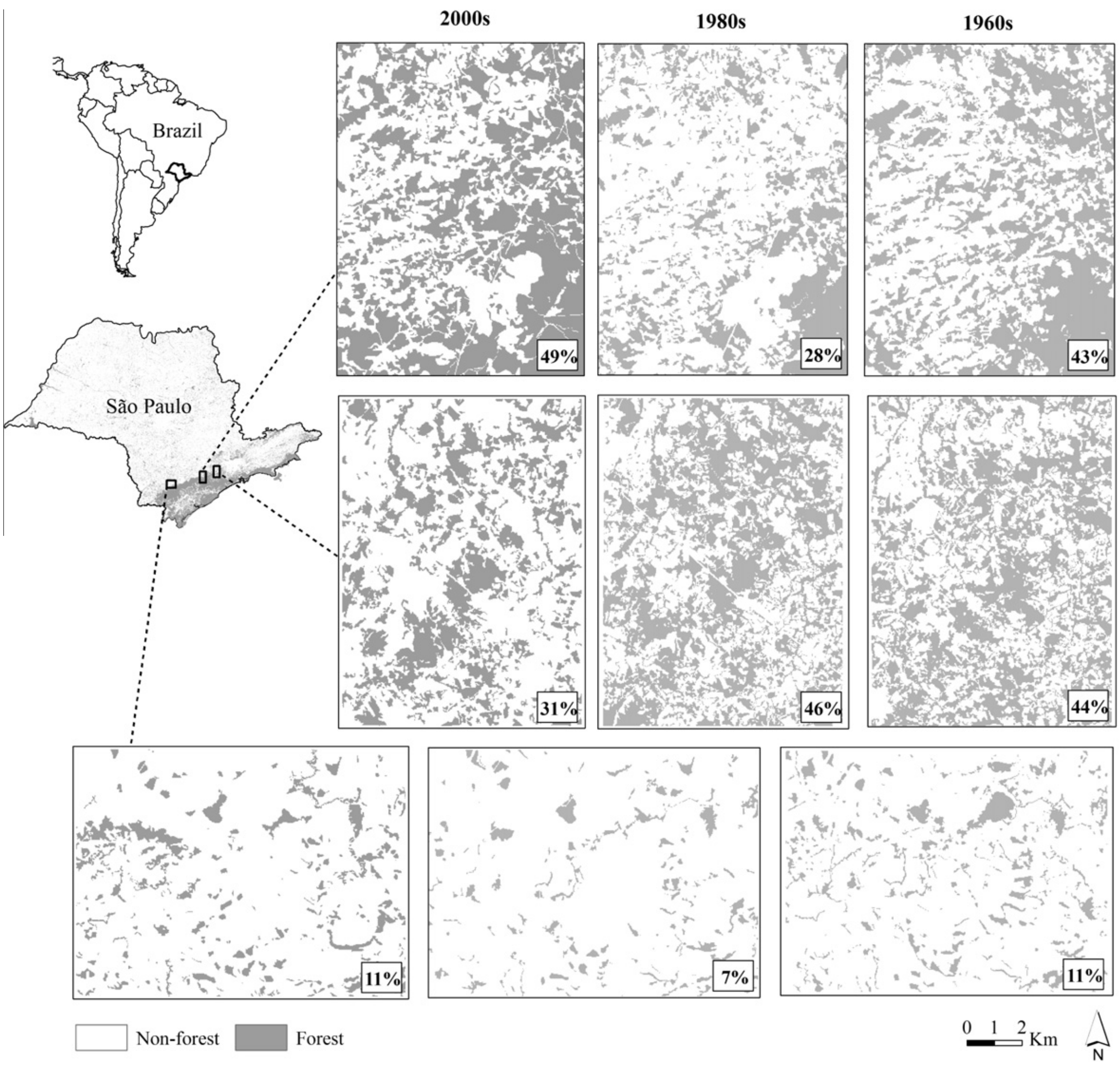

Fig. 1. Location of the three studied Atlantic Forest fragmented landscapes in the State of São Paulo (south-eastern – Brazil) and their forest cover dynamics between the 1960s and 2000s (from right to left). The percentage of forest cover is shown at the bottom of each forest cover map.

the annual rainfall is between 1350 and 2000 mm and the mean annual temperature varies from 15 °C to 22 °C (www.cpa.unicamp.br). Originally, 60% of the Brazilian Atlantic Forest was located between 400 and 1200 m above sea level and on steeper relief, nowadays 50% of the remaining forest is located in those altitudinal range and 30% on steeper relief (Ribeiro et al., 2011; Tabarelli et al., 2010).

In the studied landscapes, remaining forest patches were composed of intermediate to old second growth forest while the matrix habitat surrounding forest patches was dominated by agriculture and cattle pastures. Although similar in terms of topography, relief, climate, type of forest, and type of human-use, the studied landscapes differ in the proportion of forest cover, varying from 11%, to 31% and 49% respectively (Fig. 1; hereafter referred as 10%, 30% and 50% forest cover (FC) landscapes). Potentially those differences in forest cover can affect LULCC dynamics once in landscapes with larger forest cover it would be expected to have a faster regeneration process due to the highest proximity of forest (and propagules) sources (Holl and Aide, 2011). Additionally, all three landscapes are at a similar distance to the "Serra do Mar", which contains the largest continuous tract of Atlantic Forest (1,109,546 ha) remaining in Brazil (Ribeiro et al., 2009), and are relatively close to each other being separated by distances of less than 120 km.

2.2. Land-use and land-cover change

To describe the LULCC for each studied landscape between 1960–1980s and 1980–2000s, we used aerial photographs and SPOT satellite images from the 1960s, 1980s and 2000s. For the 10% FC landscape, aerial photographs from 1962 (1:25,000) to 1980 (1:35,000) and a SPOT satellite image of 2005 (10 m resolution) were used; for the 30% FC landscape, aerial photographs from 1962 (1:25,000), 1981 (1:35,000) and 2000 (1:10,000) were used; and, finally, for the 50% FC landscape, aerial photographs from 1962 (1:25,000), 1978 (1:35,000) and a SPOT image of 2005 (10 m resolution) were used. The choice of dates was based on the availability of images, the possibility to analyze similar periods for the three study landscapes and the possibility to analyze regular time periods within each study landscape. Aerial photographs were scanned at 1.5 m resolution and georeferenced using at least 30 control points well distributed in each photograph (RMS error < 5 m), before being combined into a mosaic (one for each year) using ArcGIS software.

The aerial photographs and SPOT satellite images were categorized into five land-use or land-cover classes based on the level of detail available for the lowest resolution imagery (1:35,000). These classes were: (1) urban and rural buildings, (2) crop fields and pastures, (3) forest plantation, (4) young secondary vegetation and (5) forest (see Table A.1 for a more detailed description of each category). Hereafter, those classes are referred as urban, fields, forestry, young vegetation and forest respectively. Aerial photographs and satellite images were visually interpreted (using stereoscopy for aerial photographs), and polygons were digitalized directly over the mosaic in the computer screen using ArcGIS software. The interpretation was performed by four trained people in order to reduce errors related with different abilities of interpretation. Intense field validation indicates high accuracy levels for land-use/cover maps of recent dates (2000s) (Ribeiro et al., 2009; Silva et al., 2007).

The final land-use/cover maps were transformed to a similar resolution (15 m) to avoid biases arising from differences in resolution among images from different years or landscapes. Transitions among land-use/cover categories in each studied landscapes between 1960–1980s and 1980–2000s were quantified using ArcGIS software. All transitions among the five land-use/cover classes were considered plausible within each period analyzed (16–27 years) and the resulting transition matrices were used to assess LULCC between 1960–1980s and 1980–2000s in each of the three landscapes.

We performed chi-square tests to investigate, individually for each landscape × time period combination (i.e. each transition matrix), if LULCC deviated from a random expectation (i.e. transitions among different land-use/cover classes are not dictated by the size of classes). We also performed chi-square tests to investigate if LULCC were constant through time (i.e. was the pattern of LULCC within a landscape the same in the two time periods analyzed), and across space (i.e. did the difference in LULCC among landscapes at a given time period differ from the expected by chance).

2.3. Effects of land-use and land-cover change on landscape structure

To investigate the effects of LULCC on landscape structure, we measured size, shape and degree of isolation for all forest patches in each landscape × time period using the Fragstats software (McGarigal and Marks, 1995). Patch size was measured in hectares and the shape and degree of isolation of each forest patch was measured using the shape index (Patton, 1975) and the proximity index (Gustafson and Parker, 1992), respectively. Shape index equals patch perimeter divided by the minimum perimeter possible for a maximally compact patch of the corresponding patch area; the index equals one when the patch is maximally compacted and increases without limit as patch shape becomes more irregular. The proximity index equals the sum of each patch size divided by the square of its edge-to-edge distance to the focal patch of all patches whose edges are within a specified search radius of the focal patch (600 m in this study); the index equals zero if a patch has no neighbors and increases as the neighborhood is increasingly occupied by patches of the same type. Patch size, shape and proximity indexes were log-transformed in order to normalize the data and ANOVA was used to determine if the size, shape and degree of isolation of forest patches differed significantly among years (1960s, 1980s and 2000s) and landscapes.

We also investigated the effects of LULCC on the current proportion of forest cover at different ages of regeneration. By overlaying multi-temporal forest cover maps (1960s, 1980s and 2000s) we were able to categorize current forest cover (2000s) of each study landscape into the three ordinal classes presented in Table 1. It was

Table 1
Percentage of current forest cover (2000s) of each forest age class at three Atlantic Forest fragmented landscapes located in São Paulo, Brazil. Values are the cover as a percentage of the total landscape area and, in parentheses, as a percentage of the total forest cover. Ordinal classes of forest cover age were determined by temporal sequence of forest change. Non-forest is all land-use/cover classes presented in Table A.1 apart from forest. SF20: secondary-forest with ~20–25 years-old, SF40: secondary-forest with ~40–45 years-old, and MF60: mature forest with ⩾60 years-old.

Forest change sequence			Forest age class	Landscape		
1960s	1980s	2000s		10% FC	30% FC	50% FC
Non-forest	Non-forest	Forest	SF20	6.8 (60.7)	5.9 (18.9)	25.9 (52.9)
Forest	Non-forest	Forest				
Non-forest	Forest	Forest	SF40	1.4 (12.5)	8.5 (27.2)	4.9 (10.0)
Forest	Forest	Forest	MF60	3.0 (26.8)	16.8 (53.9)	18.2 (37.1)

Table 2
Percentage of each land-use and land-cover class for three Atlantic Forest fragmented landscapes (São Paulo, Brazil), and how they changed between the 1960s and 2000s.

Land-use/cover	10% FC landscape			30% FC landscape			50% FC landscape		
	1962	1980	2005	1962	1981	2000	1962	1978	2005
Urban	0.32	0.44	1.57	0.64	1.48	15.87	0.12	0.35	0.12
Fields	79.72	88.14	81.83	36.93	38.98	38.13	33.89	47.55	42.47
Forestry	0.20	0.63	1.19	2.12	2.97	7.12	0.90	4.36	5.06
Young vegetation	8.39	3.75	4.10	16.25	10.24	7.59	21.52	19.85	3.01
Forest	11.37	7.04	11.31	44.06	46.33	31.28	43.57	27.88	49.35

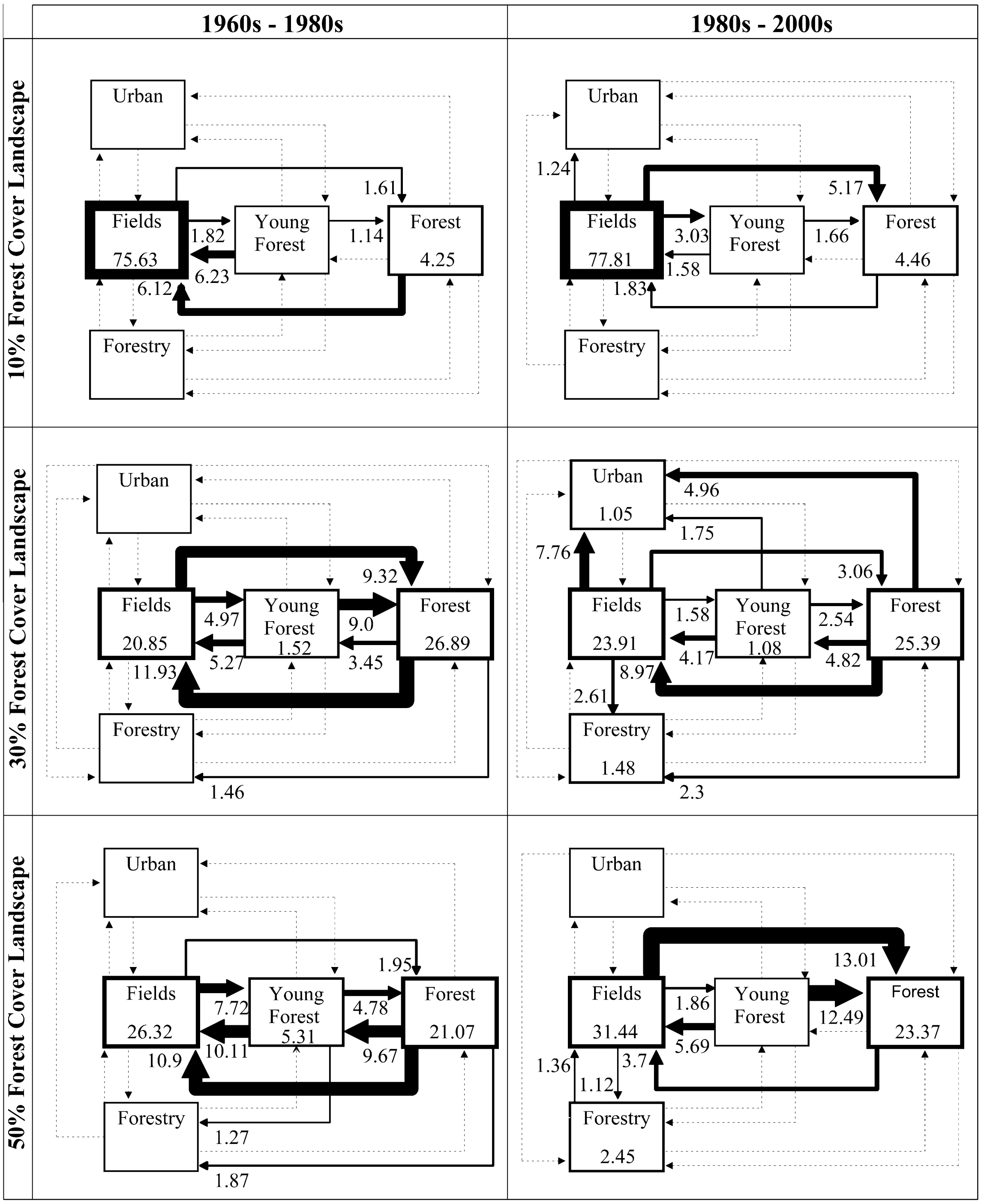

Fig. 2. Land-use/cover persistence and change between the 1960–1980s and the 1980–2000s at three Atlantic Forest landscapes, in São Paulo, Brazil. Values are % of landscape that experienced persistence (inside boxes) or transition among land-use/cover classes (on the left or below arrowheads). Values lower than 1% were omitted but can be assessed in Tables A.1 and A.2.

Table 3
Results from chi-square tests on the randomness of land-use and land-cover change through time and across space.

		10%		30%		50%	
		1960–1980s	1980–2000s	1960–1980s	1980–2000s	1960–1980s	1980–2000s
10%							
	1960–1980s	$\chi^2 = 54.0^{***}$					
	1980–2000s	$\chi^2 = 27.1^{ns}$	$\chi^2 = 39.5^{*}$				
30%							
	1960–1980s	$\chi^2 = 51.5^{***}$		$\chi^2 = 13.6^{ns}$			
	1980–2000s		$\chi^2 = 70.98^{***}$	$\chi^2 = 179.3^{***}$	$\chi^2 = 39.5^{*}$		
50%							
	1960–1980s	$\chi^2 = 101.9^{***}$		$\chi^2 = 11.3^{ns}$		$\chi^2 = 37.5^{*}$	
	1980–2000s		$\chi^2 = 90.3^{***}$		$\chi^2 = 26.8^{ns}$	$\chi^2 = 119.3^{***}$	$\chi^2 = 51.9^{***}$

ns $p > 0.05$.
* $p < 0.05$.
*** $p < 0.01$.

impossible to establish the exact age of regeneration because we do not have images for every year.

3. Results

3.1. Land-use and land-cover change

The dominant land-use/cover classes for all three studied landscapes between the 1960s and 2000s were fields and forest. In the 1960s and 1980s, urban and forestry were uncommon in the 30% FC landscape, but by the 2000s they accounted for almost one-quarter of the land area. At the 10% and 50% FC landscapes, urban accounted for a small and constant proportion of the landscape, whereas forestry increased steadily over time. Young vegetation declined between the 1960s and 2000s in all landscapes. Trajectories of forest change were more complex. Between the 1960s and 1980s, forest cover in the 10% and 50% FC landscapes was reduced while the forest cover in the 30% FC landscape increased slightly. The opposite trend was observed between the 1980s and 2000s; forest cover increased in the 10% and 50% FC landscapes whereas almost one-third of the forest cover at the 30% FC landscape was removed (Table 2).

Both time periods analyzed were highly dynamic for the 30% and 50% FC landscapes; 50% and 47% of the landscapes respectively experienced land-use/cover change between the 1960s and 1980s and 47% and 42% respectively between the 1980s and 2000s. By contrast, only 19% of the 10% FC landscape was transformed between the 1960s and 1980s and 17% between the 1980s and 2000s (Fig. 2, Table A.2).

In all landscapes and at all time periods, LULCC was significantly non-random apart from the 30% FC landscape between the 1960 and 1980s. In the 10% FC landscape, the non-random dynamic was driven mostly by the higher than expected persistence of urban and forest areas in both time periods analyzed, whereas in the 30% FC landscape between the 1980s and 2000s and in the 50% FC landscape in both periods analyzed the non-random dynamic was driven by the higher than expected persistence of forest, forestry and fields, complemented by a lower than expected exchange between fields and forest (Table 3, Fig. 2).

At the 30% and 50% FC landscapes, landscape dynamics pattern varied through time while in the 10% FC landscape dynamics were constant through time. At the 30% FC landscape, gain of urban areas between 1980s and 2000s were greater than expected according to the dynamic experienced between 1960s and 1980s; new urban and rural buildings were established mostly in former areas of forest and fields. At the 50% FC landscape, the transition of fields to forest between 1980s and 2000s was greater than expected according to the dynamic experienced by those landscapes between 1960s and 1980s.

Table 4
Results from ANOVA tests on the variation of size, shape and degree of isolation of forest patches among years and landscapes.

	DF	*F*	*P*
Patch size			
Landscape	2	57.8	<0.001
Year	2	146.4	<0.001
Landscape:Year	4	38.2	<0.001
Residuals	3715		
Patch connectivity			
Landscape	2	1815.4	<0.001
Year	2	285.8	<0.001
Landscape:Year	4	187.3	<0.001
Residuals	3715		
Patch shape			
Landscape	2	3.4	>0.05
Year	2	0.3	<0.001
Landscape:Year	4	9.9	<0.001
Residuals	3715		

LULCC were not always constant across space. The 1960–1980s landscape dynamics were significantly different between the 10% and 30% FC landscapes and between the 10% and 50% FC landscapes, and the same was true for 1980–2000s landscape dynamics. However, LULCC experienced by the 30% and 50% FC landscapes was not significantly different, either between 1960s and 1980s or between 1980s and 2000s.

3.2. Effects of land-use and land-cover change on landscape structure

Patch size and degree of isolation were significantly different among landscapes, among time periods, and among time periods in a given landscape (Table 4). Patch size increased significantly from the 1960s to the 1980s in the 10% FC landscape and from the 1980s to the 2000s in the 30% and 50% FC landscape. Patch size decreased significantly from the 1960s to the 1980s in the 30% FC landscape. The degree of patch isolation at the 10% and 50% FC landscape increased significantly from the 1960s to 1980s but decreased significantly from the 1980s to 2000s. At the 30% FC landscape, degree of patch isolation was not significantly different between the 1960s and 1980s but increased significantly from the 1980s to 2000s (Fig. 3).

Patch shape was not significantly different among landscapes but was significantly different among time periods and among time periods in a given landscape (Table 4). Patch shape at the 10% and 50% FC landscape were not significantly different among years; on the other hand, at the 30% FC landscape, patch shape became significantly more irregular in the 2000s (Fig. 3).

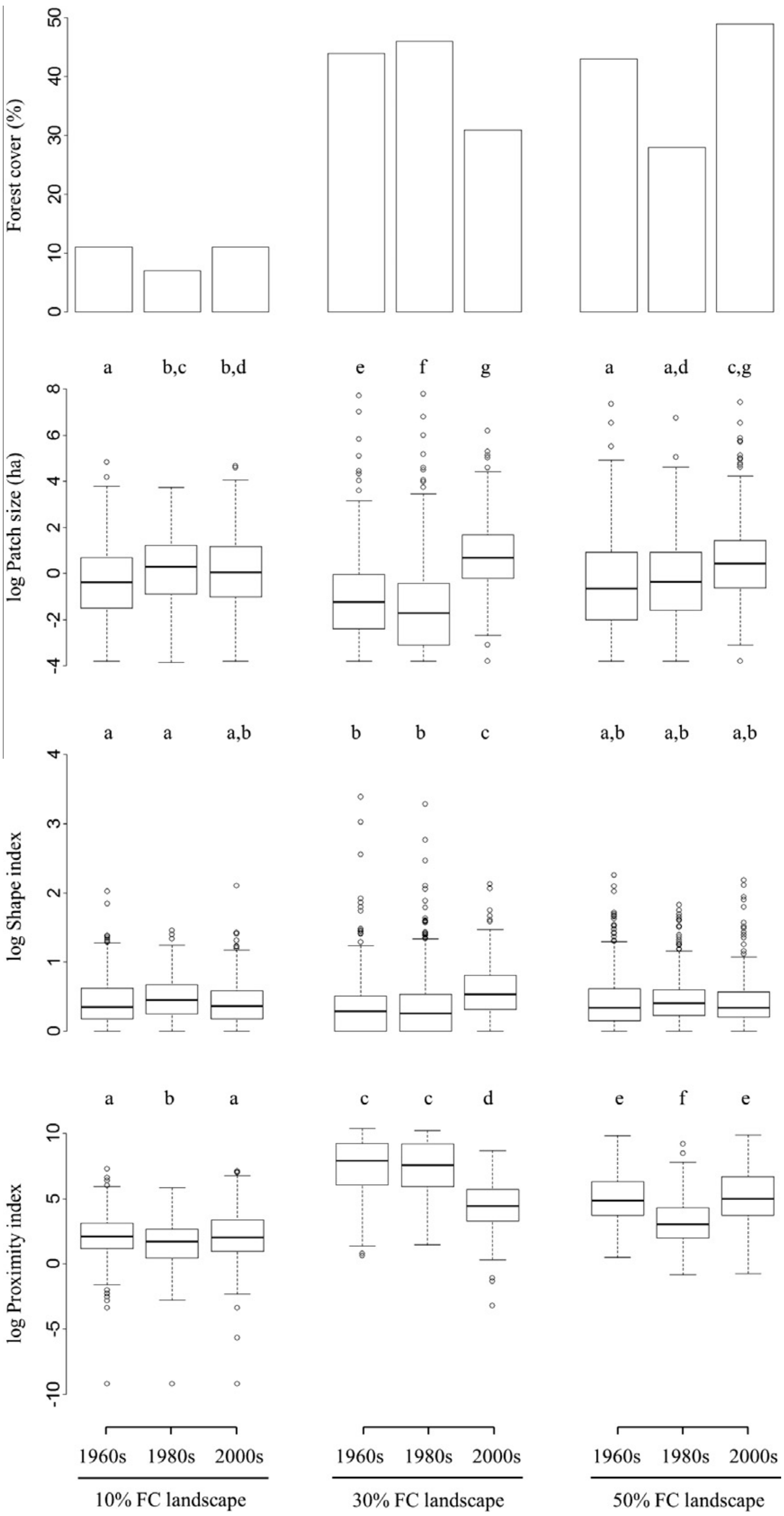

Fig. 3. Forest cover (%) dynamics and the consequent variation on landscape structure (patch size, shape index and proximity index) in three Atlantic Forest fragmented landscapes (São Paulo, Brazil). The main horizontal line shows the median, boxes represent quartiles and whiskers depict either the maximum or 1.5 times the interquartile range of the data (whichever is smaller). Points are outliers. Classes that do not have a letter in common differ significantly (Tukey's honest significant differences test: $P < 0.05$).

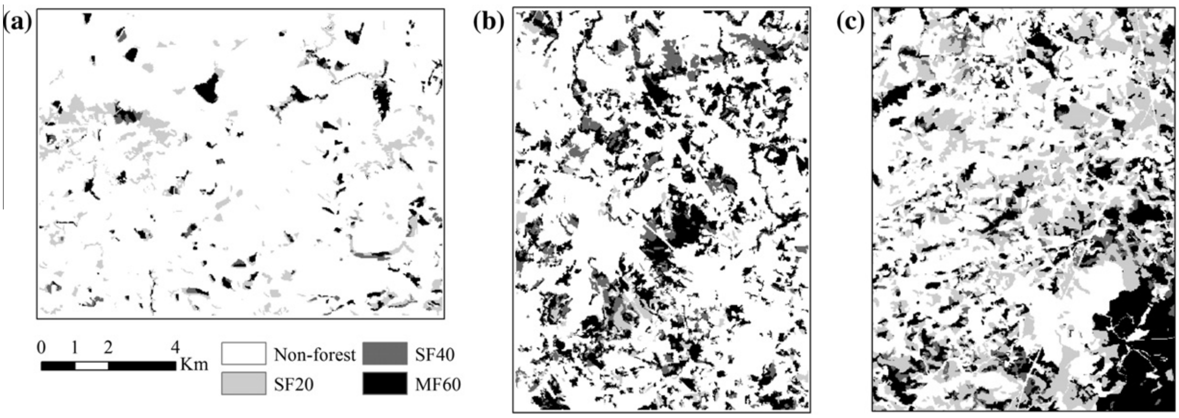

Fig. 4. Spatial distribution of forest patches of different forest age classes at the landscape with 10% (a), 30% (b) and 50% (c) of forest cover (São Paulo, Brazil). Note that individual forest patches are a mosaic of different forest age classes.

The current amount of forest with different age of regeneration at the three studied landscapes is also a consequence of the LULCC experienced between 1960s and 2000s. The largest proportion of the forest cover at the 30% FC landscape corresponds to remnant mature forest with at least 60 years old (54%) while the largest proportion of forest at the 10% and 50% FC landscapes corresponds to secondary forests that have regenerated during the last 20–25 years (Table 1). Individual forest fragments at all three studied landscapes consists of a mosaic of different forest age classes (Fig. 4).

4. Discussion

LULCC were highly dynamic for the two more forested landscapes in both time periods analyzed and more intense than in some Amazonian regions of agricultural expansion (Ferraz et al., 2005; Lu et al., 2007), while landscape persistence was much greater than transition among land-use/cover classes at the landscape dominated by crop fields and pastures. LULCC were significantly non-random in all landscapes and at all time periods, with only one exception suggesting that systematic transitions are occurring in the study landscapes. Moreover, we have also found that LULCC are not constant across time and space probably due to changes in social, political and economic conditions across time (Lambin and Meyfroidt, 2010). As a consequence systematic transitions may also vary in time and space and it is fundamental to take this landscape dynamism into account in models of LULCC so that we can accurately simulate future changes for the Atlantic Forest and prevent the negative effects on biodiversity and ecosystem services.

Effects of LULCC between the 1960s and 2000s on landscape structure (i.e. size, shape and degree of isolation of forest patches) were different at the three studied landscapes. In general, the degree of patch isolation in a given landscape increased significantly when deforestation was greater than forest regeneration and decreased significantly when forest regeneration was greater than deforestation. It is well known that isolation and the connectivity level of patches are key components for maintaining species in fragmented landscapes (Boscolo and Metzger, 2011; Damschen et al., 2006); well-connected patches can sustain a higher number of species and also a large number of individuals/population sizes (Martensen et al., 2008) because (re)colonization and rescue effect (Brown and Koldric-Brown, 1977) are often occurring in those patches (Pardini et al., 2010). Effects of LULCC on the shape of forest patches was only observed at the 30% FC landscape where deforestation between 1980s and 2000s was more likely to occur far from rivers probably because riparian vegetation is protected by Brazilian law (Teixeira et al., 2009) and as a consequence forest patches became significantly more irregular. Forest patches with irregular shapes are more susceptible to edge effects than patches with more compact shapes (Ewers and Didham, 2007), and many species have been reported to be negatively affected by edges (Ewers and Didham, 2006; Ries et al., 2004). At the 50% FC landscape, edge effects were reported as one of the most important determinants of avifauna community structure (Banks-Leite et al., 2010).

The relationship between the temporal pattern of change in patch size and the dynamic of deforestation and forest regeneration was not so clear. Patch size is considered to be related with population size and consequently with extinction probability in a given patch; thus, it is an important structural characteristic influencing species persistence in fragmented landscapes. Furthermore, the mosaic of forest ages within patches may have changed and this is also likely to impact biodiversity (Brown and Lugo, 1990; Guariguata and Ostertag, 2001) since forest age may be directly related to forest successional stage. Vegetation structure and composition are drastically different across the successional stages (Clark, 1996; Brown and Lugo, 1990; Guariguata and Ostertag, 2001; DeWalt et al., 2003) and this might have important consequences for wildlife populations as many animals rely on forest resources that vary in abundance across forest succession. However, other aspects such as the proximity to propagule sources, land-use histories and land management practices (Guariguata and Ostertag, 2001; Etter et al., 2005) are also important to determine the modification in forest structure and plant species composition across forest succession.

Half of the remaining forest at the 10% and 50% FC landscape is secondary forest that has regenerated during the last 25 years, while at the 30% FC landscape half of the remaining forest regenerated at least 60 years ago. The amount of forest with different regeneration ages at the studied landscapes is a consequence of the forest cover trajectory experienced by each landscape between 1960s and 2000s. Between 1980s and 2000s, forest regeneration was greater than deforestation at the 10% and 50% FC landscapes explaining the large amount of secondary forest with more or less 25 years nowadays and also suggesting the beginning of a forest transition in those landscapes, i.e. the change from decreasing to expanding of forest area (Mather and Needle, 1998; Rudel et al., 2002). This apparent forest transition might be related to a combination of factors, such as higher law enforcement since 1965 (when the Brazilian Forest Act was released), wood charcoal production abandonment, rural exodus of young people due to the low attractiveness of traditional familiar agricultural practices, distant markets or poor transportation conditions.

Forest transitions are associated with socio-economic transformations towards increased industrialization and urbanization (Rudel et al., 2002) but other conditions leading to the abandonment of agricultural land (e.g. war, scarcity of wood, land adjustment and environmental legislation) have been found to play important roles in some cases (Lambin and Meyfroidt, 2010; Perz and Skole, 2003). Forest transition has taken place over a century or more in several European countries and in North America (Mather et al., 1999; Rudel et al., 2005) but some recent studies have reported signs of significant reforestation at some tropical regions (Rudel et al., 2000, 2002), including regions in the Brazilian Atlantic Forest (Baptista and Rudel, 2006; Becker et al., 2004). The beginning of a forest transition would be highly positive in the long term for biodiversity conservation of the extremely imperiled Brazilian Atlantic Forest; however, although the growing young secondary forest can sustain a significant amount of biodiversity, many species need older and more pristine forest to survive (Barlow et al., 2007b; Gibson et al., 2011; Laurance, 2005). Forest cover trajectory and the resulting forest age structure are very important to assess current landscape conditions (Brown and Lugo, 1990; Ferraz et al.,

Table A.1
Description of the five land-use and land-cover classes observed in the aerial photographs and satellite images. In parentheses, the short name used throughout the text to refer to each class.

Land-use and land-cover categories		Description
Land-use		
Urban and rural buildings	(Urban)	Isolated buildings, grouped buildings, settlements
Crop fields and pastures	(Fields)	Crop fields or fallow fields, areas used for cattle ranching, abandoned/disturbed herbaceous vegetation, with or without shrubs
Forest plantation	(Forestry)	Forest plantation with exotic species, e.g. *Pinus* spp. and *Eucalyptus* spp.
Land-cover		
Young secondary vegetation	(Young vegetation)	Shrub to arboreal vegetation with up to 5–6 m height continuous canopy
Forest	(Forest)	Intermediate to old secondary forest with canopy height usually >10 m, with or without emergent trees up to 30–35 m

Table A.2
Land-use/cover persistence and change between (a) the 1960–1980s and (b) the 1980–2000s at three Atlantic Forest landscapes, São Paulo, Brazil. Values are % of the landscape that experienced persistence or transition among land-use/cover classes.

	1980s					
	Landscape (%)	Urban	Fields	Forestry	Young vegetation	Forest
(a) 1960s						
Urban	10	0.18	0.14	0.00	0.01	0.00
	30	0.09	0.30	0.01	0.09	0.14
	50	0.05	0.05	0.00	0.01	0.00
Fields	10	0.23	75.63	0.42	1.82	1.61
	30	0.89	20.85	0.90	4.97	9.32
	50	0.20	26.32	0.69	7.72	1.95
Forestry	10	0.00	0.03	0.11	0.03	0.03
	30	0.01	0.62	0.31	0.21	0.98
	50	0.01	0.15	0.53	0.14	0.07
Young vegetation	10	0.02	6.23	0.03	0.97	1.14
	30	0.16	5.27	0.30	1.52	9.00
	50	0.05	10.11	1.27	5.31	4.78
Forest	10	0.01	6.12	0.08	0.92	4.25
	30	0.33	11.93	1.46	3.45	26.89
	50	0.04	10.91	1.87	9.67	21.07
(b) 1980s						
	2000s					
Urban	10	0.26	0.16	0.00	0.01	0.01
	30	1.05	0.28	0.05	0.03	0.07
	50	0.02	0.28	0.01	0.02	0.03
Fields	10	1.24	77.81	0.89	3.03	5.17
	30	7.76	23.91	2.61	1.58	3.06
	50	0.07	31.44	1.12	1.86	13.01
Forestry	10	0.03	0.45	0.13	0.01	0.01
	30	0.34	0.80	1.48	0.08	0.23
	50	0.00	1.36	2.45	0.09	0.45
Young vegetation	10	0.03	1.58	0.04	0.43	1.66
	30	1.75	4.17	0.68	1.08	2.54
	50	0.02	5.69	0.99	0.68	12.49
Forest	10	0.01	1.83	0.13	0.62	4.46
	30	4.96	8.97	2.30	4.82	25.39
	50	0.00	3.70	0.48	0.37	23.37

2009; Guariguata and Ostertag, 2001). Studies on the effects of landscape structure on different taxonomic groups have dealt until now with landscape characteristics such as forest cover and forest configuration (e.g. Martensen et al., 2008; Pardini et al., 2010) but seldom consider forest cover trajectory and age structure (Etter et al., 2005). However those landscape characteristics may be important determinants for the maintenance of species in human-modified landscapes and we hypothesize that forest-dependent species should show a stronger response to current landscape structure if forest cover trajectory and age structure are considered.

Habitat loss and fragmentation have been recognized as a major cause of global biodiversity loss (Tilman et al., 2001), but recent studies have found that it often takes a considerable amount of time for declining populations to disappear following landscape change, resulting in an extinction debt (Tilman et al., 1994). Time delay in species response gives an opportunity to revert the negative effects of landscape change through habitat maintenance and restoration. However, the expected species colonization and recolonization following habitat regeneration might also not be immediate, resulting in a species credit (Jackson and Sax, 2010). As the dynamic of the three studied landscapes were variable between the two time periods analyzed, the current number of forest-dependent species in forest patches might be a result of the effects of forest cover contraction and expansion on species extinction and (re)colonization. Our results suggests that conceptual models aiming to predict biodiversity patterns in Atlantic Forest fragmented landscapes should take into account landscape history in order to make more reliable predictions.

5. Conclusions

Our results suggest that LULCC in the Atlantic Forest is not random and not constant through time and across space. This landscape dynamism is a key factor to be considered in models of LULCC for the Atlantic Forest so that models can accurately predict future changes that can affect species conservation. Moreover, current landscape structure and age structure of forest patches in Atlantic Forest landscapes are influenced by the LULCC. Furthermore, some Atlantic Forest landscapes seem to be starting to experience a forest transition process, what could be of great importance for biodiversity conservation since young secondary forest can contribute in reducing isolation among fragments, and can also sustain a significant amount of biodiversity.

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Appendix A

See Tables A.1 and A.2.

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