Source-sink dynamics and forest refuges in Atlantic Forest Central Corridor

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ABSTRACT

Background. The Brazilian Atlantic Forest is one of the most diverse and threatened biomes in the world. The fragmentation and deforestation have strong impacts upon biodiversity, and many ecological theories have been brought in discussion in order to predict its consequences. Many approaches, such as Pleistocene Refuges Hypothesis, Metapopulation and Source-Sink Theories, Island Biogeography Theory, Stepping-stones and SLOSS debate have been extremely useful in this issue, but not in practice as much as in theory. In this scenario, the aim of this study is to present simple tools to apply those theories in practical measurements, classification and knowledge about the role of conservations unities and small fragments in the landscape of the Central Corridor of Atlantic Forest.

Methods. Ten forest fragments were selected over the Atlantic Forest Central Corridor territory to sample different sizes, altitudes and legal protection categories. Physical attributes and measures were taken using GIS data (as area, shape, connectivity, core area and edge).

Results. There is a vast variety of connectivity among fragments in the Central Corridor landscape. Most of the federal conservation units act as a source patch in the metapopulation, while the private areas act as sink patches. However, some source patches are too isolated to participate in the metapopulation system, acting as an isolated refuge. In addition, both source and sink fragments suffer strong edge effect, and some of them are not suitable for sustain species adapted to core area.

Discussion. Edge effect is a real threat over any fragment, mostly because of the small area or the irregular shape. Efforts must be directed to minimize this impact. Small private patches are not capable to sustain many endangered and endemic species and are not suitable for releasement of rescued wildlife, but they are very important for the metapopulation and source-sink system, relieving the competition effects inside source patches, and acting as stepping-stones. Governmental incentives to preservation of every small natural area may act as a vital component of greater conservational strategies. Maintenance of large federal conservation units alone is not enough to decrease the danger of extinctions. Some of these conservation units are isolated fragments that may represent the only remain of the Pleistocene refuges, and they need small fragments around to keep the biologic flow of the metapopulation dynamics.

KEYWORDS: SLOSS; Stepping-stones; fragmentation; landscape ecology.

INTRODUCTION

Many ecological theories are currently clarifying the deforestation scenario, in order to question about the impact of forest fragmentation upon the biodiversity. The Source-sink theory (Pulliam, 1998) establishes that, among semi-isolated subpopulations in habitat fragments, a biological flow of individuals from source patches to sink patches shall exist. The sink populations are under local extinctions conditions, but are continuously recolonized by migrations. In this model context, the edge effect is a permanent issue on debate, because the smaller the patch the stronger the effect from the matrix outside to the community homeostasis inside. Because some species are adapted to core area, ecological processes are affected in the proximity of the edge, which is highly influenced by area and shape of the fragment, once this determine the contact zone to the matrix (Murcia, 1995; Gomes et al, 2010; Ewers et al, 2007).

However, the fragmentation *per se* is not the worst scenario, as much as habitat loss by deforestation. Fragmentation produces small patches, which can act as stepping-stones, increasing the permeability of the matrix and constructing a track that can facilitate dispersion, as an intermittent ecologic corridor (Kimura & Weiss, 1964; Metzger, 2001). Because of that, the SLOSS debate (Some Large or Several Small?) argues that, in some cases, several small patches may be better than some large fragments. However, large fragments are needed to act as biodiversity refuge, and to be a refuge, many attributes are required, such as satisfactory area, regular shape, and some level of connectivity to the metapopulational system.

One of the most threatened biomes by fragmentation worldwide is the Atlantic Forest, which is distributed along the Brazilian coast in a wide extension through tropical and subtropical regions. It holds a high diversity and endemism, nearly of 1 to 8% of all species in the planet, but, from the original area, currently remains 11.7%, of which, 83.4% has less than 50 hectares, and 1.6% of the original area are under legal protection (Ribeiro et al, 2009). The Espírito Santo State, in Southeast Brazil, has the fifth higher deforestation rate among Brazilian states, although it is considered a hotspot of biodiversity and endemicity (Myers et al, 2000, INPE, 2011). On the other hand, Espírito Santo State is the eighth state with the biggest amount and most representative forest remainings fragments in the Biosphere Reserve of the Atlantic Forest, and the most representative portion of the Central Biodiversity Corridor of the Atlantic Forest (Brazil, 2006; Câmara & Galindo-Leal, 2009).

Therefore, the aim goal of this study is to describe and to analyze the relation between area, isolation, shape and edge effect on fragments of the Central Corridor of the Atlantic Forest, in

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order to verify if and how these patches and conservation units match the biological criteria to act as forest biodiversity refuge. The presented results can support decision making on conservation strategies to protection of Atlantic Forest biodiversity.

MATERIAL AND METHODS

The Espírito Santo State is in Southeast Brazil, within the Atlantic Forest Biome. This state is the most important and threatened component of the Central Biodiversity Corridor of the Atlantic Forest, as Southern Bahia.

Ten forest fragments were selected in Espírito Santo State, to sample a variety of area, altitude, location and different legal protection categories. The selected fragments were classified into five different categories according to order of magnitude of the area (Table 1). Among those are four Biological Reserve (Rebio – Federal administration), three Private Reserves of Natural Inheritance (RPPN), one Nacional Forest (Flona – Federal administration) and two private areas with no legal protection status.

For the calculation of area, perimeter and isolation, were used 14 satellite images scenes CBERS 2B, sensor CCD – Band 2, 3 and 4. The date of the images generation were from 2008 to 2010. The vector data base was obtained from Brazilian Institute of Geography and Statistics (IBGE). For the establishment of fragments boundaries, were used the combination of bands 4-3-2 false-color combination, RGB (*Red-Green-Blue*) respectively. The map composition was performed by ArcGis® system, version 10.1, and the attributes calculation assisted by Excel® and R.

With perimeter and area data, the shape Pantton index, adapted for metrical unities, was made by the equation:

$$I_s = P/[200.(\pi.A_t)^{0.5}]$$

where P = perimeter (in meters) and A_t is the fragment total area (in hectares). This index measures the shape as a deviation of the circularity, once circles has the smallest perimeter-area possible ratio. I_s nearly 1.0 suggest a regular shape, and it increases as increases the outline complexity of the fragment (understood as irregularity) (Laurance e Yensen, 1991).

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For isolation analysis, was performed a visual classification of all forest patches located in a 10 kilometers radios outside the boundaries of the studied fragment (Figure 1). The sum of area of all patches in this belt was divided by 10, in order to obtain the average area gain for each kilometer. The average gain was then divided by the number of patches found in the 10 km radius, generating the connectivity index by the following equation:

$$I_c = Ag / nf$$

Where *Ag* corresponds to average gain of area of each 1 kilometer, and *nf* corresponds to the total number of fragments found in the 10 km radius. The connectivity index is the opposite measure of isolation: the greater the index value, the less isolated the fragment is. The division by the number of fragments found around the central fragment adjusts the metric output to regions with a high number of small fragments, giving a small index value, while regions with less larger fragments has a greater connectivity index.

In order to analyze the impact of the edge effect upon the minimum area of studied fragments, it was subtracted from the fragment area the correspondent area to 50 meters edge thickness.

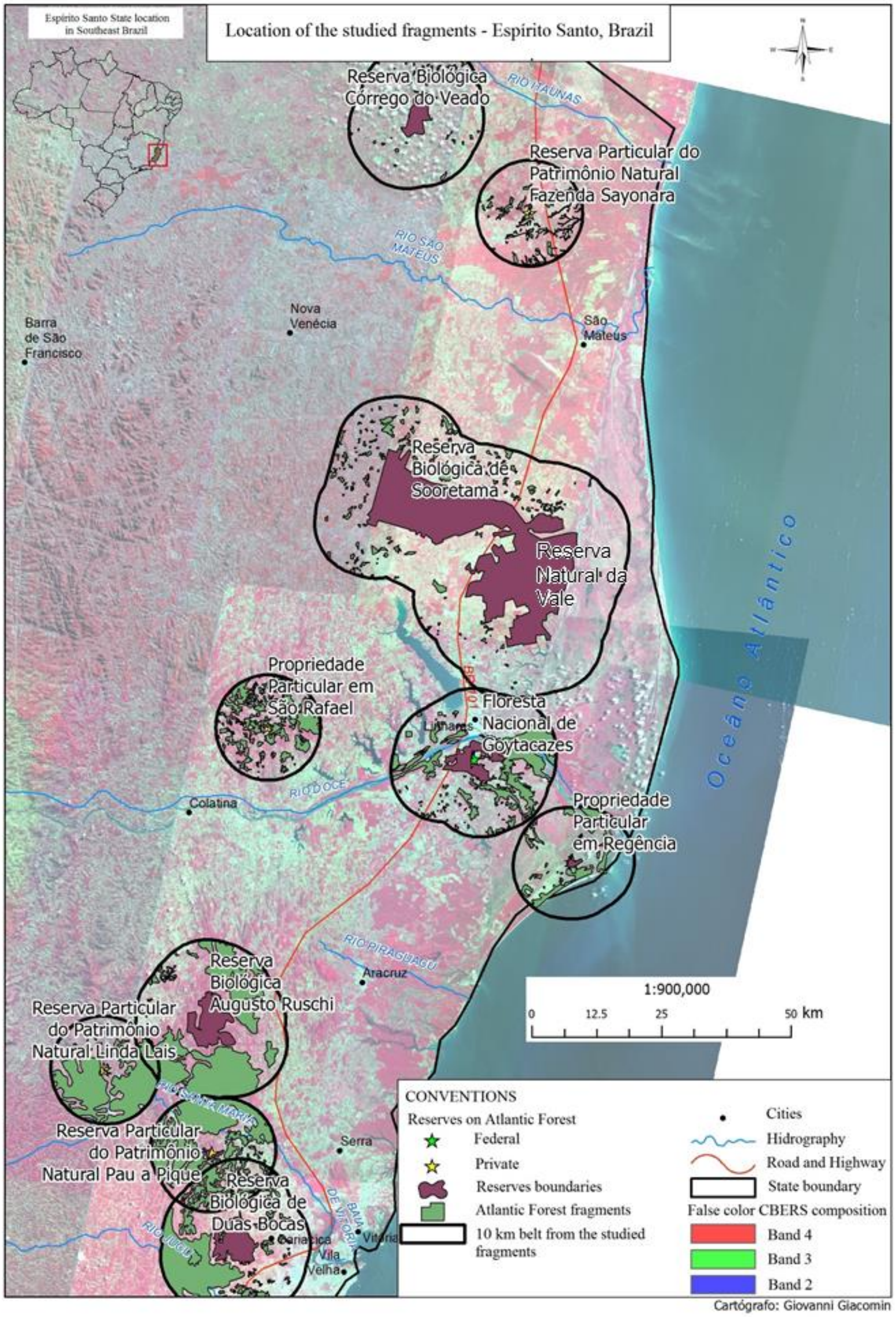

Figure 1: Location and Isolation of studied fragments.

RESULTS

The fragment shape index (I_s) varied from 1.16 to 3.28 (mean = 2.11; sd = 0.71). I_f near to 1 indicates regular shape, and those nearest to this value were São Rafael private area (I_f = 1.16), RPPN Fazenda Sayonara (I_f = 1.29), Regência private area and Rebio Córrego do Veado (both I_f = 1.58). Except for Rebio Córrego do Veado, all federal conservation unities have satisfactory area, but the most irregular shape indexes. The connectivity index (I_c) has shown variation between 1.01 (low connectivity) to 94.33 (high connectivity) (mean = 29.37; sd = 33.32) (Table 1). The most isolated patches were found in northern of Espírito Santo State, and the most connected ones, near to the southern region of the state.

The comparative analysis between the ten studied fragments area and the mean size of the patches around each of them shows that, using area as a surrogate variable of diversity content, some of the fragment may act as source in the source-sink system, while others act as sink. This classification is a function of area and connectivity to the other patches. If the fragment area has a greater value than the mean area of the patches around, it may indicate its source-sink role, while the connectivity index shows if the studied fragment can effectively play that role in the system.

Using the area criteria, the identified sources were Rebio de Duas Bocas, Rebio Augusto Ruschi, Rebio de Sooretama and Natural Reserve of Vale, Rebio de Pinheiros, and National Forest of Goytacazes. On the other hand, the sinks patches were: RPPN Linda Laís, RPPN Pau a Pique, RPPN Fazenda Sayonara and São Rafael Private Area.

The simulation of the edge effect upon the studied fragments has shown that two of them does not have the minimum size to preserve a core area under the proposed scenarios of a 50 meters edge: RPPN Linda Laís and São Rafael Private Area.

Table 1: Atributes of studied fragments

Area (ha) category	**Studied Fragments**	**County and Coordinates**	**Area** (ha) mean= 7304.49 sd=16973.97	**Shape** (I_s) mean= 2.11 sd= 0.71	**Conectivity** (I_c) mean= 29.37 sd= 33.32	**Core Area (- 50 m edge)**	**Mean area patches around (ha)**	**Role**
1 to 10	São Rafael Private Area	Linhares 19°22.708'S; 40°26.279'W	4.67	1.16	11.32	0	144.41	Sink
10 to 100	RPPN Fazenda Sayonara	Conceição da Barra 18°29.757'S; 39°57.330'W	10.99	1.29	3.94	4.69	88.91	Sink/Island
	RPPN Linda Laís	Santa Teresa 19°57.148'S; 40°45.151'W	19.10	2.29	74.63	0	912.58	Sink
100 to 1.000	RPPN Pau a Pique	Santa Leopoldina 20°07.705'S; 40°33.189'W	281.56	2.3	55.71	214.53	694.17	Sink
	Regência Private Area	Linhares 19°37'78.55"S; 39°52'94.81"W	297.09	1.58	14.03	250.43	206.53	Source
1.000 to 10.000	Rebio Córrego do Veado	Pinheiros 18°21.692'S; 40°09.988'W	2491.93	1.58	1.01	2353.91	27.08	Source/Island
	Flona de Goytacazes	Linhares 19°26.159'S; 40°04.398'W	4118.12	3.28	13.81	3748.10	171.53	Source
	Rebio de Duas Bocas	Cariacica 20°16.357'S; 40°28.782'W	4853.74	2.57	22.49	4539.38	280.17	Source
	Rebio Augusto Ruschi	Santa Teresa 19°51.101'S; 40°33.798'W	5773.84	2.1	94.33	5492.97	1106.43	Source
Above 10.000	Rebio de Sooretama and Reserva Natural da Vale	Sooretama/Linhares 19°02.676'S; 40°00.335'W	55193.89	2.96	2.39	53966.60	35.21	Source/Island

DISCUSSION

Evidently, physical metrics and measurements are not the only ones, or even the most important parameter, that determines if a certain fragment acts as a source or a sink in its system. The flow dynamics of organisms and the migration patterns between patches are the main aspects on the source-sink system (Gilroy & Edwards, 2017). However, the role classification of the patches relies on each species environmental and ecological requirement, resulting on a singular analysis. Because physical attributes are indicators of environmental quality, this study offers an approach that may act supplementary view of the scenario.

The most important consequences of the fragmentation process identified upon Atlantic Forest Central Corridor are (1) the decrease of habitat area inside a forest fragment and (2) the decrease of the connectivity among them, which can empower the environmental vulnerability. This process has been severely accelerated by human activities (Laurance e Yensen, 1991; Ewers e Didham, 2007). The concomitant analysis of the fragment attributes (area, shape, connectivity) shows that different patches play different roles in the source-sink system of Central Corridor of the Atlantic Forest. In general, federal conservation unities may act as forest refugees, and sources components of the metapopulation, while patches that do not match the criteria for being a wildlife refuge, act as a sink of the biological flow.

However, the source-sink role is not only a function of area, but, simultaneously, a function of connectivity. Results showed that the landscape in Espírito Santo presents a wide varied connectivity: from a low isolation on the central region to a high insulation in the northern of the state. The likelihood of a local extinction in an isolated remain forest is much higher than those on a metapopulation (Levins, 1970). However, the isolation is not only a function of the distance among fragments, but also feature of the matrix (Barnes, 2000). Therefore, besides matching the area criterion for been a source in a metapopulation system, Rebio Córrego do Veado, Rebio Sooretama and Natural Reserve of Vale presents an extremely low connectivity, and probably act as an insulated habitat spot, or a refuge, for the majority of species. Populations restricted to those areas may not survive much longer without stepping-stones or sink components in the landscape around.

In this scenario, area and connectivity are surrogate variables useful to identify a metapopulational system and indicates a role in the source-sink system, although, it has

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not the same functionality for every species. The relative area of the fragment compared to the mean area of all patches around may indicate the sources and sinks of the system, considering that the larger the area, the greater the diversity (McArthur & Wilson, 2015). Nevertheless, the connectivity index may suggest if there is an actually metapopulation functional system in the landscape. In this case, three classes of fragmentation level were identified in the studied dataset: low connectivity ($I_c < 10$), verified for Rebio Córrego do Veado, Rebio of Sooretama and Natural Reserve of Vale, and RPPN Fazenda Sayonara, all in the northern region of Espírito Santo state. The intermediate connectivity ($11 < I_c < 30$) is verified for São Rafael Private Area, Regência Private Area, National Forest of Goytacazes and Rebio de Duas Bocas, most of them are also located in the northern region. Finally, the highest connectivity index found ($I_c > 30$) correspond to fragments on central region of the state: RPPN Linda Laís, RPPN Pau a Pique, and Rebio Augusto Ruschi. This last category may be the only scenario that can meet the requirement for a considerable biodiversity. Although this is an arbitrary classification, based on one single analysis, it is possible that the increment of studies will consolidate these findings.

In addition, although the majority of the federal conservation unities analyzed present a satisfactory area, their irregular shape act as an opponent of the area, because irregularity decreases the core area of the refuge, by increasing the edge effect upon it. There is a strong relationship between the fragment shape complexity and the response of species to the area, which characterizes the geometric effect (Ewers et al, 2007; Gomes et al, 2010). The edge effect magnitude results from the combination of fragment area and shape. Two patches with the same size but different shape complexities may experience edge effects differently, because a high shape complexity increases the contact zone with the matrix, decreasing the protected core area, inside (Dramstad et al, 1996).

Edges are the contact zone between the inside and the outside. A long contact of the interior area with the matrix conditions reduces the ability of the system to buffer its interior microclimate. Those perturbations may reflect on abundance and richness of resources, influencing spatial distributions of populations and community structures (Ewers & Banks-Leite, 2013). The simulation of edges exclusion and analysis of the minimum area left shows that two of the studied fragments can not be considered as suitable habitat spot for species adapted to core area. In a fragmented landscape, it is expected that remaining core species will suffer population decline in a stronger rate than it is expected for the punctual habitat loss. That happens because, the greater the

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fragmentation, the smaller the ratio between core area and total area of the system, which creates a greater proportion of edge compared to core habitat (Bender et al, 1998).

On the other hand, the sink patches play a very important role in the dynamic stability of the source-sink system. As the sink patches receive individuals and groups from the sources, the maintenance of the sink patches can relieve the competition effects inside the sources. Another determinant participation is as connective spots between farther refuges, as stepping-stones. Groups or individuals in dispersion or migration process may use those spots to follow their path to a refuge of destination. Therefore, small fragments may act increasing the permeability of the matrix, feeding the dispersion biological flow (Metzger, 2001). However, a set of small patches may be a continuum for some species but at the same time, a barrier to another (Dramstad et al, 1996).

The connective spots (or stepping-stones) may be considered a better alternative to ecologic corridors, and the small fragments has played that role. The mean isolation between forest patches on the entire Atlantic Forest is 1440 meters, but removing from this count all fragments smaller than 50 hectares, the value increases to 3500 meters (Ribeiro et al, 2009). This means that the importance of small patches is notorious in reducing the insulation. Although, increasing the area of existing patches might be better than ecological corridors. This is a noticing matter called the SLOSS issue. Except by the habitat loss, the fragmentation of a landscape may even protect the system from spreading damaging events, as fire or epidemic diseases (Fahrig, 2003).

Nevertheless, it is important to notice that sink patches are not capable to sustain species populations that require many environmental specificities. Those limitations can lead a resident population to many genetic effects that can result in the local extinction. Thus, they are not appropriate to release rescued wildlife. Before proceeding to the release of wildlife to a fragment, it is important to verify the viability of that fragment to act as refuge to that species, considering its environmental requirements (such as territory), identifying if the fragment have a minimum area to hold a core habitat.

In the past, during the Pleistocene, forest fragments have act as wildlife refuges. Because of the landscape fragmentation that resulted from climatic changes, structured populations were isolated, which may have increased the diversity and endemicity in the Atlantic Forest Central Corridor. In the present, Rebio Córrego do Veado, Rebio of Sooretama and Natural Reserve of Vale, and National Forest of Goytacazes may be the

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only remain of important Pleistocene refuges of the Central Corridor of Atlantic Forest in northern Espírito Santo (Resende et al, 2010). Nevertheless, in the present time, the fragmentation has not been a natural process, and it is probably more intense, accelerated, with less and smaller patches, which can no longer act as refuges. There is no evidence that the past forest refuges were as small as the current ones. In that case, keeping only isolated conservation unities will be no longer enough to save species from extinction: small fragments are important to keep the biologic flow of life.

~~CONCLUSION~~

The Atlantic Forest Central Corridor faces a decisive time: the chance to preserve the remaining of the biome biodiversity. However, the implemented conservation strategies applied so far may are not enough to achieve this purpose. Besides most of the federal conservation unities analyses act as a biodiversity refuge, the isolation is a serious threat upon the wildlife. Metapopulation systems, on the other hand, is a better strategy, where private patches have played in important role. Hence, government division may stimulate the conservation of small private areas, as much as increase area and regularity of shape in the conservation unities. One of these strategies will not work satisfactorily without the other.

Simple landscape metrics as size and shape of patches and the connectivity among them can be relevant do analyze the biological functionality of a system, in order to identify the existence of a forest refuge, a metapopulation and to classify its components in source or sink, although this measurement does not predominate for every species in the biome. Each species has specific environmental requirements, which make them very differently subordinated to edge effect. The analysis of a minimum area and a core area of a patch is an indispensable to verify its suitability of populations, especially to releasement of rescued wildlife.

The current landscape is clearly not comparable to the Pleistocene fragmented landscape, and the biodiversity is threatened as is has never been before. All efforts must be apply to a varied spectrum of solutions and interventions, as much as on investigations and researches, in order to indicate, as in the present study, that the alternatives are no so complex to be achieved.

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