



Prospects for biodiversity conservation in the Atlantic Forest: Lessons from aging human-modified landscapes

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ABSTRACT

Recent global assessments have shown the limited coverage of protected areas across tropical biotas, fuelling a growing interest in the potential conservation services provided by anthropogenic landscapes. Here we examine the geographic distribution of biological diversity in the Atlantic Forest of South America, synthesize the most conspicuous forest biodiversity responses to human disturbances, propose further conservation initiatives for this biota, and offer a range of general insights into the prospects of forest species persistence in human-modified tropical forest landscapes worldwide. At the biome scale, the most extensive pre-Columbian habitats across the Atlantic Forest ranged across elevations below 800 masl, which still concentrate most areas within the major centers of species endemism. Unfortunately, up to 88% of the original forest habitat has been lost, mainly across these low to intermediate elevations, whereas protected areas are clearly skewed towards high elevations above 1200 masl. At the landscape scale, most remaining Atlantic Forest cover is embedded within dynamic agro-mosaics including elements such as small forest fragments, early-to-late secondary forest patches and exotic tree monocultures. In this sort of aging or long-term modified landscapes, habitat fragmentation appears to effectively drive edge-dominated portions of forest fragments towards an early-successional system, greatly limiting the long-term persistence of forest-obligate and forest-dependent species. However, the extent to which forest habitats approach early-successional systems, thereby threatening the bulk of the Atlantic Forest biodiversity, depends on both past and present landscape configuration. Many elements of human-modified landscapes (e.g. patches of early-secondary forests and tree monocultures) may offer excellent conservation opportunities, but they cannot replace the conservation value of protected areas and hitherto unprotected large patches of old-growth forests. Finally, the biodiversity conservation services provided by anthropogenic landscapes across Atlantic Forest and other tropical forest regions can be significantly augmented by coupling biodiversity corridor initiatives with biota-scale attempts to plug existing gaps in the representativeness of protected areas.

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1. Introduction

The relentless growth and spatial dispersion of human activities will continue to alter tropical landscapes so that even vast tracts of remote old-growth forests are likely to be eventually converted into archipelagos of old-growth and regenerating forest patches (Aide and Grau, 2004; Wright and Muller-Landau, 2006). With the expansion and consolidation of agricultural frontiers, forest fragments remaining within private landholdings are likely to be confined to economically-marginal lands, and become gradually

embedded in a harsh matrix of human-managed habitats, dominated by pastures, croplands, and urban areas (Tabarelli et al., 2004; Ribeiro et al., 2009). These anthropogenic and highly fragmented agro-mosaics (hereafter defined as human-modified landscapes) already represent the predominant landscape type across many previously forested tropical lands (Corlett, 2000; Sodhi et al., 2004). Furthermore, most human-modified landscapes in aging tropical deforestation frontiers are currently comprised of very small forest fragments embedded within predominantly harsh and open-habitat matrices (Turner and Corlett, 1996; Ranta et al., 1998; Gascon et al., 2000).

Expansion of human-modified landscapes is in fact a pantropical phenomenon that poses enormous threats to forest biotas since

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edge-affected habitats, such as small fragments and forest borders, are prone to become early-successional systems with limited capacity to retain the old-growth species that account for the bulk of tropical forest biodiversity (Tabarelli et al., 2008; Banks-Leite et al., in press). Therefore, the future of tropical forest biodiversity and provision of forest ecosystem services (e.g. carbon storage and sequestration, soil stabilization, and the modulation of precipitation, infiltration and flooding) are inextricably tied to our ability to understand the changes triggered by human disturbances and the conservation value of human-modified landscapes (Daily et al., 2003; Harvey et al., 2008). However, our understanding of the biodiversity prospects in human-modified tropical forests is still precarious and frequently biased for several reasons. First, forest responses to human disturbance are frequently examined at the species level. Second, incongruent species responses to disturbances, measurement errors and research biases frequently result in overestimates of the conservation value provided by human-modified landscapes. Finally, the habitat value of these landscapes to forest biotas has been largely inferred on the basis of a very limited subset of species and localities (Gardner et al., 2009). These limited approaches are at odds with the fact that tropical forest biodiversity responses to human disturbances reflect the dynamic interplay of both historical and contemporary human disturbances and ongoing ecological processes (Metzger et al., 2009). These complex, context-dependent responses clearly pose enormous challenges for tropical conservation science since we cannot effectively assess the threats and opportunities for biodiversity conservation in human-modified landscapes without a clear understanding of species responses to human disturbances (Gardner et al., 2009).

The Atlantic Forest once consisted of a huge block of evergreen and seasonally-dry forests (~1.5 million km²) stretching across a long latitudinal gradient (3–30°S) of over 3300 km of the Brazilian Atlantic coast and extending west into smaller, inland areas of Paraguay and Argentina (Fig. 1). This biome hosts thousands of endemic species, from >8000 plant species to >650 vertebrate species, and has been internationally recognized as one of the key global biodiversity hotspots (Mittermeier et al., 2005a). Since ~120 million people (or 70% of the Brazilian population) live along the Brazilian Atlantic coast, this biome has experienced unprecedented levels of habitat loss and other human disturbances since the 16th century following abrupt European arrival in Brazil and the first waves of coastal agricultural settlements (Dean, 1997; Cincotta et al., 2000). Today, only ~12.9% (194,524 km²) of the original Atlantic Forest cover remains in Brazil, Paraguay and Argentina (Chebez and Hilgert, 2003; Huang et al., 2007, 2009; Ribeiro et al., 2009; De Angelo, 2009). High levels of deforestation continue in most regions, attaining annual rates of 0.5% for the whole Atlantic Forest, and up to 2.9% in the São Paulo metropolitan area (Teixeira et al., 2009). The rate of forest loss has decreased recently in Brazil (SOS Mata Atlântica and INPE, 2008), and was never very high in Argentina due to the small and late settlement of humans populations and strict forest protection (Holz and Placci, 2003), but recent deforestation in Paraguay (1970–2000) has been far more intensive (Huang et al., 2009). Such alarming rates of habitat loss and fragmentation, frequently associated with other human disturbances (e.g. hunting, logging, collection of non-timber forest products), have led to the near extinction of a large proportion of Atlantic Forest biodiversity, including 112 bird species now officially threatened with global extinction (Marini and Garcia, 2005). In fact, few tropical biodiversity hotspots are ‘hotter’ than the Atlantic Forest in terms of both threats and conservation value (Laurance, 2009).

This prolonged history of human disturbance renders many Atlantic Forest landscapes invaluable experimental sites for understanding the long-term impacts caused by human activities on

tropical forest biotas, and the role played by human-modified tropical landscapes in terms of biodiversity conservation and the provisioning of ecosystems goods and services (Metzger, 2009). Moreover, many of the drastic ecological changes experienced by the Atlantic Forest today, and associated conservation challenges, are likely to be eventually manifested across other increasingly fragmented tropical forest landscapes, such as the Amazon (Santos et al., 2008; Peres, in press). Actually, the Atlantic Forest has already provided a substantial research contribution in terms of tropical forest ecology, the biological dynamics of hyper-fragmented forest landscapes, and conservation science issues ranging from assisted habitat restoration to regional scale conservation planning (Morellato and Haddad, 2000; Tabarelli and Gascon, 2005; Rodrigues et al., 2009; Laurance, 2009).

Here we examine the geographic distribution of Atlantic Forest biological diversity in relation to the remaining formally protected and unprotected forest habitat cover in order to identify biome scale trends in biodiversity retention as different forms of human-induced disturbance proceed rapidly. We also synthesize the most conspicuous population to ecosystem level responses to human disturbances to project long-term patterns of biodiversity persistence in human-modified landscapes throughout the Atlantic Forest region. Finally, we propose further conservation initiatives for this biota, and offer a range of general insights into the prospects of forest species persistence in human-modified tropical forest landscapes worldwide.

2. Atlantic Forest biogeography and altitudinal distribution

The Atlantic Forest exhibits outstanding levels of species endemism, which account for ~40% of its vascular flora and 16–60% of its bird, mammal, reptile and amphibian fauna (Mittermeier et al., 2005b; Metzger, 2009). Endemic species, however, are not homogeneously distributed across the extraordinary latitudinal and elevational range of the Atlantic Forest biota, whether one considers the pre-Columbian or contemporary patterns of biogeographic distribution. Rather, endemic species are clustered within distinct biogeographic subregions (Fig. 1). Five of these subregions are widely recognized as centers of species endemism – Brestos Nordestinos, Pernambuco, Bahia, Diamantina and Serra do Mar (*sensu* Silva and Casteleti, 2003). With a size range of 12,517–129,408 km², these five centers of endemism represent only 25.6% (397,754 km²) of the historical extent of the Atlantic Forest, but host the vast majority of endemic species, including plants, butterflies, amphibians, birds and mammals (Table 1). Many of the endemic species are in fact geographically restricted to only one or two areas of endemism and/or exhibit very narrow distribution as illustrated by endemic mammals: 35 species (40.2% of all endemic mammals) are restricted to sites smaller than 50 km², and 20 species have been recorded at only one site (A. Paglia, pers. comm.), leading to high levels of species turnover across centers of endemism [see Eisenberg and Redford, 1999; Thomas et al., 1998; Silva et al., 2004 and Siqueira-Filho and Leme, 2006 for the geographic distribution of endemic mammals, vascular plants, passerine birds and bromeliads, respectively]. Furthermore, several centers of endemism (e.g. Bahia; Serra do Mar) sustain exceptionally high levels of alpha and beta diversity for plants, mammals, birds, frogs, butterflies and ants (Brown and Freitas, 2000; Costa et al., 2000). For instance, the Bahia Center is truly outstanding, hosting some of the world’s most biologically diverse forests (Thomas et al., 1998); tree species endemism can exceed 25%, with primary forest stands supporting over 140 tree species per 0.1 hectare plot or 405 tree species per hectare, thereby exceeding forest sites anywhere else in the tropics (Martini et al., 2007). In addition to centers of endemism, three additional subregions – Araucaria, Interior

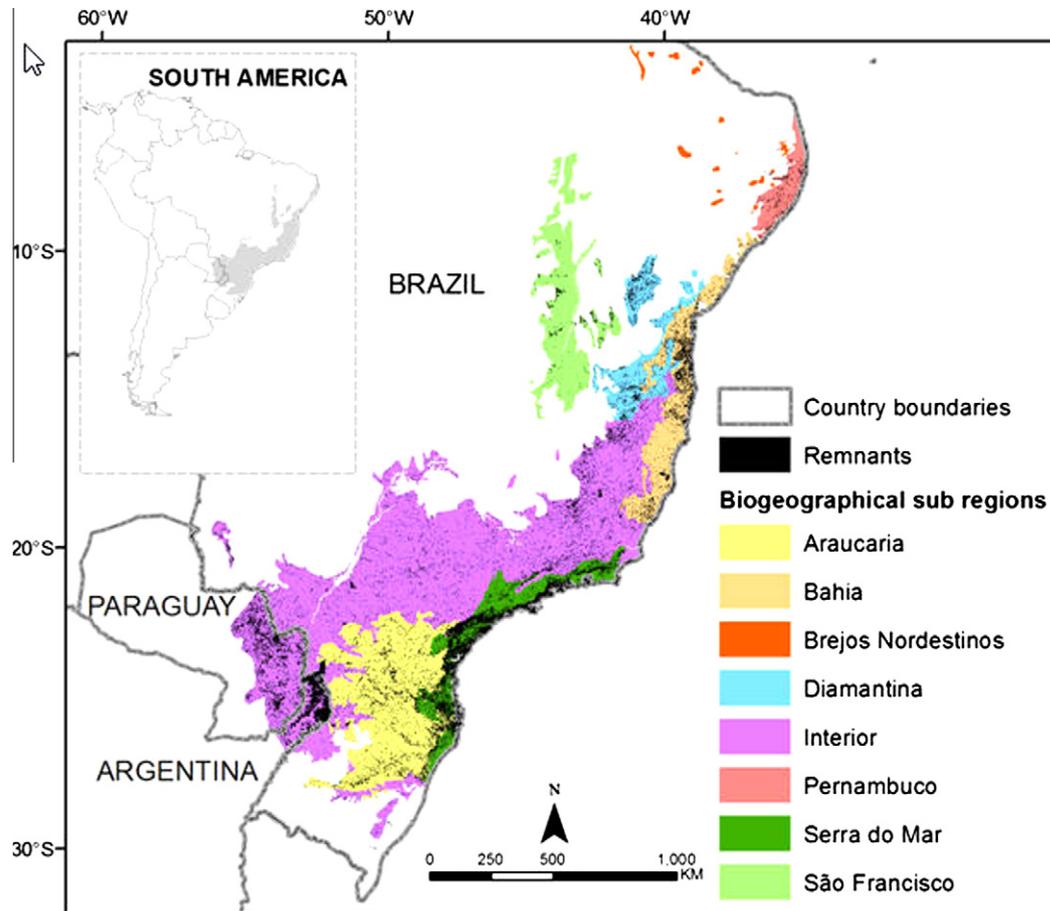


Fig. 1. Biogeographic distribution of the Atlantic Forest cover, showing its original extent and current remnants divided into the eight major sub-regional units (adapted from Silva and Casteleti, 2003). Sources for remaining forest cover: Argentina: Giraudo et al. (2003); Brazil: Ribeiro et al. (2009); and Paraguay: Huang et al. (2007).

Table 1
Main features of the centers of species endemism of the Atlantic Forest of South America. Sources: Galindo-Leal and Câmara (2003), Silva and Casteleti (2003), Silva et al. (2004), Ribeiro et al. (2009).

Endemism centers	Original extent (km ²)	Elevation gradient (m)	Main endemic taxa	Number of exclusive bird species
Brejos Nordestinos	12,518	600–1200	Birds, amphibians	1
Pernambuco	38,938	0–600	Birds, plants	6
São Francisco	129,409	400–1200	Birds	0
Diamantina	82,895	200–1200	Birds	4
Bahia	122,412	0–800	Butterflies, birds, mammals, plants	4
Serra do Mar	114,135	0–1200	Butterflies, birds, mammals, plants amphibians	15

Forests and São Francisco – have been assigned as transitional areas accounting for 74.4% of the entire Atlantic Forest extent (Fig. 1). Although more sparsely represented in terms of endemic species, these areas usually exhibit elevated species turnover due to conspicuous environmental heterogeneity including plant responses to variation in topography, precipitation and temperature (Oliveira-Filho and Fontes, 2000; Almeida-Neto et al., 2008), and bird responses to altitude (Machado and Fonseca, 2000).

The Atlantic Forest centers of endemism and transitional areas clearly diverge in terms of altitudinal distribution. Centers of endemism are more equally distributed across the altitudinal gradient covered by the entire Atlantic Forest (0–1600 masl) with 52% of their forest cover represented by lowland forests below 400 masl, whereas transitional areas are primarily distributed between 400 and 1200 masl (Fig. 2, see Supplementary Information). In fact, approximately one-half of the lowland Atlantic Forest encompasses centers of endemism, particularly along more coastal re-

gions, as only one center of endemism (Brejos Nordestinos) is completely restricted to montane forests (see Table 1). Some 39 mammal species (or 34% of all endemic Atlantic Forest mammals) are restricted to these lowland endemic areas, mostly coastal flatlands across Pernambuco and Bahia (A. Paglia, pers. comm.), including world-renowned flagship species such as the golden lion-tamarin (*Leontopithecus rosalia*) and the golden-headed lion-tamarin (*Leontopithecus chrysomelas*). A similar pattern has been observed for critically endangered birds and mammals (Brooks and Rylands, 2003), reinforcing the importance of low to intermediate elevations as irreplaceable hotspots of the Atlantic Forest biodiversity.

3. Spatial patterns of habitat loss and conservation efforts

Tropical deforestation is far from random in space. Physical access, topography, infrastructure and economic opportunity costs

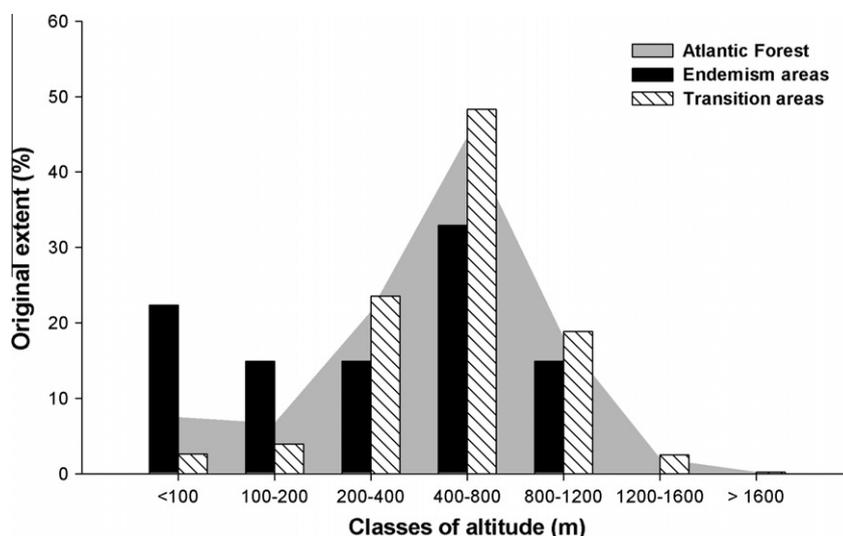


Fig. 2. Relative distribution of the original Atlantic Forest cover, transitional areas, and centers of endemism across different classes of elevation above sea level. Data from Giraudo et al. (2003), Ribeiro et al. (2009) and Huang et al. (2007).

profoundly influence patterns of forest clearing and fragmentation (Geist and Lambin, 2002). The distribution of biodiversity and the ensuing patterns of species richness in any tropical forest region are also nonrandom, but it is usually the product of evolutionary processes, such as speciation, biotic interchange and local patterns of extinction, and environmental variables that still operate today, as rainfall, temperature and elevation (see Oliveira-Filho and Fontes, 2000). At the biome scale, biodiversity retention in response to the establishment of human-modified landscapes thus largely depends on the level of spatial congruence between habitat conversion/degradation and areas of high species diversity, thereby rendering human-related extinctions largely predictable at this spatial scale. This is particularly true for 'old' agricultural frontiers, like the Atlantic Forest, where any significant conservation effort has been invariably preceded by wholesale human encroachment of pristine landscapes (Galindo-Leal and Câmara, 2003; Mittermeier et al., 2005a).

Despite its extraordinary levels of biodiversity, the Atlantic Forest has long experienced relentless habitat loss since the arrival of European colonists. A massive rate of expansion in colonial agriculture, followed by industrialization and urban development has profoundly affected the Atlantic Forest biota, which is now confined to only ~11.7% (163,377 km²) of its original extent in Brazil (Ribeiro et al., 2009) and 24.9% (11,618 km²) in Paraguay (Cartes and Yanosky, 2003; Huang et al., 2007, 2009). The Atlantic Forest of northern Argentina, however, still retains ~38.7% (9950 km²) of its original cover (Chebez and Hilgert, 2003; De Angelo, 2009), but forest loss across centers of endemism has already achieved a range from 95.3% (São Francisco) to 63.5% (Serra do Mar) (Ribeiro et al., 2009). In Brazil, a massive forest conversion into croplands, abandoned pastures, real estate properties and urban areas has occurred primarily across low to intermediate elevations. Lowland and lower-montane forests spanning 200–800 masl have been reduced to <10% of their original extent, with remaining forest patches sizing <30 ha on average. Conversely, nearly 40% of all forest habitat at elevations >1600 masl still persist (Fig. 3). Intermediate elevations across the Atlantic Forest, which include the flatlands of the Pernambuco, Bahia, São Francisco, Forest Interior Centers and the Araucaria transitional region, are largely comprised of suitable agricultural soils that have been historically allocated to primary agro-pastoral commodities such as sugar-cane, coffee, cattle and more recently

soybean and biofuel crops (Coimbra-Filho and Câmara, 1996; Galindo-Leal and Câmara, 2003a,b). This apparent sparing of high-altitude habitats has not been enough to avert massive biota-scale habitat loss, as high elevations >1600 masl represent only <1% of the entire Atlantic Forest.

Yet, the conservation effort allocated to the Atlantic Forest biota exceeds that of most other tropical forest regions: over 700 protected areas have been set-aside, mostly during the last four decades (Galindo-Leal and Câmara, 2003). However, this biota is far from effectively protected in terms of habitat cover, species distribution and population viability (Chiarello and Melo, 2001; Tabarelli et al., 2005). First, protected areas of any category (IUCN categories I–VI) cover only ~4% of the entire biome biota (Lairana, 2003), and strictly protected areas (IUCN categories I and II) encompass only 1.7% of the biome and 13.2% of all forest remnants (Lairana, 2003; Ribeiro et al., 2009). Second, most protected areas are too small to ensure long-term species persistence; e.g. ~75% of all protected area polygons are smaller than 100 km² (Silva and Tabarelli, 2000; Marsden et al., 2005). Third, almost 80% of all remaining forest cover is farther than 10 km from the nearest protected area (Ribeiro et al., 2009). Finally, 57 of the 104 threatened vertebrate species have yet to be recorded in any protected area and, as such, can be defined as 'gap-species' (Paglia et al., 2004). In addition to these fragilities in the species 'safety-net', habitat protection across the altitudinal range covered by the Atlantic Forest is clearly skewed towards elevations above 1200 masl (Fig. 4). In other words, the most extensive range of pre-Columbian altitudinal habitats across the entire Atlantic Forest is currently the most devastated and has been allocated the lowest level of protection regardless of its biological representativeness. As a result, most Atlantic Forest vertebrate 'gap-species' are restricted to as-of-yet unprotected patches of lowland/lower-montane forests, particularly across the Serra do Mar, Bahia and Pernambuco centers of endemism (Paglia et al., 2004); a similar pattern has been documented for threatened birds (Marini and Garcia, 2005). This regional scale pattern of habitat retention helps clarify why so many species threatened by global extinction occur in the Atlantic Forest, and which component of biodiversity exhibits higher chances to persist through further human encroachment of forest habitats, namely the relatively small set of species thriving in viable populations at high elevations and steep slopes.

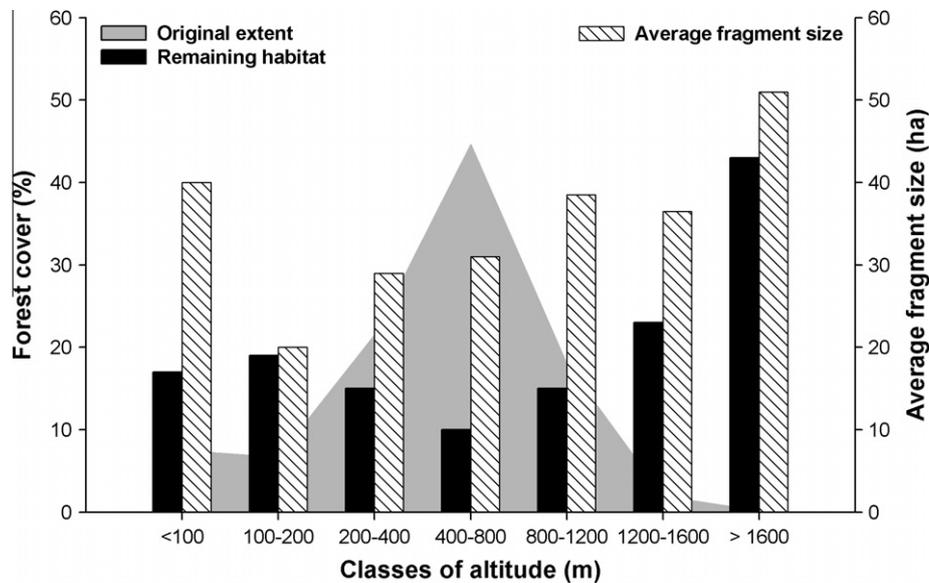


Fig. 3. Original extent, remaining habitat and average fragment size of the Atlantic Forest biome across classes of elevation. Data from Girauo et al. (2003), Ribeiro et al. (2009) and Huang et al. (2007).

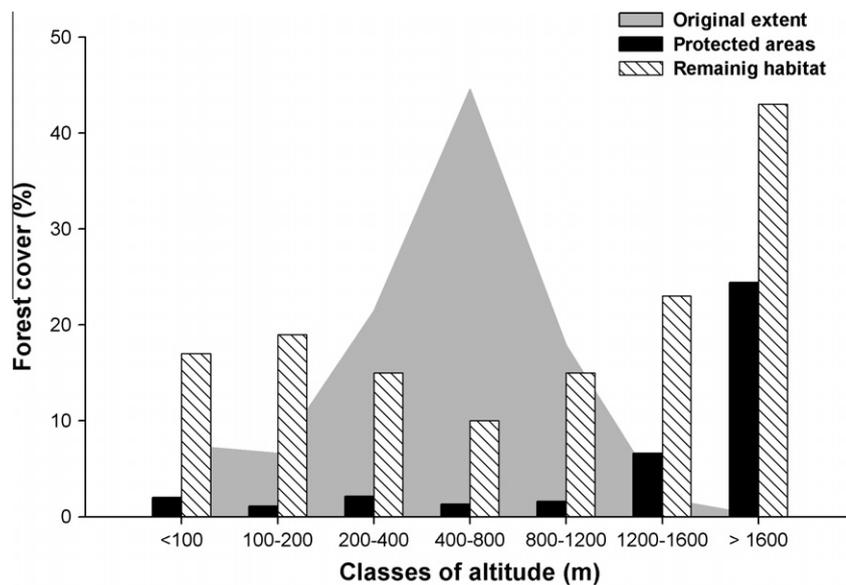


Fig. 4. Original and remaining extent of forest habitat within the Atlantic Forest biome, and total extent of protected areas across classes of elevation. Data from Girauo et al. (2003), Ribeiro et al. (2009) and Huang et al. (2007).

4. Atlantic Forest biodiversity responses to human disturbance

4.1. Landscape alterations and ecosystem level shifts

In the context of tropical forests, habitat loss and fragmentation represent but one of the initial steps of a broader human-induced cascade of alterations of the original forest landscape, eventually resulting in mostly small forest fragments embedded within a matrix of non-forest habitat (Tabarelli and Gascon, 2005). In the case of the Atlantic Forest, human-modified or anthropogenic landscapes typically refer to agro-mosaics with a dynamic combination of the following main habitat components: a few large patches of old-growth forests, a large set of many small, edge-affected forest remnants of varying degrees of disturbance (83% of all patches are smaller than 50 ha and almost half of the remaining forest is within 100 m from the nearest edge; Ribeiro et al., 2009), early-to-late

secondary forest patches recovering from cropland or pasture abandonment, small patches of assisted regenerating forests (*sensu* Chazdon, 2008), agroforestry patches, and managed plantations of exotic trees such as *Pinus* and *Eucalyptus* (Fonseca et al., 2009). In general, Atlantic Forest agro-mosaics are spatially arranged as variegated landscapes (landscapes with a moderate degree of habitat destruction – i.e. with 60–90% of habitat remaining), and more often truly fragmented (10–60% of remaining habitat) or relictual landscapes (<10% of remaining habitat) *sensu* McIntyre and Hobbs (1999). Such mosaics are usually hyper-dynamic as deforestation of native forest is still an ongoing process, concomitant with cycles of land abandonment resulting from agricultural fallow periods, suppression of secondary forest patches for crop/pasture lands, and shifting economic activities (Cartes, 2003; Metzger et al., 2009; Teixeira et al., 2009). Regardless of any variation in composition and dynamics, most Atlantic Forest landscapes retain much

<30% of native forest cover (except for those in the Serra do Mar center), i.e. the theoretical fragmentation threshold, below which spatial configuration, particularly fragment size and connectivity, play a disproportionate role in species extinctions (Andr en, 1994; Fahrig, 2003).

Currently available studies across the Atlantic Forest region suffer from the same biases and limitations observed across all tropical regions: (1) patterns of biodiversity distribution and persistence have been examined with little replication and for few landscapes, which differ in terms of forest type, structure, composition and disturbance history; (2) research have usually addressed atypical landscapes that still retain high levels of forest cover (fragmented rather than relictual landscapes), and (3) biodiversity retention patterns have been characterized via severely limited timescales (i.e. snapshots) and single-taxa surveys, such as those of mammals and trees (Table 2). However, by examining both landscape- and patch-based studies, some general patterns have emerged at least as working hypotheses.

Woody plant studies in many aging or long-term fragmented Atlantic Forest landscapes indicate that habitat fragmentation can effectively drive edge-dominated portions of forest fragments towards an early-successional system (see Santos et al., 2008 in Table 2) in which both short- and long-lived pioneers (e.g. r-strategists, light-demanding plant species) proliferate. This sort of novel ecosystem (*sensu* Hobbs et al., 2006) emerges through a sort of retrogressive succession – i.e. enhanced mortality of large trees and loss of long-lived tree species regeneration (*sensu* Tabarelli et al., 2008), thereafter persisting for as long as edge effects and associated shifts in the light regime continue. Through this retrogressive succession process, a small set of light-demanding plant species dominate the new flora, to the detriment of the old-growth flora comprised of a highly diverse pool of species (Oliveira et al., 2004; Tabarelli et al., 2008). Because Atlantic Forest remnants in persistent human-modified landscapes are overwhelmingly dominated by very small forest patches (Ranta et al., 1998; Gascon et al., 2000), they may be composed of no more than a collection of early- to mid-successional secondary forest stands (see Tabanez and Viana, 2000; Santos et al., 2008; Lopes et al., 2009 in Table 2).

4.2. Species response and drivers of species persistence in human-modified landscapes

The notion that habitat fragmentation alters plant community dynamics across edge-affected habitats towards early-successional systems implies that edge-intolerant species and those requiring old-growth or core forest areas (i.e. forest-obligate and forest-dependent species) are unlikely to persist in hyper-fragmented Atlantic Forest landscapes, regardless of other associated anthropogenic disturbances such as hunting, wildfires, and extraction of timber and non-timber products (Tabarelli et al., 2008). These ‘losers’ (*sensu* McKinney and Lockwood, 1999) include a wide range of functional groups of tree species, such as emergents (Oliveira et al., 2008), large-seeded (Melo et al., 2006), understory and shade-tolerant (Tabarelli et al., 1999), vertebrate-dispersed and vertebrate-pollinated (Gir o et al., 2007; Lopes et al., 2009), heavy-wooded (Santos et al., 2008), and outbreeding species (Gir o et al., 2007). In addition, many faunal groups exhibit detrimental responses to increasing levels of forest loss and fragmentation, particularly carnivorous and nectarivorous bats (Gorresen and Willig, 2004), forest-obligate birds (Giraud et al., 2008; Martensen et al., 2008; Banks-Leite et al., in press), medium and large carnivores (Lyra-Jorge et al., in press), chironomid insects (Roque et al., in press), leaf-litter lizards (Dixo and Metzger, 2009), terrestrial forest-dwelling small mammals and those with low-dispersal capacity (Castro and Fernandez, 2004; Metzger et al., 2009). Conversely, species that benefit from successional habitats, including short-lived pio-

neers (Oliveira et al., 2004; Aguiar and Tabarelli, in press), leaf-cutting ants (Wirth et al., 2007), disturbance-adapted and generalist frugivorous bats (Gorresen and Willig, 2004), matrix-tolerant marsupials (Pires et al., 2002), edge-tolerant and gap-crossing birds (Anjos, 2006; Awade and Metzger, 2008), edge-dwelling butterflies (Uehara-Prado et al., 2007) and non-forest frogs (Dixo and Martins, 2008) often persist or even proliferate in these landscapes by spilling-over across edge-dominated habitats (Oliveira et al., 2004; Lopes et al., 2009), and as such could be described as ‘winners’.

The extent to which, forest habitats in human-modified landscapes approach early-successional systems and threaten forest-obligate species is a function of the former and current landscape configuration. In the Atlantic Forest, fragment size distribution, structural connectivity, matrix quality, remaining forest cover, presence of old-growth forest patches and/or proportion of edge-affected habitats have all been identified as key correlates of species richness and abundance in bats (Faria et al., 2007), reptiles (Dixo and Metzger, 2009), birds (Martensen et al., 2008; Metzger et al., 2009), canopy/emergent trees (Santos et al., 2007; Oliveira et al., 2008), small mammals (Pardini, 2004; Pardini et al., 2005; Umetsu and Pardini, 2007), mammalian carnivores (Lyra-Jorge et al., in press), butterflies (Brown and Freitas, 2000), chironomid insects (Roque et al., in press), and frogs and lizards (Faria et al., 2009). Although some taxa present incongruent responses (see Martensen et al., 2008; Metzger et al., 2009, Table 2), clear emergent patterns in relation to biodiversity persistence have been elucidated. As fragmentation proceeds, forest fragments become smaller, functional connectivity is either reduced or collapses (Ribeiro et al., 2009), and old-growth forest patches serving as source habitats gradually succumb to edge-dominated habitats (Tabarelli et al., 2008). Disturbance-sensitive species, which probably account for the bulk of Atlantic Forest species diversity (e.g. birds: Goerck, 1997; Loiselle et al., in press), experience landscape scale population declines in response to one or multiple forces including the reduction in fragment size (Pardini et al., 2005), population sub-division and isolation (Vieira et al., 2009), and habitat degradation by edge effects (Oliveira et al., 2008; Faria et al., 2009; Lyra-Jorge et al., in press). In fact, species richness and abundance for several taxa have been shown to be negatively correlated with the proportion of edge-affected and structurally homogeneous habitat, particularly in long-term archipelagos of small forest fragments (Santos et al., 2008; Faria et al., 2009). Population declines and local extinctions ultimately result in impoverished biological assemblages in aging fragmented forest landscapes, in which disturbance-adapted, habitat generalist, edge- and matrix-tolerant, early-successional and pioneer species become increasingly dominant, while many forest-obligate or strict forest dwellers become rare or absent. Long-term bird surveys in a 120 km² landscape in southern Brazil have documented a 50% reduction on bird species richness compared to the 1930s, although forest cover (currently reaching 33%) and isolation level of forest fragments have remained stable during the last decades; terrestrial and understory bird populations (including many endemics) have declined considerably while omnivore and nectarivorous birds proved to be more tolerant to habitat loss and fragmentation (Ribon et al., 2003, see Table 2).

This gradual erosion of the Atlantic Forest biota via a selective process of species extinction is a time-lag response that may exhibit considerable cross-taxa variation but will sooner or latter be manifested as edge effects and human disturbances persist (Lyra-Jorge et al., in press; Faria et al., 2009; Metzger et al., 2009). Moreover, forest biodiversity retention in these landscapes can be further depressed by negative effects imposed by historical and contemporary logging (Villela et al., 2006), hunting (Cullen et al., 2000; Galetti, 2001; Galetti et al., 2009), and exploitation of other non-timber forest resources (Galetti and Aleixo, 1998). Hunting

Table 2
Studies examining patterns of biodiversity distribution and persistence across human-modified landscapes throughout the Atlantic Forest biome with their site descriptions and main conservation lessons.

References	Type of forest ^a	Type of matrix	Landscape pattern	Taxonomic groups	Spatial and temporal scales	Main objective	Main conservation lesson
Bragagnolo et al. (2007)	Montane	Heterogeneous agricultural areas	Fragmented (31%)	Opiliones	Landscape, snapshot	To assess Opilione response to habitat disturbance	Opiliones are highly susceptible to habitat loss and fragmentation
Dixo and Metzger (2009)	Montane	Multiple use	Fragmented	Lizards	Landscape, snapshot	Examine the role of patch and landscape metrics on leaf-litter lizards	Leaf-litter lizards are sensitive to fragmentation per se but not to fragment size or connection by corridors
Faria et al. (2009)	Lowland	Secondary forests, pastures, crops, rubber tree plantations, and shade cacao plantations	Relictual	Lianas and trees	Landscape, snapshot	Understand the major changes in forest structure related to fragmentation	Conservation effort should target the protection of old-growth forest remnants
Fonseca et al. (2009)	Lower-montane and montane	Tree plantations	Fragmented	Small mammals, birds, leaf-litter frogs, butterflies, galling insects, spiders, opiliones, flatworms, woody plants, epiphytic angiosperms, ferns, lichens and fungi	Landscape, snapshot	To test the effectiveness of ecologically managed tree monocultures in maintaining biodiversity	Ecologically-managed tree plantations can retain a substantial portion of biodiversity depending on landscape context
Girão et al. (2007)	Lowland	Sugar-cane fields	Relictual (9.2% of forest cover)	Trees	Landscape, snapshot	To examine tree assemblage responses to habitat fragmentation	Habitat fragmentation reduces the functional diversity of tree assemblages
Giraud et al. (2008)	Lower-montane	Crops, <i>Pinus</i> and <i>Eucalyptus</i> plantations.	Fragmented	Birds	Landscape, multiple	Compare bird assemblages between small and large forest fragments	Forest-dependent, and endemic birds require large forest remnants
Lopes et al. (2009)	Lowland	Sugar-cane monoculture	Relictual (9.2% of forest cover)	Trees	Landscape (670 km ²), snapshot	To test the habitat fragmentation and edge effects on tree reproductive traits	Large blocks of core primary forest remain an irreplaceable target for biodiversity conservation
Martensen et al. (2008)	Montane	Heterogeneous agricultural areas	Fragmented (31%)	Trees, small mammals, birds, frogs	Landscape, snapshot	To evaluate the effects of patch and landscape metrics on bird assemblages	Bird functional groups were differently affected by area and connectivity. Well connected fragments can sustain an elevated number of species and individuals
Metzger et al. (2009)	Montane	Heterogeneous agricultural areas	Fragmented (31%)	Trees, small mammals, birds, frogs	Landscape, snapshot	To test the existence of a time-lag in responses to fragment area and connectivity	The efficiency of conservation actions will depend on our capacity to consider historical landscape structure and dynamics
Oliveira et al. (2004)	Lowland	Sugar-cane fields	Relictual (9.2% of forest cover)	Trees	Landscape, snapshot	To examine tree assemblage responses to habitat fragmentation	Edge-affected habitats become permanently dominated by pioneer woody plants
Pardini et al. (2005)	Montane	Heterogeneous agricultural areas	Fragmented (31%)	Small mammals	Landscape, snapshot	Examine the effects of fragment size and corridors on mammal assemblages	Small and isolated fragments are largely impoverished in terms of small mammal species
Pardini et al. (2009)	Lowland	Heterogeneous, with second-growth forest, shade cacao plantation and open areas	Variigated (49% of mature forest and 15% second-growth)	Ferns, trees, frugivorous butterflies, leaf-litter frogs and lizards, bats, small mammals and birds	Landscape, snapshot	To test the potential for biodiversity conservation of a landscape exhibiting a high proportion of mature forest and high permeable matrix habitats	Landscape dominated by mature forest sustain species rich assemblages for multiple taxa

Pires et al. (2002)	Lowland	Introduced grasses, shrubs, and scattered pioneer trees	Relictual	Small mammals	Landscape, long-term surveys	To examine marsupial and rodent species movements	Species ability to move among fragments is not related to their abundance in the matrix.
Ribon et al. (2003)	Lower-montane	Multiple uses	Fragmented (33% of forest cover)	Birds	Landscape, long-term surveys	Long-term responses of bird assemblages to habitat loss and fragmentation	Forest-dependent, endemic and threatened birds are extirpated of fragmented landscapes
Santos et al. (2007)	Lower-montane and montane	Multiple uses	Relictual	Trees	Landscape, snapshot	Investigate the influence of fragment size on tree species richness and seed dispersal modes	Small fragments exhibit high conservation value as they increase the likelihood of species persistence
Santos et al. (2008)	Lowland	Sugar-cane fields	Relictual (9.2% of forest cover)	Trees	Landscape, snapshot	To examine tree assemblage responses to habitat fragmentation	Habitat fragmentation drive edge-affected habitats toward early-successional systems
Silva and Mendes-Pontes (2008)	Lower-montane	Pastures, and sugar-cane monoculture	Relictual	Large mammals	Landscape snapshot	To evaluate occurrence and abundance of the medium- and large bodied mammals in forest fragments	Only generalist and with small-bodied species can use small fragments
Tabanez and Viana (2000)	Lower-montane	Agricultural lands	Relictual	Trees	Landscape snapshot	To evaluate the effects of habitat fragmentation of tree assemblages and forest structure	Small forest fragments tend to retain a degraded structure (i.e. low forest patches)
Tabarelli et al. (1999)	Montane	Multiple uses	Relictual	Trees	Landscape, snapshot	To examine tree assemblage responses to habitat fragmentation	Small fragments lose understorey tree species
Uehara-Prado et al. (2009)	Montane	Second and old-growth forest	Intact	Landhoppers, woodlice, ground-dwelling spiders, harvestmen, fruit-feeding butterflies, false blister and beetles.	Landscape, snapshot	To assess the effects of forest disturbance on terrestrial arthropods and select groups that could be used as ecological indicators	Fruit-feeding butterflies and epigaeic Coleoptera, have a huge potential as indicator species.
Vieira et al. (2009)	Lowland	Agriculture, cattle ranching and peri-urban areas	Fragmented	Small mammals	Landscape, snapshot	To examine the effects of fragment size, isolation and land use on species composition and richness	Fragment size and isolation are drivers of community composition in fragmented landscapes.
Zurita et al. (2006)	Lowland	Exotic tree plantations	Fragmented	Birds	Landscape, snapshot	To examine bird assemblage response to habitat fragmentation	Forest-dependent and threatened bird species respond negatively to forest conversion to tree plantations

^a Lowland: <400 masl lower-montane: 400–800 m. Montane: >800 m.

and trapping for the pet trade have in fact promoted local extinctions of medium-to-large birds (Ribon et al., 2003), primates (Almeida et al., 1995), and ungulates (Chiarello, 1999) over large portions of the Atlantic Forest, reducing human-modified landscapes to a semi-defaunated condition (Silva and Mendes-Pontes, 2008). Defaunation resulting from either direct depletion or habitat loss may impose severe seed dispersal limitations concomitant with high rates of seed predation among tree populations stranded along forest edges and small forest fragments as these edge-affected habitats often lack large frugivorous vertebrates but may sustain hyper-abundant small mammal populations acting as seed predators (Silva and Tabarelli, 2000; Pardini et al., 2005; Pinto et al., 2009). This scenario led to one of the first regional scale estimates of species extinction based on the disruption of a mutualistic plant-animal interactions. Silva and Tabarelli (2000) predicted that nearly one third of all tree species inhabiting the Pernambuco Center would face regional extinction as their vertebrate seed-dispersers are extirpated regionally due to habitat fragmentation and persistent hunting. Galetti et al. (2006) has also proposed the regional extinction of many palm species by documenting seed dispersal collapse associated with reduced seedling recruitment within defaunated fragments of southeast Brazil.

4.3. Landscape composition and prospect for biodiversity

Both single and multitaxa surveys across the Atlantic Forest region suggest that the conservation value of fragmented forest landscapes pales in comparison with those provided by large patches of old-growth stands. Despite the variation of species occurrence and species-specific response across taxa, many species and entire functional groups are missing from early to intermediate secondary forest patches (Tabarelli and Peres, 2002; Silva et al., 2007; Liebsch et al., 2008; Faria et al., 2009), exotic tree monocultures (Zurita et al., 2006; Fonseca et al., 2009), native tree plantations (Zurita et al., 2006), and agroforestry systems, such as the traditional shade-cocoa plantations of southern Bahia (Faria et al., 2007). Surveying a wide range of taxa (from lichens to birds, Table 2) within a large forest mosaic, Fonseca et al. (2009) recorded nearly half of the old-growth forest species richness within patches of tree plantations (*Araucaria*, *Pinus* and *Eucalyptus*). Several studies consistently show that >60% of bird species are restricted to relatively undisturbed forest habitats (Goerck, 1997; Zurita et al., 2006 – see Table 2). Therefore, disturbed-forest habitats alone often fail to support viable populations of forest-specialists, forest-dependent or disturbance-sensitive species (hereafter forest-obligate species), including many endemic and threatened species (Zurita et al., 2006; Bihn et al., 2008; Faria et al., 2009). Moreover, the elevated abundance of generalist species is apparently insufficient to avoid decreased species richness caused by the extinction of forest-obligate species, e.g. only one of 34 species of opiliones responded positively to habitat loss and fragmentation in southeast Brazil (Bragagnolo et al., 2007), which results in reduced alpha/beta diversity and taxonomic/functional convergence within and between disturbed-forest habitats as also revealed for tree species in a sugar-cane dominated landscape of northeast Brazil (Santos et al., 2008).

Being repeatedly disturbed via timber harvesting and clear cutting, these forest-obligate species will likely continue to depend on nearby source populations from old-growth forest patches (see Pardini et al., 2009; Groeneveld et al., 2009). Yet there is convincing evidence that secondary forests following clear cutting are becoming increasingly younger in many Atlantic Forest landscapes (Teixeira et al., 2009). Reducing regeneration-time before the next clearance, the long period required for secondary forests to resemble the compositional status of old-growth (up to 300 years; Liebsch et al., 2008), and the reduced species richness across

early-secondary forest patches due to high pioneer dominance (Tabarelli and Peres, 2002; Liebsch et al., 2008), clearly limit the potential of this expanding element of human-modified landscapes (Chazdon, 2008) to retain forest biodiversity. For example, emergent, large-seeded and large-fruited trees species are largely underrepresented in secondary forest patches (<40 years old) (Tabarelli and Peres, 2002; Santos et al., 2008) which require at least 40 years following land abandonment to recover ant assemblages (Silva et al., 2007). In synthesis, short-term surveys, failure to consider time-lagged responses (Metzger et al., 2009) and the assumption that disturbed-forest elements are protected against further disturbance (including second-growth suppression) may lead to an over-optimistic perspective on the conservation services/value provided by these habitats (Faria et al., 2009). The available evidence to date therefore suggests that old-growth forest patches across the Atlantic Forest operate both as irreplaceable habitats for forest-obligate species and as stable source areas across highly dynamic patchwork mosaics (Metzger et al., 2009).

There is a clear gradient of biodiversity retention ranging from remaining large patches of native old-growth forest to edge-dominated small forest fragments, early to intermediate aged secondary forests, agroforestry systems, native species plantations, exotic tree plantations, and finally degraded and open pasturelands. However, the exact conservation value of different intermediate landscape forms along this gradient remains unclear for different taxa. Along this gradient, the relative importance of forest-obligate species decrease while disturbance-adapted (e.g. edge species, generalists, matrix-tolerant, and gap-crossing species) and exotic species increase their contribution. Again, this implies that rather than replacing old-growth forest patches, disturbed-forest elements should be used to provide additional forest habitat for native species, buffer microclimatic edge effects and enhance landscape connectivity (e.g. as stepping stones). This would extend the conservation services provided by human-modified landscapes and reduce the extinction debt across the Atlantic Forest region. In synthesis, although the different elements of human-modified landscapes are an excellent opportunity for conservation, they cannot replace the conservation value of protected areas and hitherto unprotected large patches of old-growth forests.

5. Conserving Atlantic Forest biodiversity

The Atlantic Forest has a long tradition of successful conservation initiatives, including strict legal protection, management of threatened species, implementation of protected areas and the development of economic alternatives for deforestation, most of which supported by science-based conservation planning (see Galindo-Leal and Câmara, 2003a,b). Certainly, the Atlantic Forest experience informs the conservation community worldwide that severely altered biotas are not hopeless situations (e.g. Russo, 2009). However, without further conservation actions, some Atlantic Forest areas can not retain viable populations or intact communities of their original forest biodiversity, and will eventually consist of biologically impoverished and homogeneous landscapes (Silva and Tabarelli, 2000; Lopes et al., 2009). Networks of protected areas connected by forest corridors, stepping stones and immersed within a benign, permeable matrix where land-use can coexist with forest biodiversity (Sanderson et al., 2003) represents one of the most appealing modern set of guidelines in biodiversity conservation planning. In fact, these networks or biodiversity corridors have come to represent the basic foundation of any effective biodiversity conservation strategy in highly fragmented forest biotas (Santos et al., 2008). In this context, the biodiversity corridor approach would represent an excellent opportunity to (1) extend the overall coverage of the protected area system, particularly in

low to intermediate elevations (see Fig. 3), (2) reduce the isolation of biological communities in existing protected areas, (3) augment structural and functional connectivity among key forest patches and other landscape elements, (4) reduce edge effects and the proportion of edge-affected habitats, particularly in protected areas, key unprotected forest patches and forest corridors, (5) incorporate regenerating forest patches into conservation landscapes before they are converted again into crop/pasture/forestry lands, and (6) increase the benign effects of matrix permeability (e.g. via agroforestry). In fact, biodiversity corridors should consist of a network of functionally linked mosaics (*sensu* Ribeiro et al., 2009), in which protected areas and unprotected old-growth forest patches operate as central points (or 'backbones') for structural connectivity across the landscape. Some of these large-scale goals can substantially benefit from newly available approaches that have been intensively developed over the last three decades to rapidly recreate forests via native tree plantations (or assisted forest regeneration). Namely, forest patches and corridors hosting over 80 tree species can be rapidly implemented within realistic costs, even in highly degraded habitats, such as abandoned pastures (Ribeiro et al., 2009). This also serves increasingly louder societal claims for active forest restoration to boost the provision of forest ecosystems services (see Rodrigues et al., 2009).

Obvious candidate sites for biodiversity corridors include: (1) those landscapes still retaining old-growth forest patches and declining populations of large mammals (Galetti et al., 2009), (2) landscapes with high species extinction debt (Tilman, 1994), or hosting populations of gap-species and irreplaceable/critical sites [*sensu* Paglia et al. (2004) and Pinto and Viveiros-Grelle (2009)], and (3) landscapes with reduced forest cover hosting threatened/endemic species restricted to small protected areas (Brooks and Rylands, 2003; Pinto and Viveiros-Grelle, 2009), such as those scattered across lowland areas of the Serra Mar, Bahia, and Pernambuco centers of endemism (Marini and Garcia, 2005). These subregions and their high-productivity coastal forests (see Castro et al., 2007; Almeida-Neto et al., 2008) are severely under-protected and continue to be exposed to burgeoning land-use pressures (see Figs. 2–4). Such recommendations combine the two basic conservation demands highlighted here: further protection effort towards species and habitats restricted to low to intermediate elevations (see Figs. 2–4) and any effort facilitating the retention of forest-obligate species. In the current scenario of louder societal calls for sustainable development initiatives, the biodiversity corridor approach creates a favorable environment to integrate the ambitious pool of ongoing conservation actions in Atlantic Forest, including the consolidation of the regional scale corridors already being implemented throughout the Atlantic Forest region (Aguar et al., 2003). This is an excellent opportunity for avoiding species extinctions across many hyper-diverse subregions of the Atlantic Forest biota (Tabarelli et al., 2005; Tabarelli and Roda, 2005), such as those predicted for tree, bromeliad, bird and mammal assemblages of the Pernambuco Center (Brooks and Rylands, 2003; Silva and Tabarelli, 2000; Silva and Mendes-Pontes, 2008),

6. Lessons from the Atlantic Forest and way forward

Recent global assessments have shown the limited coverage of protected areas across tropical biotas (Brooks, 2004; Rodrigues et al., 2004a,b), fuelling a growing interest in the potential conservation services provided by anthropogenic landscapes (e.g. Harvey and Saénz, 2008). Benefiting from this opportunity requires an understanding of the forces controlling the long-term persistence of forest biodiversity across a wide array of mixed landscapes in terms of structure, composition, land-use dynamics and legacy of human disturbances. Our analysis supports the notion that habitat

loss and protection in the Atlantic Forest biota are nonrandom processes that are largely governed by opportunity cost constraints on land acquisition, which are as dynamic as the underlying markets and commodity prices. In other words, historical patterns of habitat selection and occupation by human populations (e.g. flatlands instead of steep terrains; Silva et al., 2008) largely determine which fraction of the original complement of species has better chance to persist in the long-term. By targeting economically valuable lands across the Atlantic Forest, human disturbance initially drove to the brink of extinction the pool of species inhabiting the most productive forest habitats, such as the lowland and lower-montane forests (see Siqueira-Filho and Tabarelli, 2006). However, given ever growing demands for new croplands (e.g. sugar-cane plantations) and novel technology enabling agricultural conversion of even previously "marginal lands", many remaining forest tracts may continue to succumb to the same fate of much of this biome, thereby threatening forest-obligate species across the entire altitudinal range. One of many emblematic examples is illustrated by six critically endangered bird species currently persisting within a single 15 km² lower-montane forest patch in the Pernambuco Center as the lowland surroundings areas were completely converted into sugar-cane monoculture (Brooks and Rylands, 2003).

Moving from the biome to the landscape scale, Atlantic Forest conservation science also substantiates more general insights into the biodiversity prospects of human-modified landscapes worldwide (Gardner et al., 2009): (1) the structural complexity and proportion of edge-affected habitats provides a crude proxy of biodiversity value across land-use intensification gradients, (2) biodiversity persistence in human-modified landscapes is determined by biological fluxes across the entire landscape mosaic, (3) landscape context exert a profound influence on the prospects for biodiversity conservation, particularly landscape history in relation to its human disturbance regime (e.g. hunting, logging, non-timber resource extraction, harvesting of firewood) and landscape structure (e.g. past patterns of landscape connectivity) as many taxonomic groups tend to exhibit time-lagged responses (Metzger et al., 2009), (4) forest biotas that originally contained large fractions of forest-obligate species are likely to experience the highest levels of biodiversity erosion in human-dominated landscapes, and (5) old-growth forest patches are crucial for retaining native species diversity and operate as both irreplaceable habitats and source areas. These general findings imply that patterns of biodiversity persistence in anthropogenic tropical forest systems are highly context and scale-dependent (Lindenmayer and Hoobs, 2000), but also clearly deterministic and predicable at the biome and landscape scale.

Assuming that a significant fraction of tropical forest biodiversity depends on undisturbed habitats and landscape connectivity, the conservation services provided by anthropogenic landscapes can be significantly augmented by coupling biodiversity corridor initiatives (if they can ensure the persistence of old-growth forest remnants connected to disturbed-forest elements) with any attempt to plug existing gaps in the representativeness of protected areas. These potential services alone cannot justify further forest conversion into competing land-uses, particularly in the case of highly fragmented tropical forests below the critical forest cover threshold. As human encroachment proceeds, however, conservation science must inform the realistic opportunities available for long-term biodiversity retention. Briefly, a basic research agenda should address forest biodiversity responses to human disturbance, the forces driving the biological dynamics in hyper-fragmented forest landscapes, the conservation role of different landscape components, and how the potential services of these components can be amplified. Finally, the economic costs and opportunities to implement and maintain biodiversity corridors and their network of functionally connected mosaics must be

continuously re-examined as the relentless demand for new crop-lands is unlikely to be saturated given our growing appetite for food and biofuel commodities. Regardless of any bias and limitations of our current perspectives on the biodiversity value of anthropogenic landscapes, the general guidelines provided here are sufficiently objective to support immediate *in situ* conservation action and extend ongoing research efforts to reduce significant extinction debts in tropical forest regions. We hope that the so-called Atlantic Forest 'experiment' can strengthen societal concerns about the biodiversity costs of further forest habitat conversion, ensuring effective on-the-ground conservation initiatives.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.biocon.2010.02.005.

References

- Aguiar, A.V., Tabarelli, M., in press. Edge-effects and seedling bank depletion: the role played by the early successional palm *Attalea oleifera* (Arecaceae) in the Atlantic Forest. *Biotropica*.
- Aguiar, P.A., Chiarello, A.G., Mendes, S.L., Matos, L.N., 2003. The Central and Serra do Mar corridors in the Brazilian Atlantic Forest. In: Galindo-Leal, C., Câmara, I.G. (Eds.), *The Atlantic Forest of South America: Biodiversity Status, Threats, and Outlook*. Island Press, Washington, DC, pp. 118–132.
- Aide, T.M., Grau, H.R., 2004. Globalization, migration, and Latin American ecosystems. *Science* 305, 1915–1916.
- Almeida, R.T., Pimentel, D.S., Silva, E.M.S., 1995. The red-handed howling monkey in the state of Pernambuco, Northeast Brazil. *Neotropical Primates* 3, 174–175.
- Almeida-Neto, M., Campassi, F., Galetti, M., Jordano, P., Oliveira, A., 2008. Vertebrate dispersal syndromes along the Atlantic Forest: broad-scale patterns and macroecological correlates. *Global Ecology and Biogeography* 17, 503–513.
- Andrén, H., 1994. Effects of habitat fragmentation on birds and mammals in landscapes with different proportions of suitable habitat – a review. *Oikos* 71, 355–366.
- Anjos, L., 2006. Bird species sensitivity in a fragmented landscape of the Atlantic Forest in southern Brazil. *Biotropica* 38, 229–234.
- Awade, M., Metzger, J.P., 2008. Using gap-crossing capacity to evaluate functional connectivity of two Atlantic rain forest birds and their response to fragmentation. *Austral Ecology* 33, 863–871.
- Banks-Leite, C., Ewers, R.M., Metzger, J.P., in press. Edge effects as the principal cause of area effects on birds in fragmented secondary forest. *Oikos*.
- Bihn, J.H., Verhaagh, M., Brandle, M., Brandl, R., 2008. Do secondary forests act as refuges for old growth forest animals? Recovery of ant diversity in the Atlantic Forest of Brazil. *Biological Conservation* 141, 733–743.
- Bragagnolo, C., Nogueira, A.A., Pinto-Da-Rocha, R., Pardini, R., 2007. Harvestmen in an Atlantic Forest fragmented landscape: evaluating assemblage response to habitat quality and quantity. *Biological Conservation* 139, 389–400.
- Brooks, T., 2004. Coverage provided by the global protected-area system: is it enough? *BioScience* 54, 1081–1091.
- Brooks, T., Rylands, A.B., 2003. Species on the brink: critically endangered terrestrial vertebrates. In: Galindo-Leal, C., Câmara, I.G. (Eds.), *The Atlantic Forest of South America: Biodiversity Status, Threats, and Outlook*. Island Press, Washington, DC, pp. 360–371.
- Brown, K.S., Freitas, A.V.L., 2000. Atlantic Forest butterflies: indicators for landscape conservation. *Biotropica* 32, 934–956.
- Cartes, J.L., 2003. Brief history of conservation in the interior Atlantic Forest. In: Galindo-Leal, C., Câmara, I.G. (Eds.), *The Atlantic Forest of South America: Biodiversity Status, Threats, and Outlook*. Island Press, Washington, DC, pp. 269–287.
- Cartes, J.L., Yanosky, A., 2003. Dynamics of biodiversity loss in the Paraguayan Atlantic Forest: an introduction. In: Galindo-Leal, C., Câmara, I.G. (Eds.), *The Atlantic Forest of South America: Biodiversity Status, Threats, and Outlook*. Island Press, Washington, DC, pp. 267–269.
- Castro, E.B.V., Fernandez, F.A.S., 2004. Determinants of differential extinction vulnerabilities of small mammals in Atlantic Forest fragments in Brazil. *Biological Conservation* 119, 73–80.
- Castro, E.R., Galetti, M., Morellato, L.P.C., 2007. Reproductive phenology of *Euterpe edulis* (Arecaceae) along a gradient in the Atlantic rain forest of Brazil. *Australian Journal of Botany* 55, 725–735.
- Chazdon, R.L., 2008. Beyond deforestation: restoring forests and ecosystem services on degraded lands. *Science* 320, 1458–1460.
- Chebez, J.C., Hilgert, N., 2003. Brief history of conservation in the Paraná Forest. In: Galindo-Leal, C., Câmara, I.G. (Eds.), *The Atlantic Forest of South America: Biodiversity Status, Threats, and Outlook*. Island Press, Washington, DC, pp. 141–159.
- Chiarello, A.G., 1999. Effects of fragmentation of the Atlantic Forest on mammal communities in south-eastern Brazil. *Biological Conservation* 89, 71–82.
- Chiarello, A.G., Melo, F.R., 2001. Primate population densities and sizes in Atlantic Forest remnants of northern Espírito Santo, Brazil. *International Journal of Primatology* 22, 379–396.
- Cincotta, R.P., Wisniewski, J., Engelman, R., 2000. Human population in the biodiversity hotspots. *Nature* 404, 990–992.
- Coimbra-Filho, A.F., Câmara, I.G., 1996. Os limites originais do bioma Mata Atlântica na região Nordeste do Brasil. Fundação Brasileira para a Conservação da Natureza, Rio de Janeiro.
- Corlett, R.T., 2000. Environmental heterogeneity and species survival in degraded tropical landscapes. In: Hutchings, M.J., John, E.A., Stewart, A.J.A. (Eds.), *The Ecological Consequences of Environmental Heterogeneity*. Blackwell Science, Oxford, UK, pp. 333–356.
- Costa, L.P., Leite, Y.L.R., da Fonseca, G.A.B., da Fonseca, M.T., 2000. Biogeography of South American Forest mammals: endemism and diversity in the Atlantic Forest. *Biotropica* 32, 872–881.
- Cullen, L., Bodmer, R.E., Padua, C.V., 2000. Effects of hunting in habitat fragments of the Atlantic Forests, Brazil. *Biological Conservation* 95, 49–56.
- Daily, G.C., Ceballos, G., Pacheco, J., Suzan, G., Sanchez-Azofeifa, A., 2003. Countryside biogeography of neotropical mammals: conservation opportunities in agricultural landscapes of Costa Rica. *Conservation Biology* 17, 1814–1826.
- De Angelo, C., 2009. El paisaje del Bosque Atlántico del Alto Paraná y sus efectos sobre la distribución y estructura poblacional del jaguar (*Panthera onca*) y el puma (*Puma concolor*). Ph.D. Dissertation, Buenos Aires, p. 252.
- Dean, W., 1997. *With Broadax and Firebrand: The Destruction of the Brazilian Atlantic Forest*. University of California Press.
- Dixo, M., Martins, M., 2008. Are leaf-litter frogs and lizards affected by edge effects due to forest fragmentation in Brazilian Atlantic Forest? *Journal of Tropical Ecology* 24, 551–554.
- Dixo, M., Metzger, J.P., 2009. Are corridors, fragment size and forest structure important for the conservation of leaf-litter lizards in a fragmented landscape? *Oryx* 43, 435–442.
- Eisenberg, J.F., Redford, K.H., 1999. *Mammals of the Neotropics: The Central Neotropics*. The University of Chicago Press, Chicago.
- Fahrig, L., 2003. Effects of habitat fragmentation on biodiversity. *Annual Review of Ecology and Systematics* 34, 487–515.
- Faria, D., Paciencia, M.L.B., Dixo, M., Laps, R.R., Baumgarten, J., 2007. Ferns, frogs, lizards, birds and bats in forest fragments and shade cacao plantations in two contrasting landscapes in the Atlantic Forest, Brazil. *Biodiversity and Conservation* 16, 2335–2357.
- Faria, D., Mariano-Neto, E., Martini, A.M.Z., Ortiz, J.V., Montingelli, R., Rosso, S., Paciencia, M.L.B., Baumgarten, J., 2009. Forest structure in a mosaic of rain forest sites: the effect of fragmentation and recovery after clear cut. *Forest Ecology and Management* 257, 2226–2234.
- Fonseca, C.R., Ganade, G., Baldissera, R., Becker, C.G., Boelter, C.R., Brescovit, A.D., Campos, L.M., Fleck, T., Fonseca, V.S., Hartz, S.M., Joner, F., Kaffer, M.I., Leal-Zanchet, A.M., Marcelli, M.P., Mesquita, A.S., Mondin, C.A., Paz, C.P., Petry, M.V., Piovensan, F.N., Putzke, J., Stranz, A., Vergara, M., Vieira, E.M., 2009. Towards an ecologically-sustainable forestry in the Atlantic Forest. *Biological Conservation* 142, 1209–1219.
- Galetti, M., 2001. Indians within conservation units: lessons from the Atlantic Forest. *Conservation Biology* 15, 798–799.
- Galetti, M., Aleixo, A., 1998. Effects of palm heart harvesting on avian frugivores in the Atlantic rain forest of Brazil. *Journal of Applied Ecology* 35, 286–293.
- Galetti, M., Donatti, C.I., Pires, A.S., Guimaraes, P.R., Jordano, P., 2006. Seed survival and dispersal of an endemic Atlantic Forest palm: the combined effects of defaunation and forest fragmentation. *Botanical Journal of the Linnean Society* 151, 141–149.
- Galetti, M., Giacomini, H.C., Bueno, R.S., Bernardo, C.S.S., Marques, R.M., Bovendorp, R.S., Steffler, C.E., Rubim, P., Gobbo, S.K., Donatti, C.I., Begotti, R.A., Meirelles, F., Nobre, R.D., Chiarello, A.G., Peres, C.A., 2009. Priority areas for the conservation of Atlantic Forest large mammals. *Biological Conservation* 142, 1229–1241.
- Galindo-Leal, C., Câmara, I.G., 2003a. *The Atlantic Forest of South America: Biodiversity Status, Threats, and Outlook*. Island Press, Washington.
- Giraud, A.R., Krauczuk, E.R., Arzamendia, V., Povedano, H., 2003. Critical analysis of protected areas in the Atlantic Forest of Argentina. In: Galindo-Leal, C., Câmara, I.G. (Eds.), *The Atlantic Forest of South America: Biodiversity status, Threats, and Outlook*. Island Press, Washington, DC, pp. 245–261.
- Gardner, T.A., Barlow, J., Chazdon, R., Ewers, R.M., Harvey, C.A., Peres, C.A., Sodhi, N.S., 2009. Prospects for tropical forest biodiversity in a human-modified world. *Ecology Letters* 12, 561–582.
- Gascon, C., Williamson, G.B., da Fonseca, G.A.B., 2000. Receding forest edges and vanishing reserves. *Science* 288, 1356–1358.

- Geist, H.J., Lambin, E.F., 2002. Proximate causes and underlying driving forces of tropical deforestation. *BioScience* 52, 143–150.
- Girão, L.C., Lopes, A.V., Tabarelli, M., Bruna, E.M., 2007. Changes in tree reproductive traits reduce functional diversity in a fragmented Atlantic Forest landscape. *PLoS ONE* 2, e908.
- Girauo, A.R., Matteucci, S.D., Alonso, J., Herrera, J., Abramson, R.R., 2008. Comparing bird assemblages in large and small fragments of the Atlantic Forest hotspots. *Biodiversity and Conservation* 17, 1251–1265.
- Goerck, J.M., 1997. Patterns of rarity in the birds of the Atlantic Forest of Brazil. *Conservation Biology* 11, 112–118.
- Corresen, P.M., Willig, M.R., 2004. Landscape responses of bats to habitat fragmentation in Atlantic Forest of Paraguay. *Journal of Mammalogy* 85, 688–697.
- Groeneveld, J., Alves, L.F., Bernacci, L.C., Catharino, E.L.M., Knogge, C., Metzger, J.P., Putz, S., Huth, A., 2009. The impact of fragmentation and density regulation on forest succession in the Atlantic rain forest. *Ecological Modelling* 220, 2450–2459.
- Harvey, C.A., Saénz, J.C., 2008. Evaluación y Conservación de Biodiversidad en Paisajes Fragmentados de Mesoamérica. INBio, Costa Rica.
- Harvey, C.A., Komar, O., Chazdon, R., Ferguson, B.G., Finegan, B., Griffith, D.M., Martínez-Ramos, M., Morales, H., Nigh, R., Soto-Pinto, L., Van Breugel, M., Wishnie, M., 2008. Integrating agricultural landscapes with biodiversity conservation in the Mesoamerican hotspot. *Conservation Biology* 22, 8–15.
- Hobbs, R.J., Arico, S., Aronson, J., Baron, J.S., Bridgewater, P., Cramer, V.A., Epstein, P.R., Ewel, J.J., Klink, C.A., Lugo, A.E., Norton, D., Ojima, D., Richardson, D.M., Sanderson, E.W., Valladares, F., Vilà, M., Zamora, R., Zobel, M., 2006. Novel ecosystems: theoretical and management aspects of the new ecological world order. *Global Ecology and Biogeography* 15, 1–7.
- Holz, S., Placci, G., 2003. Socioeconomic roots of biodiversity loss in misiones. In: Galindo-Leal, C., Câmara, I.G. (Eds.), *The Atlantic Forest of South America, In the Atlantic Forest of South America: Biodiversity Status, Threats, and Outlook*. Island Press, Washington, DC.
- Huang, C.Q., Kim, S., Altstatt, A., Townshend, J.R.G., Davis, P., Song, K., Tucker, C.J., Rodas, O., Yanosky, A., Clay, R., Musinsky, J., 2007. Rapid loss of Paraguay's Atlantic Forest and the status of protected areas – a landsat assessment. *Remote Sensing of Environment* 106, 460–466.
- Huang, C.Q., Kim, S., Song, K., Townshend, J.R.G., Davis, P., Altstatt, A., Rodas, O., Yanosky, A., Clay, R., Tucker, C.J., Musinsky, J., 2009. Assessment of Paraguay's Forest cover change using landsat observations. *Global and Planetary Change* 67, 1–12.
- Lairana, A.V., 2003. A challenge for conservation: Atlantic Forest protected areas. In: Galindo-Leal, C., Câmara, I.G. (Eds.), *The Atlantic Forest of South America: Biodiversity Status, Threats, and Outlook*. Island Press, Washington, DC, pp. 444–457.
- Laurance, W.F., 2009. Conserving the hottest of the hotspots. *Biological Conservation* 142, 1137.
- Liebsch, D., Marques, M.C.M., Goldenberg, R., 2008. How long does the Atlantic rain forest take to recover after disturbance? Changes in species composition and ecological futures during secondary succession. *Biological Conservation* 141, 1717–1725.
- Lindenmayer, D.B., Hoops, R.J., 2000. *Managing and designing landscapes for conservation*. Blackwell Publishing, London.
- Loiselle, B.A., Graham, C.H., Goerck, J.M., Ribeiro, M.C., in press. Assessing the impact of deforestation and climate change on range size and environmental niche in the Atlantic Forests, Brazil. *Journal of Biogeography*.
- Lopes, A.V., Girao, L.C., Santos, B.A., Peres, C.A., Tabarelli, M., 2009. Long-term erosion of tree reproductive trait diversity in edge-dominated Atlantic Forest fragments. *Biological Conservation* 142, 1154–1165.
- Lyra-Jorge, M.C., Ribeiro, M.C., Ciocheti, G., Tambosi, L.R., Pivello, V.R., in press. Influence of multi-scale landscape structure on the occurrence of carnivorous mammals in a human-modified savanna, Brazil. *European Journal of Wildlife Research*.
- Machado, R.B., Fonseca, G.A.B., 2000. The avifauna of Rio Doce valley, Southeastern Brazil, a highly fragmented area. *Biotropica* 32 (4b), 914–924.
- Marini, M.A., Garcia, F.I., 2005. Bird conservation in Brazil. *Conservation Biology* 19, 665–671.
- Marsden, S.J., Whiffin, M., Galetti, M., Fielding, A.H., 2005. How well will Brazil's system of Atlantic Forest reserves maintain viable bird populations? *Biodiversity and Conservation* 14, 2835–2853.
- Martensen, A.C., Pimentel, R.G., Metzger, J.P., 2008. Relative effects of fragment size and connectivity on bird community in the Atlantic rain forest: implications for conservation. *Biological Conservation* 141, 2184–2192.
- Martini, A.M.Z., Fiaschi, P., Amorim, A.M., da Paixão, J.L., 2007. A hot-spot within a hot-spot: a high diversity site in Brazil's Atlantic Forest. *Biodiversity and Conservation* 16, 3111–3128.
- McIntyre, S., Hobbs, R., 1999. A framework for conceptualizing human effects on landscapes and its relevance to management and research models. *Conservation Biology* 13, 1282–1292.
- McKinney, M.L., Lockwood, J.L., 1999. Biotic homogenization: a few winners replacing many losers in the next mass extinction. *Trends in Ecology and Evolution* 14, 450–453.
- Melo, F.P.L., Dirzo, R., Tabarelli, M., 2006. Biased seed rain in forest edges: evidence from the Brazilian Atlantic Forest. *Biological Conservation* 132, 50–60.
- Metzger, J.P., 2009. Conservation issues in the Brazilian Atlantic Forest. *Biological Conservation* 142, 1138–1140.
- Metzger, J.P., Martensen, A.C., Dixo, M., Bernacci, L.C., Ribeiro, M.C., Teixeira, A.M.G., Pardini, R., 2009. Time-lag in biological responses to landscape changes in a highly dynamic Atlantic Forest region. *Biological Conservation* 142, 1166–1177.
- Mittermeier, R.A., Da Fonseca, G.A.B., Rylands, A.B., Brandon, K., 2005a. A brief history of biodiversity conservation in Brazil. *Conservation Biology* 19, 601–607.
- Mittermeier, R.A., Gill, P.R., Hoffmann, M., Pilgrim, J., Brooks, J., Mittermeier, C.J., Lamourux, J., Fonseca, G.A.B., 2005b. Hotspots revisited: Earth's biologically richest and most endangered terrestrial ecoregions. CEMEX, Washington, DC.
- Morellato, L.P.C., Haddad, C.F.B., 2000. Introduction: the Brazilian Atlantic Forest. *Biotropica* 32, 786–792.
- Oliveira, M.A., Grillo, A.S., Tabarelli, M., 2004. Forest edge in the Brazilian Atlantic Forest: drastic changes in tree species assemblages. *Oryx* 38, 389–394.
- Oliveira, M.A., Santos, A.M.M., Tabarelli, M., 2008. Profound impoverishment of the large-tree stand in a hyper-fragmented landscape of the Atlantic Forest. *Forest Ecology and Management* 256, 1910–1917.
- Oliveira-Filho, A.T., Fontes, M.A.L., 2000. Patterns of floristic differentiation among Atlantic Forests in southeastern Brazil and the influence of climate. *Biotropica* 32, 793–810.
- Paglia, A.P., Paese, A., Bedê, L., Fonseca, M., Pinto, L.P., Machado, R.B., 2004. Conservation gaps and irreplaceable sites for protecting vertebrates species in the Brazilian Atlantic Forest. In: *Congresso Brasileiro de Unidades de Conservação. Fundação o Botânico de Proteção à Natureza & Rede Nacional Pró Unidades de Conservação, Curitiba, PR*, pp. 39–50.
- Pardini, R., 2004. Effects of forest fragmentation on small mammals in an Atlantic Forest landscape. *Biodiversity and Conservation* 13, 2567–2586.
- Pardini, R., de Souza, S.M., Braga-Neto, R., Metzger, J.P., 2005. The role of forest structure, fragment size and corridors in maintaining small mammal abundance and diversity in an Atlantic Forest landscape. *Biological Conservation* 124, 253–266.
- Pardini, R., Faria, D., Accacio, G.M., Laps, R.R., Mariano-Neto, E., Paciencia, M.L.B., Dixo, M., Baumgarten, J., 2009. The challenge of maintaining Atlantic Forest biodiversity: a multi-taxa conservation assessment of specialist and generalist species in an agro-forestry mosaic in southern Bahia. *Biological Conservation* 142, 1178–1190.
- Peres, C.A. et al. in press. Biodiversity conservation in human-modified Amazonian Forest landscapes. *Biological Conservation*.
- Pinto, M.P., Viveiros-Grelle, C.E., 2009. Reserve selection and persistence. Complementing the existing Atlantic Forest reserve system. *Biodiversity and Conservation* 18, 957–968.
- Pinto, S.R.R., Santos, A.M.M., Tabarelli, M., 2009. Seed predation by rodents and safe sites for large-seeded trees in a fragment of the Brazilian Atlantic Forest. *Brazilian Journal of Biology* 69, 763–771.
- Pires, A.S., Lira, P.K., Fernandez, F.A.S., Schittini, G.M., Oliveira, L.C., 2002. Frequency of movements of small mammals among Atlantic Coastal Forest fragments in Brazil. *Biological Conservation* 108, 229–237.
- Ranta, P., Blom, T., Niemela, J., Joensuu, E., Siitonen, M., 1998. The fragmented Atlantic rain forest of Brazil: size, shape and distribution of forest fragments. *Biodiversity and Conservation* 7, 385–403.
- Ribeiro, M.C., Metzger, J.P., Martensen, A.C., Ponzoni, F.J., Hirota, M.M., 2009. The Brazilian Atlantic Forest: how much is left, and how is the remaining forest distributed? Implications for conservation. *Biological Conservation* 142, 1141–1153.
- Ribon, R., Simon, J.E., De Mattos, G.T., 2003. Bird extinctions in Atlantic Forest fragments of the Viosa region, southeastern Brazil. *Conservation Biology* 17, 1827–1839.
- Rodrigues, A.S.L., Akcakaya, H.R., Andelman, S.J., Bakarr, M.I., Boitani, L., Brooks, T.M., Chanson, J.S., Fishpool, L.D.C., Da Fonseca, G.A.B., Gaston, K.J., Hoffmann, M., Marquet, P.A., Pilgrim, J.D., Pressey, R.L., Schipper, J., Sechrest, W., Stuart, S.N., Underhill, L.G., Waller, R.W., Watts, M.E.J., Yan, X., 2004a. Global gap analysis: priority regions for expanding the global protected-area network. *BioScience* 54, 1092–1100.
- Rodrigues, A.S.L., Akcakaya, H.R., Andelman, S.J., Bakarr, M.I., Boitani, L., Brooks, T.M., Chanson, J.S., Fishpool, L.D.C., Fonseca, G.A.B., Gaston, K.J., Hoffmann, M., Marquet, P.A., Pilgrim, J.D., Pressey, R.L., Schipper, J., Sechrest, W., Stuart, S.N., Underhill, L.G., Waller, R.W., Watts, M.E.J., Yan, X., 2004b. Global gap analysis: priority regions for expanding the global protected-area network. *BioScience* 54, 1092–1100.
- Rodrigues, R.R., Lima, R.A.F., Gandolfi, S., Nave, A.G., 2009. On the restoration of high diversity forests: 30 years of experience in the Brazilian Atlantic Forest. *Biological Conservation* 142, 1242–1251.
- Roque, F.O., Siqueira, T., Bini, L.M., Ribeiro, M.C., Tambosi, L.R., Ciocheti, G., Trivino-Strixino, S., in press. Untangling chironomid taxon associations in Neotropical streams using local and landscape filters. *Freshwater Biology*.
- Russo, G., 2009. Biodiversity's bright spot. *Nature* 462, 266–269.
- Sanderson, J., Alger, K., Fonseca, G.A.B., Galindo-Leal, C., Inchausti, V.H., Morrison, K., 2003. *Biodiversity Conservation Corridors: Planning, Implementing, and Monitoring Sustainable Landscapes*. CABS, Conservation International, Washington, DC.
- Santos, K., Kinoshita, L.S., Santos, F.A.M., 2007. Tree species composition and similarity in semideciduous forest fragments of southeastern Brazil. *Biological Conservation* 135, 268–277.
- Santos, B.A., Peres, C.A., Oliveira, M.A., Grillo, A., Alves-Costa, C.P., Tabarelli, M., 2008. Drastic erosion in functional attributes of tree assemblages in Atlantic Forest fragments of northeastern Brazil. *Biological Conservation* 141, 249–260.

- Silva, J.M.C., Casteleti, C.H., 2003. Status of the biodiversity of the Atlantic Forest of Brazil. In: Galindo-Leal, C., Câmara, I.G. (Eds.), *The Atlantic Forest of South America: Biodiversity Status, Threats, and Outlook*. Island Press, Washington, DC, pp. 43–59.
- Silva, A.P., Mendes-Pontes, A.R.M., 2008. The effect of a mega-fragmentation process on large mammal assemblages in the highly-threatened Pernambuco Endemism centre, north-eastern Brazil. *Biodiversity and Conservation* 17, 1455–1464.
- Silva, J.M.C., Tabarelli, M., 2000. Tree species impoverishment and the future flora of the Atlantic Forest of northeast Brazil. *Nature* 404, 72–74.
- Silva, J.M.C., de Sousa, M.C., Castelletti, C.H.M., 2004. Areas of endemism for passerine birds in the Atlantic Forest, South America. *Global Ecology and Biogeography* 13, 85–92.
- Silva, R.R., Feitosa, R.S.M., Eberhardt, F., 2007. Reduced ant diversity along a habitat regeneration gradient in the southern Brazilian Atlantic Forest. *Forest Ecology and Management* 240, 61–69.
- Silva, W.G., Metzger, J.P., Bernacci, L.C., Catharino, E.L.M., Durigan, G., Simoes, S., 2008. Relief influence on tree species richness in secondary forest fragments of Atlantic Forest, SE, Brazil. *Acta Botanica Brasílica* 22, 589–598.
- Siqueira-Filho, J.A., Leme, E.M.C., 2006. Fragments of the Atlantic Forest of Northeast Brazil. *Andrea Jakobsson Estúdio*, Rio de Janeiro.
- Siqueira-Filho, J.A., Tabarelli, M., 2006. Bromeliad species of the Atlantic Forest of north-east Brazil: losses of critical populations of endemic species. *Oryx* 40, 218–224.
- Sodhi, N.S., Koh, L.P., Brook, B.W., Ng, P.K.L., 2004. Southeast Asian biodiversity: an impending disaster. *Trends in Ecology and Evolution* 19, 654–660.
- Tabanez, A.A.J., Viana, V.M., 2000. Patch structure within Brazilian Atlantic Forest fragments and implications for conservation. *Biotropica* 32, 925–933.
- Tabarelli, M., Gascon, C., 2005. Lessons from fragmentation research: Improving management and policy guidelines for biodiversity conservation. *Conservation Biology* 19, 734–739.
- Tabarelli, M., Peres, C.A., 2002. Abiotic and vertebrate seed dispersal in the Brazilian Atlantic Forest: implications for forest regeneration. *Biological Conservation* 106, 165–176.
- Tabarelli, M., Roda, S.A., 2005. Uma oportunidade para o Centro de Endemismo Pernambuco. *Natureza and Conservação* 3, 22–28.
- Tabarelli, M., Mantovani, W., Peres, C.A., 1999. Effects of habitat fragmentation on plant guild structure in the montane Atlantic Forest of southeastern Brazil. *Biological Conservation* 91, 119–127.
- Tabarelli, M., Da Silva, M.J.C., Gascon, C., 2004. Forest fragmentation, synergisms and the impoverishment of Neotropical Forests. *Biodiversity and Conservation* 13, 1419–1425.
- Tabarelli, M., Pinto, L.P., Silva, J.M.C., Hirota, M., Bede, L., 2005. Challenges and opportunities for biodiversity conservation in the Brazilian Atlantic Forest. *Conservation Biology* 19, 695–700.
- Tabarelli, M., Lopes, A.V., Peres, C.A., 2008. Edge-effects drive Tropical Forest fragments towards an early-successional system. *Biotropica* 40, 657–661.
- Teixeira, A.M.G., Soares, B.S., Freitas, S.R., Metzger, J.P., 2009. Modeling landscape dynamics in an Atlantic rain forest region: implications for conservation. *Forest Ecology and Management* 257, 1219–1230.
- Thomas, W.W., de Carvalho, A., Amorim, A.M.A., Garrison, J., Arbelaez, A.L., 1998. Plant endemism in two forests in southern Bahia, Brazil. *Biodiversity and Conservation* 7, 311–322.
- Tilman, D., 1994. Competition and biodiversity in spatially structured habitats. *Ecology* 75, 2–16.
- Turner, I.M., Corlett, R.T., 1996. The conservation value of small, isolated fragments of lowland tropical rain forest. *Trends in Ecology and Evolution* 11, 330–333.
- Uehara-Prado, M., Brown, K.S., Freitas, A.V.L., 2007. Species richness, composition and abundance of fruit-feeding butterflies in the Brazilian Atlantic Forest: comparison between a fragmented and a continuous landscape. *Global Ecology and Biogeography* 16, 43–54.
- Uehara-Prado, M., Fernandes, J.D., Bello, A.D., Machado, G., Santos, A.J., Vaz-de-Mello, F.Z., Freitas, A.V.L., 2009. Selecting terrestrial arthropods as indicators of small-scale disturbance. A first approach in the Brazilian Atlantic Forest. *Biological Conservation* 142, 1220–1228.
- Umetsu, F., Pardini, R., 2007. Small mammals in a mosaic of forest remnants and anthropogenic habitats-evaluating matrix quality in an Atlantic Forest landscape. *Landscape Ecology* 22, 517–530.
- Vieira, M.V., Olifiers, N., Delciellos, A.C., Antunes, V.Z., Bernardo, L.R., Grelle, C.E.V., Cerqueira, R., 2009. Land use vs. fragment size and isolation as determinants of small mammal composition and richness in Atlantic Forest remnants. *Biological Conservation* 142, 1191–1200.
- Villela, D.M., Nascimento, M.T., Aragão, L.E.O.C., Gama, D.M., 2006. Effect of selective logging on forest structure and nutrient cycling in a seasonally dry Atlantic forest. *Journal of Biogeography* 33, 506–516.
- Wirth, R., Meyer, S.T., Almeida, W.R., Araujo, M.V., Barbosa, V.S., Leal, I.R., 2007. Increasing densities of leaf-cutting ants (*Atta* spp.) with proximity to the edge in a Brazilian Atlantic Forest. *Journal of Tropical Ecology* 23, 501–505.
- Wright, S.J., Muller-Landau, H.C., 2006. The uncertain future of Tropical Forest species. *Biotropica* 38, 443–445.
- Zurita, G.A., Rey, N., Varela, D.M., Villagra, M., Bellocq, M.I., 2006. Conversion of the Atlantic Forest into native and exotic tree plantations: effects on bird communities from the local and regional perspectives. *Forest Ecology and Management* 235, 164–173.