sid.inpe.br/mtc-m19/2011/11.18.13.17-TDI

SITE SELECTION FOR ATLANTIC FOREST RESTORATION: A LANDSCAPE BASED STANDARD PROTOCOL

Verônica Fernandes Gama

Master Thesis at Post Graduation Course applied in Remote Sensing, advised by Drs. Flávio Jorge Ponzoni, and Milton Cezar Ribeiro, approved in September 19, 2011.

URL of the original document:
<http://urlib.net/8JMKD3MGP7W/3AQSHB5>

INPE
São José dos Campos
2011

PUBLISHED BY:

Instituto Nacional de Pesquisas Espaciais - INPE
Gabinete do Diretor (GB)
Serviço de Informação e Documentação (SID)
Caixa Postal 515 - CEP 12.245-970
São José dos Campos - SP - Brasil
Tel.:(012) 3208-6923/6921
Fax: (012) 3208-6919
E-mail: pubtc@sid.inpe.br

Ministério da
Ciência, Tecnologia
e Inovação

GOVERNO FEDERAL
BRASIL
PAÍS RICO É PAÍS SEM POBREZA

sid.inpe.br/mtc-m19/2011/11.18.13.17-TDI

SITE SELECTION FOR ATLANTIC FOREST RESTORATION: A LANDSCAPE BASED STANDARD PROTOCOL

Verônica Fernandes Gama

Master Thesis at Post Graduation Course applied in Remote Sensing, advised by Drs. Flávio Jorge Ponzoni, and Milton Cezar Ribeiro, approved in September 19, 2011.

URL of the original document:
<http://urlib.net/8JMKD3MGP7W/3AQSHB5>

INPE
São José dos Campos
2011

Cataloging in Publication Data

G14s

Gama, Verônica Fernandes.

Site selection for Atlantic Forest restoration: a landscape based standard protocol / Verônica Fernandes Gama. – São José dos Campos : INPE, 2011.

xx + 75 p. ; (sid.inpe.br/mtc-m19/2011/11.18.13.17-TDI)

Master Thesis (Master Thesis in Remote Sensing) – Instituto Nacional de Pesquisas Espaciais, São José dos Campos, 2011.

Advisers : Drs. Flávio Jorge Ponzoni, and Milton Cezar Ribeiro.

1. Ecological restoration. 2. Landscape ecology. 3. Geoprocessing. 4. Decision theory. I.Título.

CDU 528.88:630*23

Aprovado (a) pela Banca Examinadora em cumprimento ao requisito exigido para obtenção do Título de Mestre **em**

Sensoriamento Remoto

Dr.	João Roberto dos Santos	Presidente / INPE / SJCampos - SP
Dr.	Flávio Jorge Ponzoni	Orientador(a) / INPE / SJCampos - SP
Dr.	Milton Cezar Ribeiro	Orientador(a) / UNESP / Rio Claro - SP
Dra.	Dilce de Fátima Rossetti	Membro da Banca / INPE / São José dos Campos - SP
Dr.	Silvio Frosini de Barros Ferraz	Convidado(a) / USP / Piracicaba - SP

Este trabalho foi aprovado por:

( ) maioria simples

(X) unanimidade

Aluno (a): Verônica Fernandes Gama

São José dos Campos, 19 de setembro de 2011

EDWARD O. WILSON, 1988.

"The next century will, I believe, be the era of restoration in ecology."

EDWARD O. WILSON, 1988.

To all forms of life on Earth,

specially my husband and daughter.

ACKNOWLEDGEMENTS

Firstly, I would like to thank my lovely husband Rafael and my little daughter (who is on the way) for the support, inspiration and patience in all the moments. I am also very grateful to my father Luiz, mother Glace, brother Pedro, Aunt Dag, and Titinha and Florzinha for having always standing by me and for understanding my absence. I love you all.

I definitely owe a great deal to my dear advisors: Flávio, Miltinho and Alexandre, all shining stars, who through their own research, comments and questions have encouraged, supported and enlightened me. Thanks for giving me the opportunity to interact with you, the patience and the academic and non-academic advice.

A number of friends from the 2009 team shared their ideas and helped me learn a lot about the disciplines, research and, very importantly, friendship, turning this hard journey in INPE´s graduate program a lot easier and more humorous. In this regard, I am indebted to each one, and I am going to miss all the moments we spent together studying, talking, partying, and mainly arguing about vegetarianism during all the pleasant meals we had together.

Finally, thanks to the financial and logistical support of INPE, National Counsel of Technological and Scientific Development (CNPq) and Bacabal Transportation Company.

ABSTRACT

Site prioritization for ecological restoration is challenging world-wide, in particular in tropical regions where habitat loss and fragmentation have reached high degree of degradation. Therefore, the objective of this research is to propose a protocol to contribute in the designing, prioritization and selection of sites for tropical forest restoration, particularly to support restoration projects within the Brazilian Atlantic Forest. This has been possible by defining replicable and adjustable rules which can be manipulated in accordance to pre-defined goals. Such methods integrate a set of Geographic Information Systems tools, remote sensing-derived products and landscape-based parameters. The designed restoration options can be used alone or combined in order to diagnose areas in regard to deficits of Permanent Protection Areas and Legal Reserves (as regulated by the Brazilian Legislation) and/or design restoration alternatives. This enables (1) to improve the flow of species; (2) to restore Permanent Protected Areas that promote structural connectivity; or (3) to enlarge cores areas to benefit edge sensitive species. In order to demonstrate and evaluate the proposed methodology, each criterion is used for a different scale of analysis as follows: (I) legislation-based diagnosis for characterizing the entire *Atlantic Plateau of São Paulo region* and each of its 5th order subwatersheds (SWSs) and (II) landscape-based to design sites for restoration within one of the SWSs. After the five landscape based criteria have been processed for this SWS, each resultant scenario is compared with the current forest cover scenario using landscape indexes. At last two different objectives and offers for restoration are simulated within this basin using some of the designed restoration candidates. Results showed that the restoration options designed by the computer based-algorithms are highly supported by ecologically meaningful theories that provide the base for applied landscape management. This brings new opportunity to achieve spatio-temporal biodiversity maintenance considering a variety of different objectives. Additionally, even small offers for restoration can be optimized in order to attend a species demand, (re)establish ecological processes and/or fit to logistical constrainers, with improvements in habitat connectivity and area of the remnants. Finally a conceptual model for the "Restoration Hotspots Toolbox" is proposed to be developed as a plug-in for ArcGIS software, which will aid experts and non-experts take advantages of the proposed protocol. Future developments include geomorphometry features, information about resilience gradient and type of matrix surrounding the habitat patches, which impact the permeability for forest-dependent species and landscape percolation for species with high dispersability.

ESCOLHA DE ÁREAS PARA RESTAURAÇÃO NA MATA ATLÂNTICA: PROTOCOLO PADRONIZADO BASEADO NA PAISAGEM

RESUMO

A priorização de áreas para a restauração ecológica é uma tarefa desafiadora no mundo inteiro, e especialmente nas regiões tropicais, onde predominam grande perda de habitat e fragmentação. Portanto, o objetivo desta pesquisa é propor um protocolo replicável que subsidie a escolha de áreas para a restauração ecológica em florestas tropicais, em particular na Mata Atlântica. Isto foi possível com a definição de regras replicáveis e ajustáveis para a geração, hierarquização e escolha das áreas, que podem ser manipuladas com base em objetivos pré-definidos. Estes métodos envolvem ferramentas de Sistemas de Informações Geográficas, produtos derivados de sensoriamento remoto e parâmetros de paisagens. As opções de restauração exploradas podem ser utilizadas separadamente ou combinadas para diagnosticar áreas em relação à déficits de Áreas de Proteção Permanente (APPs) e Reserva Legal e/ou gerar alternativas de restauração que: (1) propiciem a migração de espécies, (2) promovam conectividade estrutural por APPs, ou (3) incrementem a área de habitat de espécies de interior. Para demonstrar e avaliar a metodologia proposta, cada critério é utilizado em uma escala diferente de análise: (I) baseado na legislação para diagnosticar o Planalto Atlântico Paulista e cada uma de suas subbacias hidrográficas de 5ª ordem e (II) baseado na paisagem para gerar áreas candidatas à restauração dentro de uma destas subbacias. Depois de gerar as cinco opções de restauração para esta subbacia, cada cenário resultante é comparado com o cenário atual de cobertura de floresta utilizando-se índices de paisagem. Por fim, dois diferentes objetivos e ofertas de restauração são simulados utilizando-se os candidatos à restauração gerados anteriormente. Os resultados mostram que apesar de as opções de restauração constituírem elementos de processamento computacional, estas são subsidiadas por teorias ecológicas importantes para a administração de paisagens considerando uma variedade de diferentes objetivos. Adicionalmente, até pequenas ofertas de restauração podem ser otimizadas para atender demandas de espécies, (re)estabelecer processos ecológicos e/ou adequar-se a limitantes logísticos, com a melhora na conectividade e área dos remanescentes. Finalmente, um modelo conceitual da “Caixa de Ferramentas dos *Hotspots* para a Restauração” é proposto para a implementação como um *plug-in* do aplicativo ArcGIS, que auxiliará especialistas e não-especialistas usufruírem deste protocolo. Trabalhos futuros incluirão informações de geomorfometria, a capacidade de resiliência de cada região e os diferentes tipos de matrizes antrópicas, aspectos importantes para espécies florestais e para espécies com muita mobilidade.

LIST OF FIGURES

Page

Figure 2.1 Forest Formations and associated ecosystems in the Atlantic Forest according to Decree n°6.660/2008.. 6

Figure 3.1 Flowchart of the methods necessary to prioritize sites for restoration......... 16

Figure 3.2 Composition of an analysis area in any part of the Atlantic Forest, where: PPAs=Permanent Preservation Areas and NRs=Nature Reserves. 18

Figure 3.3 Scheme of the approach used in the case study to demonstrate the application of the methods developed for this protocol. 22

Figure 3.4 The *Atlantic Plateau of São Paulo* (~5 million ha) and its coastal areas with a buffer of 2 km, which included adjacent inland (whole region occupies approximately 6,1 million ha, within the Brazilian São Paulo State).. 24

Figure 3.5 Ninety 5th order subwatersheds in the analysis region, and in red the one named in this research *Guapiara Basin* (~150 thousand ha), where part of the methods is run to demonstrate the use of the protocol... 25

Figure 4.1 Distribution of the area of the remaining forest and simulated scenarios per class of sizes (ha) and number of patches (NP)... 34

Figure 4.2 Guapiara Basin and a zoom on the detail (red square) with results for: a) fixed width corridors, b) enhanced corridors, c) enlargements, d) resilience zones and e) corridor PPAs (Atlantic Forest remnants in green and corridor candidates in black).... 35

Figure 4.3 Percentage of remaining forest categorized as core and edge areas for 50 m and 100 m edge widths. 36

Figure 4.4 Guapiara subwatershed, on the southwest of São Paulo state, Brazil. Red square is the location of simulation I´s Figure 10 and blue square is the location of simulation II´s Figure 11 with the restoration options results....................................... 42

Figure 4.5 In black and grey we illustrate a subset of the selected restoration priorities to improve long term local biodiversity within Guapiara subwatershed given a restoration offer constrainer. Fixed width corridors (in black) are 30 meters wide. 43

Figure 4.6 In black and grey a subset of the selected restoration priorities to comply with simulation II constrainers to restore along SP-250 State Road in Guapiara subwatershed. 30 m wide corridor is shown by the arrow. 44

Figure 4.7 Simulation 2 alternative restoration strategy, considering establishment of the road underpasses on corridor PPAs. 47

Figure 5. 1 Scheme of the conceptual model we called "Restoration Hotspots Toolbox" and its toolsets, designed as an ArcGIS plug-in. The process may be used by a restoration planner sequentially in order to generate and select sites for restoration..... 50

Figure 5.2 Windows for Restoration Hotspots Toolbox´s Toolset I: Layers Preparation. 51

Figure 5.3 Windows for Restoration Hotspots Toolbox´s Toolset II: Restoration Options (Legislation Based). 52

Figure 5.4 Windows for Restoration Hotspots Toolbox´s Toolset III: Restoration Options (Landscape Based). 54

Figure 5.5 Windows for Restoration Hotspots Toolbox´s Toolset IV: Hierarching Restoration Options. 56

LIST OF TABLES

Page

Table 3.1 Permanent Protection Areas used for the case studies and the targets they protect, according to the Brazilian Forest Act 4.771_15/1965 definitions.................... 17

Table 4.1 Proportion of Permanent Preservation Areas, areas apt to be regulated as Legal Reserves and Natures Reserves (preserved and not-preserved) in the *Atlantic Plateau of São Paulo Region*, which is composed of these and the water bodies (not shown in this table). In the deficit column, values with an asterisk (*) represent surplus of what should be preserved as regulated by the Brazilian Forest Act 4.771_15/1965 definitions. 30

Table 4.2 Proportion of Permanent Preservation Areas, areas apt to be regulated as Legal Reserves and Natures Reserves (preserved and not-preserved) in the *Guapiara Basin*, which is composed of these and the water bodies (not shown in this table). In the deficit column, values with an asterisk (*) represent surplus of what should be preserved as regulated by the Brazilian Forest Act 4.771_15/1965 definitions. 31

Table 4.3 Area (in ha) and number of fragment patches (NP) per classes of size, mean patch size (MPS), area weighted mean shape index (AWMSI) and core and edge areas (in ha) for actual vegetation cover and the five simulated restoration options. 33

Table 4.4 Fixed width (30 meters) corridors attributes showing only corridors adjacent to the largest patch in the landscape. Areas of each corridor plus areas of the fragments it connects (ACC_CL0000) hierarchized prioritizing largest areas. Sum of all corridors areas (AHA_CO0030) is 3.46 ha... 39

Table 4.5 Enhanced corridors attributes showing only corridors adjacent to the largest patch in the landscape. Areas of each corridor plus areas of the fragments it connects (ACC_CL0000) hierarchized prioritizing largest areas. Sum of corridors areas selected for restoration excluding overlapping fixed width corridors (AHA_noCorI) is 96.07 ha. 40

Table 4.6 Fixed width corridors attributes showing only corridors crossing the road. Areas of the two patches plus its enlargements (AHA_EP0000 and AHA_EP00_1) each corridor connects hierarchized and prioritized by largest areas. Sum of selected corridors areas (AHA_CO0030) is 0.62 ha. 45

Table 4.7 Attributes of the enlargements of the selected fragments to be connected. They have been hierarchized by area and prioritized from the largest to the smallest (AHA_EN0200). Sum of selected enlargements areas is 299.36 ha. 46

Table B.1 Area of the subwatersheds in the study area (*The Atlantic Plateau of São Paulo Region*) and amount of vegetation present in each one. Information of the *Guapiara Basin* are on line of ID 56. 73

SUMMARY

Page

1 INTRODUCTION 1
1.1 Overall Objective.. 3
1.1.1 Specific Objectives 3
2 THEORETICAL BACKGROUND 5
2.1 A brief historical of the Atlantic Forest.. 5
2.2 Habitat fragmentation 7
2.3 Biodiversity Conservation 8
2.4 Ecological restoration 9
2.4.1 Planning Restoration 10
2.4.1.1 The approach with Remote Sensing and Geoprocessing.................................. 11
2.4.2 Prioritizing and selecting sites for restoration 12
3. MATERIAL AND METHODS 15
3.1 Designing Sites for Restoration.. 15
3.2. Prioritizing Sites: Hierarchization and Selection.. 21
3.3 Case Study 21
4 RESULTS AND DISCUSSION 29
4.1 Characterizing the Atlantic Plateau of São Paulo region 29
4.2 Restoration sites design and analysis in the *Guapiara Basin*.................................. 31
4.3 Simulations 38
5 RESTORATION HOTSPOTS TOOLBOX.. 49
6 CONCLUSIONS... 57
REFERENCES 59
APPENDIX A... 69
APPENDIX B... 73

1 INTRODUCTION

Brazil has at least 1.8 million species, representing 13.1% of the world's biodiversity (LEWINSOHN; PRADO, 2005), with high endemism rates (MYERS *et al*, 2000). Despite its richness and uniqueness, the Brazilian biodiversity has been degraded for centuries, particularly as a consequence of habitat loss and fragmentation, but also by natural resources excessive exploitation and pollution (JOLY *et al*, 2008). The Atlantic Forest is a typical case, since it harbors a large fraction of the world's biodiversity (SILVA; CASTELETI, 2003), and has been reduced to only 12% of its original domain, distributed through thousands of small forest fragments (most with less than 50 ha), isolated from each other and under severe edge effect (RIBEIRO *et al*, 2009). Thus, Atlantic Forest restoration is a global conservation priority, and urgent large scale restoration projects are needed (RODRIGUES *et al*, 2010).

Given the scarcity of forest remnants, the importance of every fragment is huge, and adequate actions of conservation and restoration play a significant role in biodiversity maintenance and ecosystem services provision in general (RODRIGUES *et al*, 2009; CALMON *et al*, 2010; RIBEIRO *et al*, 2011). However, the demand for conservation and restoration far outstrips available resources, what makes prioritization a necessary task. Site selection for conservation and restoration is at the forefront of Conservation Science as well as in applied projects nowadays, and is the main focus of this research. We proposed a new replicable approach to support site selection for restoration, considering biologically scalable landscape parameters as methodological solution for tropical region site selection for restoration, with special focus in the Atlantic Forest. We developed a set of rules that can be used by planners in order to decide in which areas to invest restoration efforts to maximize solution based on different biological characteristics and in logistical constrainers. Ecological concepts such as resilience zones, habitat connectivity, species dispersability, edge effect, source areas and functional fragment clumps are explored individually or combined in order to offer stakeholders a set of alternatives to prioritize restoration in different spatial scales.

This master dissertation is composed by seven main chapters:

- *Chapters 1 and 2* present a theoretical background for the study, which includes a brief description of the Atlantic Forest species richness and distribution, focusing on habitat loss and fragmentation as the main influences for species conservation in this very important biodiversity hotspot. It also highlights the challenges involved in site prioritization, and its applications in the field;

- *Chapter 3* describes the detailed geoprocessing methodology used to design, prioritize and select the restoration sites. Key landscape ecology concepts, such as structural and functional connectivity, habitat patch enlargement, riparian forest corridors, resilience zones and source areas have been used as an ecologically scaled alternative to guide this process. A case study is conducted to demonstrate the methodology on the *Atlantic Plateau of São Paulo region* and using a finer scale of analysis within one of its subwatersheds;

- *Chapter 4* shows the results for the case study and discusses the contributions of the proposed methodological approach and decisions taken for the sites prioritization and selection in the two hypothetical simulations;

- *Chapter 5* presents the conceptual model for the “Restoration Hotspots Toolbox”, a plug-in to ArcGIS software; designed to enable restorationers take advantage of the methodology proposed in this dissertation;

- *Chapter 6* presents the conclusions and synthesizes the contributions of the proposed methodological approach, highlighting the main findings of this master dissertation.

1.1 Overall Objective

The objective of this dissertation is to propose a replicable protocol to support sites designing, prioritization and selection for ecological restoration in areas that improve connectivity and/or increment habitat patch area, based on pre-determined objective(s). It will contribute mainly to support restoration projects in tropical forests, particularly within the Atlantic Forest based on spatial parameters in different scales. The goal can be: (1) improve the flow of species, (2) restore PPAs that promote structural connectivity, or (3) enlarge core areas in order to benefit edge sensitive species.

1.1.1 Specific Objectives

- define transparent and replicable methods containing options to design restoration sites, by integrating a set of Geographic Information Systems' (GIS) tools available on both commercial and open source software, based on two criteria: the Brazilian Legislation specifications and landscape parameters, with flexible rules that allow the user rank restoration possibilities in order to reach its objective(s);

- in order to demonstrate and evaluate the methodology, run the proposed protocol as a case study: (1) using legislation-based criteria to characterize the *Atlantic Plateau of São Paulo region*; (2) applying landscape-based criteria to design sites within one of its subwatersheds, the *Guapiara Basin*; (3) use landscape indexes to compare the current forest cover scenario with simulated scenarios of what the landscape would be like applying each of the restoration criteria in this basin; (4) and at last simulate two different objectives and offers for restoration within this subwatershed using the designed restoration candidates;

- propose a conceptual model for the "Restoration Hotspots Toolbox" to be developed as a plug-in for ArcGIS software.

2 THEORETICAL BACKGROUND

The Atlantic Forest is among the top hotspots on Earth (MYERS *et al*, 2000) and encompasses the largest UNESCO Biosphere Reserve, thus representing one of the world's most important conservation targets (CÔRREA, 1996). Centuries ago the Atlantic Forest was one of the largest tropical forests in the Americas covering approximately 150 million ha (**Figure 2.1**), and spreading mainly throughout the tropical and subtropical coastal regions of Brazil (RIBEIRO *et al*, 2009). However, nowadays the scenario is of an advanced conversion of the original vegetation to anthropogenic landscapes. SOS Mata Atlântica Foundation & INPE (2009) accounted for 7.9% of the Brazilian Atlantic Forest vegetation remaining considering only patches larger than 100 ha. Ribeiro *et al* (2009), considered fragments of any size and accounted for the existence of at least 11.4%, probably reaching as much as 16% of the original vegetation cover. Additionally they verified that more than 80% of the fragments are less than 50 ha, almost half of the forest is less than 100 m from any edge, and the mean distance between fragments is excessive for forest species to cross between them (average of 1440 m).

2.1 A brief historical of the Atlantic Forest

The history of anthropogenic influences in the Atlantic Forest has started approximately 13 thousand years ago with the arrival of the first humans to the South American plateaus. These humans were collectors-hunters and could have been, associated with climatic changes, the cause of megafauna extinction. Later they adopted the agriculture, more than a thousand years before the arrival of the Europeans, but the biodiversity and particularly the biomass loss in large areas continued. Finally, after 1500 a.c., the Portuguese aggregated the forest products on their business, and forest conversion and degradation increased enormously. From that time, the Atlantic Forest has undergone several economic cycles such as the sugar cane and coffee plantations, cattle ranching, and lately the fast industrialization process, what significantly reduced forest cover in the region. However, despite the long history of disturbance, most of the deforestation has occurred in the last hundred years (DEAN, 1996).

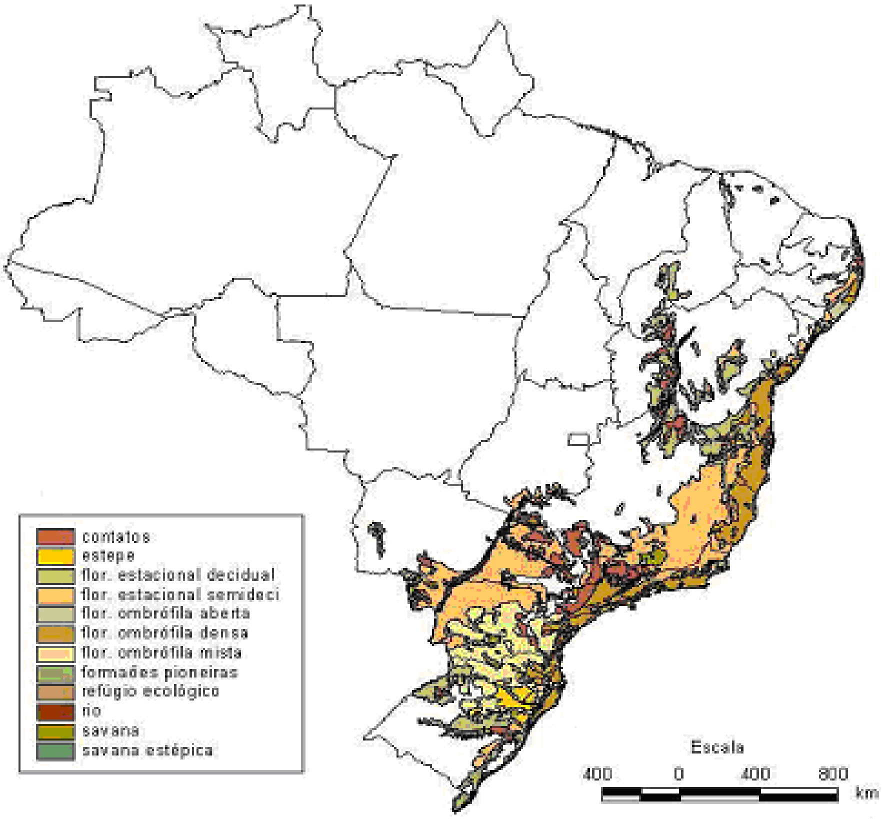

Figure 2.1 Forest Formations and associated ecosystems in the Atlantic Forest according to Decree n°6.660/2008
Source: Adapted from SOS MATA ATLÂNTICA FOUNDATION; INPE, 2009.

Nowadays 70% of the Brazilian population live in areas remotely covered by this ecosystem (METZGER, 2009), what makes the few last remnants critical for the economy and society, which rely on the natural resources and environmental services produced or maintained by them. The amount and quality of water, for instance, are directly related to the protection of springs and rivers, as well as, temperature regulation and air humidity, plagues and diseases vectors control, the provision of pollination in agricultural crops, nutrient cycling, erosion contention, among many others (BENAYAS *et al,* 2009). Indeed, the Atlantic Forest existence provides much more than these practical and tangible aspects. For example: it has an immense and little studied biodiversity that is under risk of vanishing before we could have gotten to know it (e.g. plants that cure diseases, genes that could have been used for the biotechnology advance). Each part of forest that falls down takes with it precious Brazilian heritage not accounted by the economic statistics.

2.2 Habitat fragmentation

Habitat fragmentation can be described as the rupture of landscape continuity (FAHRIG, 2003) and is a major driver of biodiversity loss (HOBBS, 1994). This process triggers changes in the landscape structure and consequently in the composition and diversity of communities (METZGER, 1999). When a given habitat necessary for a particular population is reduced and isolated, local extinctions occur, what leads to a decrease in alpha diversity within the remnants (WILCOX; MURPHY, 1985) and an increase in beta diversity among them (LOREAU, 2000). Fundamentally, risks get higher as the populations size is reduced (OUBORG, 1993).

Area and isolation of the fragments are landscape structure parameters which affect processes related to population's dynamics and community diversity (METZGER, 1999). Large fragments are able to maintain large populations with abundant individuals, what can support stochastic fluctuations with high genetic variability (GALBUSERA *et al*, 2000). When fragment size gets smaller than the minimum areas necessary for the surviving of the populations, the species richness reduces (SAUNDERS *et al*, 1991). Patch isolation is related to the (re)colonization rates (FAHRIG; MERRIAM, 1985; HANSKI; SIMBERLOFF, 1997; FRANKEN; HIK, 2004), with rescue effect (BROWN; KODRICK-BROWN, 1977) and the possibility of using multiple fragments in daily or occasional movements (MARTENSEN *et al*, 2008). Consequently, this factor alters the individuals flux, influencing the extinction probabilities and the population's genetic variability (HITCHINGS; BEEBEE, 1997; KNUTSON *et al*, 2000).

Particularly in tropical regions, forest structure is an important factor determining the occurrence of species and the structure of animal communities (TEWS *et al*, 2004). It is drastically altered in human landscapes by edge effects, selective logging, fire and the regeneration process (DEWALT *et al*, 2003). Many Atlantic forest species - e.g. the great majority of small mammals, in PARDINI *et al* (2005) and birds, in STOTZ (1996) - do not occur in natural or anthropogenic open habitats, and the rates of movement of individuals among Atlantic Forest fragments surrounded by open fields are limited, leading to local extinctions in small fragments (PIRES *et al*, 2002).

2.3 Biodiversity Conservation

Considering the advanced process of habitat loss and fragmentation, the high importance of the forest for biodiversity conservation and the environmental services obtained from the fragments, every Atlantic Forest remnant should be protected (RIBEIRO *et al*, 2009), regardless of its size and degradation status (KIERULFF *et al*, 2008; METZGER; RODRIGUES, 2008). One of the strategies adopted worldwide for *in situ* conservation of biodiversity is the implementation of Nature Reserves (NRs), of integral protection or sustainable use. In a broad context, their function is to protect biodiversity and the ecological processes in general as well as the interaction between species. Furthermore, they promote the conservation of historical, architectonic, archeological and cultural values of the human communities inhabiting inside or close, thus integrating them to the Natural Heritage (XAVIER *et al*, 2008).

Despite the recognized benefits obtained from NRs, many important ecosystems currently lack this protection status and the expected minimum protected area is unattended. At least 10% of the original habitats should be protected as recommendation of the global conservation strategy by the Convention on Biological Diversity (CDB, 2002), however modest 1% of the Atlantic Forest is currently in strictly protected NRs (RIBEIRO *et al*, 2009), which is also much less than recently suggested in the last COP in Nagoya (17%). Considering the current Atlantic Forest remnants, approximately 9% of them are in NRs (RIBEIRO *et al*, 2009). More than 90% of the total remnants are in private lands, and the proper management of these areas is vital for biodiversity conservation in the region.

2.4 Ecological restoration

Ecological restoration is an intentional activity that initiates or accelerates the recovery of ecosystems that have been degraded, damaged, transformed or entirely destroyed. These impacts are usually direct or indirect result of human activities, but in some cases, they are caused or aggravated by natural events such as wildfire, floods, storms, or volcanic eruption, to the point at which the ecosystem cannot recover its pre-disturbance state or its historic developmental trajectory. An ecosystem has recovered - and is restored – when it contains sufficient biotic and abiotic resources to continue its development without further assistance or subsidy. It will sustain itself structurally and functionally, demonstrate resilience to normal ranges of environmental disturbance and interact with contiguous ecosystems in terms of biotic and abiotic flows and cultural interactions (SER, 2004). From the perspective of conservation biology, it is essential that restoration is undertaken before substantial losses of biodiversity have occurred (DOBSON; BRADSHAW, 1997).

Ecosystem restoration is an old practice with examples in different times and regions (RODRIGUES; GANDOLFI, 2004). However, only recently it has gotten a science character known as Restoration Ecology (PALMER *et al*, 1997). From then, it has aggregated knowledge about natural remnants formation dynamics, which allowed restoration programs leave the mere use of agronomic or forestry practices of planting perennial species and assume the challenging character of reconstructing complex community interactions (RODRIGUES; GANDOLFI, 2004).

Considering the current Atlantic Forest conservation status, it is reasonable to say that its biodiversity maintenance depends on large scale restoration strategies (RODRIGUES *et al*, 2010), focusing on improving the connectivity among fragments, preserving natural cycles and genes flow and protecting environmental services provided by the ecosystems (RIBEIRO *et al*, 2011). Forest restoration is possible, viable and has been occurring, however it is necessary to constantly improve the quality and widen the coverage of this practice (RODRIGUES *et al*, 2009; CALMON *et al*, 2010).

2.4.1 Planning Restoration

Restoration actions must be undertaken based on ecological, social and economic long term goals (PETERS, 1991). Objectives need to be derived from a broad vision of what is wanted from landscapes in the future: What should they look like? What services are expected from them? Stating a clear objective is step one in solving land management issues (POSSINGHAM, 2001). It is important to have a problem definition and priority settings because goals are different and ecosystems have different values. Nevertheless, identifying the best restoration options to achieve a particular goal minimizes the risk of failure (LINDENMAYER *et al*, 2008).

Even when restoration is the primary activity, different kinds of plans and actions will result from different objectives such as the maintenance of species diversity, the preservation of particular threatened species, maintenance of ecological processes that generate diversity or ecosystem services, among others. As there often will be no single "best" plan for a landscape, multiple scenarios need to be assessed (PETERSON *et al*, 2003). Despite the broad variety of options, some strategies are advised by many specialists around the world (e.g. LINDENMAYER *et a,l* 2008; DOBSON; BRADSHAW, 1997), such as landscape level management and care for both species and ecosystems.

Patch-based management ignores flows of biota, water and nutrients as well as interactions among elements of a mosaic. A single patch can be subjected to state-of-the-art conservation, but that management can fail if the surrounding landscape continues to degrade, with adverse impacts on the patch. Hence, patches need to be assessed and managed within the context of landscape mosaics and the entire landscape (LINDENMAYER *et al*, 2008). The other important consideration: to manage both species and ecosystems (at multiple scales), assumes there is no single "right" or "sufficient" scale for conservation and restoration management. A single strategy adopted at a single spatial scale will meet only a limited number of goals. For example, it will provide suitable habitat for only a limited number of taxa. Multiple management scales are needed because there are multiple ecological scales, not only for different ecological processes and different species, but also for the same species. In addition, different processes at different spatial scales are inter-dependent (WU, 2007).

2.4.1.1 The approach with Remote Sensing and Geoprocessing

Given the natural difficulties for in situ observations, the vastness of the Atlantic Forest domain and the urgency for answers that subside the monitoring and management of this threatened ecosystem, remote sensing data and techniques and geoprocessing tools are of outstanding value (SHARKOV, 1998). These have made possible many extensive studies in the Atlantic Forest in recent years (e.g. RIBEIRO *et al*, 2009; RODRIGUES *et al*, 2008; RODRIGUES *et al*, 2009; CANASAT, 2011). Especially when the focus is working at landscape level or ecosystem scale, most objectives may only be achievable with the use of reliable maps that characterize the landscape, grouping elements into categories and⁄or allocating different objects into classes with the accuracy and precision required by the situation considered (SHARKOV, 1998), and geoprocessing techniques available at Geographic Information Systems (GIS).

Since the Atlantic Forest is covered by highly heterogeneous landscapes, composed by many vegetation patches, urban areas, water bodies, croplands, etc, data with minimum spatial resolution that enables mapping all these usually complex shaped targets is required. Currently, most synoptic maps of the Atlantic Forest, or States within this ecosystem, are products of 20 or 30 m resolution images (e.g. SOS MATA ATLÂNTICA FOUNDATION; INPE, 2009; KRONKA et al, 2005) and only locally some higher resolution maps are available. However, a new product is under production by the Brazilian Ministry of the Environment (MMA) that will cover the whole Atlantic Forest with maps resultant from 10 m spatial resolution images of the sensors AVNIR-II/ALOS (EORC-JAXA, 2007) and HRG/SPOT-5 (ASTRIUM, 2011).

Landscapes can be classified using: structural attributes, such as the amount and configuration of vegetation (e.g. FORMAN, 1995); habitat for a particular species (e.g. FISCHER *et al*, 2004) and functional attributes or landscape processes (e.g. LUDWIG *et al*, 1997). A commonly used model to classify landscapes is the island model or Forman’s (1995) patch-corridor-matrix model. It is applied particularly in cases where landscapes are subject to human modification - i.e. the majority of fragmentation studies; HAILA (2002). Such models often portray landscapes in a binary form composed of "habitat" and "non-habitat", as is the main map used in this study (see Methods section).

2.4.2 Prioritizing and selecting sites for restoration

In the Atlantic Forest, different authors that, somehow, define strategies to standardize the definition of potential or priority areas for restoration have different approaches to hierarchize the importance of each area. However, several are unanimous in relation to some criteria, for example: among many (e.g. METZGER, 2003; RODRIGUES *et al*, 2008; RODRIGUES *et al*, 2009) it is common defining Permanent Protection Areas (PPAs) and areas susceptible to promote connectivity by ecological corridors as priority.

The Brazilian Forest Act 4.771_15/1965 defines PPAs as areas along rivers and other water bodies (artificial or natural), heads of rivers (buffer of 50 m), steep terrains (>45^{o}) and high elevations (>1800 m). These areas have the status for being safeguarded by the Brazilian legislation as well as to naturally function as ecological corridors, allowing the connection of most fragments in a landscape (METZGER, 2003; RODRIGUES *et al*, 2008) and as seed dispersal sources (METZGER, 2003; RODRIGUES; BONONI, 2008; RODRIGUES *et al*, 2009). Additionally, actions in these areas reflect in the reestablishment of several other functions like avoidance of soil erosion, flooding and river clogging (METZGER, 2003). It is important to consider that riparian corridors are effective for forest biological flux of non-riparian species when they have enough width to include areas not flooded by water (METZGER *et al*, 1999).

Ecological corridors are linear landscape structures that differ from neighboring units and connect at least two fragments formerly united (SAUNDERS *et al*, 1991). These areas increase landscape connectivity and are priority for restoration because they enable genes flow of plants (by movement of pollinators and seed dispersers) and of animals through the landscape.

Additionally to the PPAs, other legal mechanism that can be implemented to restore connections are the Legal Reserves (LRs). This means that implementation of non-riparian ecological corridors through the matrix can be possible by the establishment of LRs in rural properties (METZGER, 2003; KIERULFF *et al*, 2008). According to the Brazilian Forest Act, LRs are a percentage of each rural property (e.g. 20% in the Atlantic Forest and 80% in the Amazon Domains) where clear cut is prohibited (METZGER, 2003). These reserves can also be used for the implementation of other elements that improve landscape connectivity, such as stepping-stones which shorten distances between fragments. Undoubtedly, several benefits can be obtained by starting restoration in areas safeguarded by Law (METZGER, 2003).

Another commonly used strategy for the prioritization of areas to be restored is to focus on regions with high levels of biodiversity, with endemic and/or endangered species (METZGER, 2003; RODRIGUES *et al*, 2009). However, facing the problem of obtaining sufficient and standardized data to be used systematically, several authors suggest the use of non-biological indicators (FAITH, 2003) or a combination of biological and environmental indicators (COWLING *et al*, 2004). Among the suggested environmental indicators are the landscape structure parameters (WILLIAMS *et al*, 2002). Theses parameters allow the detection of areas with more native species, since larger, more circular fragments which are immerse on a permeable matrix are potentially richer than fragments with different characteristics (METZGER, 1999).

There are certainly several criteria that can be considered when exercising the prioritization of areas to be restored regarding environmental peculiarities and institutional, economical and social aspects, inherent to each specific region (RODRIGUES *et al*, 2009). Hence, the list of criteria is far longer than this, and we only stressed some which can support the implantation of restoration projects in tropical regions, particularly within the Atlantic Forest.

3. MATERIAL AND METHODS

All the processing described in this section have been tested over *shapefile* maps, except for the altimetry and slope that were *raster* maps.

3.1 Designing Sites for Restoration

Two sets of rules have been developed to characterize a region or to design sites for restoration: (I) legislation-based and (II) landscape-based, which can be used alone or combined (**Figure 3.1**).

I. Legislation-based criteria

The Brazilian Forest Act defines two groups of areas that must be preserved: the Permanent Preservation Areas (PPAs) and Legal Reserves (LRs). The PPAs include riparian areas along rivers, springs, steep terrains, and high elevations (details on **Table 3.1**). The LRs mandatory conservation of native vegetation in private land changes among the Brazilian biomes, but for the Atlantic Forest 20% of the areas excluding the PPAs and Nature Reserves (NRs) should be conserved. The PPAs map can be used to guide restoration and both the PPAs and LRs maps can be used to diagnose and select sub-regions within a larger region to continue the selection of sites.

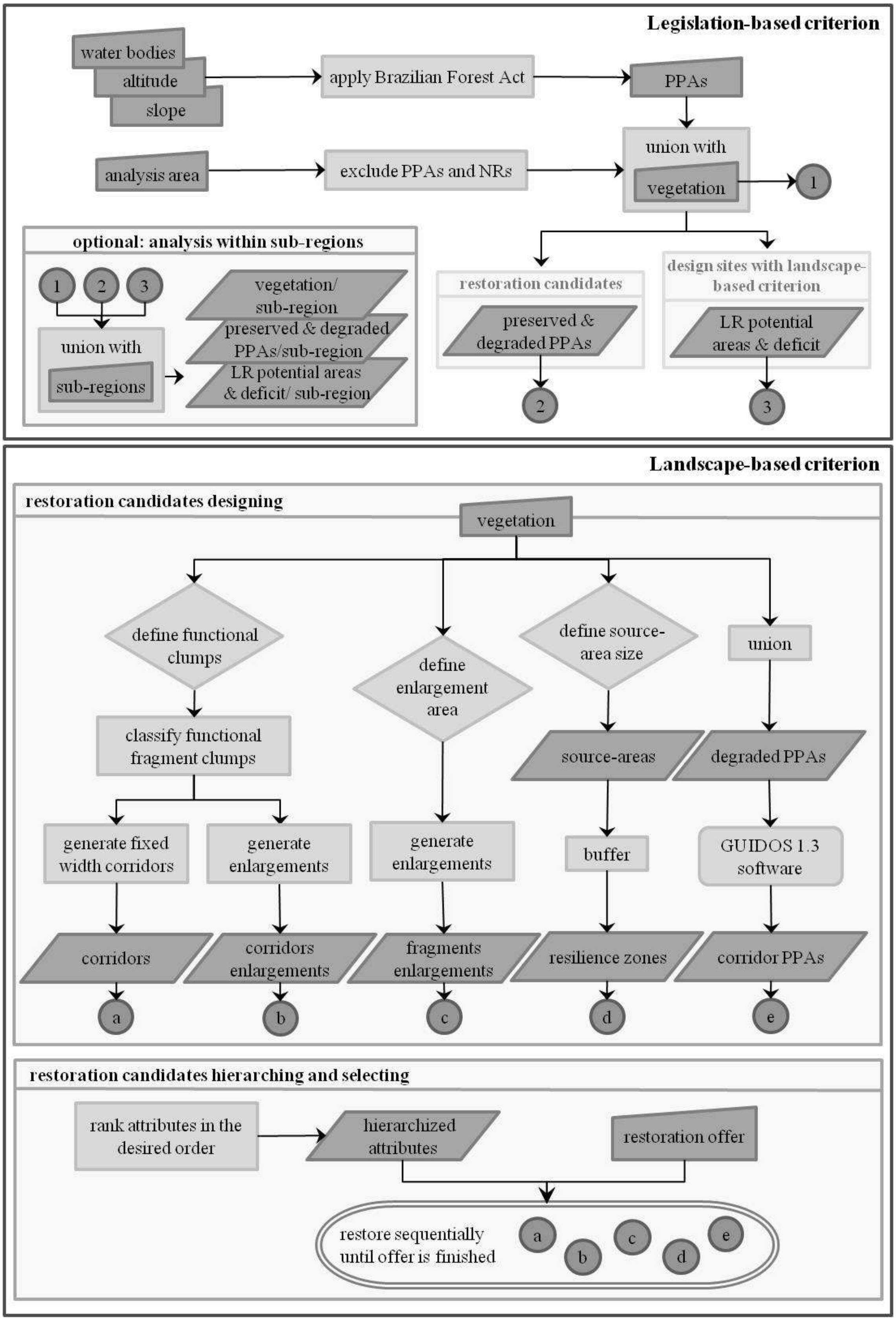

Figure 3.1 Flowchart of the methods necessary to prioritize sites for restoration.

Table 3.1 Permanent Protection Areas used for the case studies and the targets they protect, according to the Brazilian Forest Act 4.771_15/1965 definitions.

PRESERVATION TARGETS		PERMANENT PRESERVATION AREAS
RIVER WIDTH	**Until 10 m**	buffer of 30 m
	10-50 m	buffer of 50 m
	50-200 m	buffer of 100 m
	200-600 m	buffer of 200 m
	Larger than 600 m	buffer of 500 m
springs		buffer of 50 m
steep terrains		all areas > than 45^o
and high elevations		all areas > than 1800 m

a) Permanent Preservation Areas

A map containing the water bodies is necessary to generate the PPAs map. The riparian PPAs must be defined to rivers, lakes and dams following the Brazilian legislation. The relief maps (elevation and slope) must be mapped for elevations above 1800m and slopes > 45%.

Erasing the PPAs map with the forest cover map, results in a "degraded PPAs map" that alone can be used to guide actions if the objective is to restore all PPAs. Otherwise, the selection of PPA sites can be continued to *Permanent Preservation Areas Corridors* (explained ahead as "Landscape-based selection of sites, option *e*"), in case not all, but only PPAs that enable structural connectivity between fragments is the target.

b) Legal Reserves

Three sets of maps are needed to define the LRs: (1) PPAs, (2) Integral Protection NRs and (3) an analysis area. All areas except PPAs and NRs are able to be defined as LRs. As the amount of LRs is a proportion (20%) of the analysis area (**Figure 3.2**), one needs to define the boundary of analysis, as it is defined in the case study (described on item 3.3) the *Atlantic Plateau of São Paulo region* and the 5th order subwatersheds.

The LRs map obtained as explained here contains the locations where to choose sites to implement LRs. Overlaying it with a forest cover map, it is possible to calculate rather there is a deficit of LRs or not in the entire analysis area and its sub-regions. The problem of where to allocate the deficit of vegetation within these LRs polygons can be solved using the *Landscape-based criteria*.

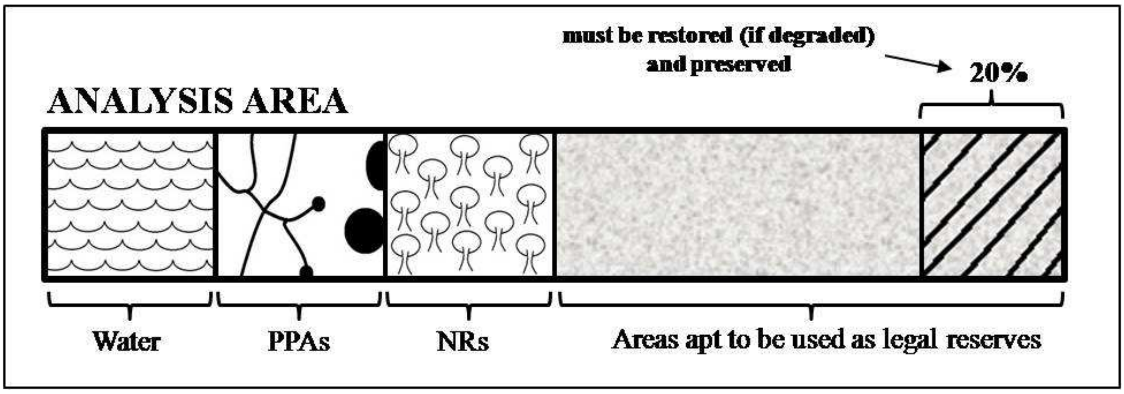

Figure 3.2 Composition of an analysis area in any part of the Atlantic Forest, where: PPAs=Permanent Preservation Areas and NRs=Nature Reserves.

<u>II. Landscape-based criteria</u>

The landscape criteria consider (1) the movement behavior and habitat area of a species, and/or (2) logistical restoration constraints. There are five possibilities (detailed as follows) for the design of areas for restoration, which can be used in the desired sequence until the species is well preserved, and/or the budget for restoration is over.

a) Corridors with fixed width

Corridors of fixed width that form clumps of structurally connected patches located within a maximum distance a species is able to cross within the designed corridors. These corridors can also optimize the logistics of restoration, since it limits the maximum offer to be invested in each corridor, which is defined by the area of the corridor (its width times the maximum length).

Defining the fragments clumps (also used for b):

Connectivity is the capacity of a landscape to facilitate the flux of species and ecological resources and processes (URBAN; SHUGART, 1986), which presents a double aspect: structural and functional (WIENS *et al*, 1997). The structural aspect refers to the actual spatial disposal of the fragments, corridors' density and complexity and matrix permeability, and the functional aspect refers to each species biological response to the landscape structure (METZGER, 1999). For example, while a given edge sensitive species will inhabit one (structural) forest fragment, another which is able to cross 50 m through the matrix will inhabit a clump of fragments that are less than 50 m apart from each other. In this second situation, the species inhabits a functional clump which is composed of several fragments working as one for it. If corridors are implemented to structurally connect these fragments, the establishment of ecological flow of biota and processes might benefit this mentioned species (HITCHINGS; BEEBEE, 1997, KNUTSON *et al*, 2000).

In this step, the user must decide the fragments functional clumps to be considered for the design of the corridors, which means that fragments located within each clump will be structurally connected forming a unique patch. Since the application of these methods (section 3.3) are demonstrated within the *Atlantic Plateau of São Paulo* region, where many species are known to cross 100 m in ecological corridors (AWADE; METZGER 2008, BOSCOLO et al. 2008) and the restoration projects don't usually implement corridors longer than this length (MCR personal observation), the methods are described as considering 100 m functional clumps.

In order to define these 100 m clumps: buffer the existing vegetation patches using half the maximum distance (in this case 50 m), dissolve the intersecting patches and give them a unique ID (here called PID_CL0100). Each of these new polygons delimits an area that contains the patches of same clump. Then overlay the vegetation map with the buffered map, and attribute the clump's unique ID (PID_CL0100) to all forest patches. At last, sum the area of each fragments contained in each PID_CL0100 in order to obtain the area of vegetation in each clump of 100 m (ACL_CL0100). This step allows identify which forest patches belong to the same clump, and avoid clumps out of any interval of interest in the prioritization process (e.g. smaller and larger than any area size). See **Appendix A** for details about fixed width corridors designing.

b) Enhanced connections

This model generates corridors that do not connect all the patches in a clump, but those that enable connections by larger corridors, and for some processes/species create core areas within the corridors, much as connecting fragments and incrementing vegetation simultaneously. Firstly it is necessary to define the clumps of fragments to be connected (as detailed previously). Although a different corridor length from the fixed width corridors can be chosen, the enhanced corridors design methods is described considering 100m length again, and use the previously processed vegetation layer with the attributes: clumps IDs (PID_CL0100), and clumps areas (ACL_CL0100). See **Appendix A** for details about enhanced corridors designing.

c) Enlarge forest patches

This is useful to conduct restoration of areas that increment the fragment sizes, by “filling” invaginations, what gives the fragments a circular shape and consequently enhances core-area. This is possible by applying a buffer (without dissolving) and subsequently a negative buffer on the forest cover layer. See **Appendix A** for details about enlargements designing.

d) Resilience zones

Resilience zones are benefited by the resources provided by adjacent source-areas, and considers large patches as best choices for biodiversity maintenance and sources of biotic and abiotic factors. In these areas, less intervention is necessary to promote natural vegetation succession, what constitutes an interesting alternative considering that the cost for restoration in this case is lower when compared to fully active restoration (HOLL; AIDE 2010). See **Appendix A** for details about resilience zones designing.

e) Corridor Permanent Preservation Areas

All non-preserved PPA areas should be restored, however considering that the demand for restoration outstrips available resources and not all the PPAs can be restored at once, here it is possible to define as priority the ones that constitute corridors. See **Appendix A** for details about Corridor PPAs designing.

3.2. Prioritizing Sites: Hierarchization and Selection

After all the processing described above and detailed on the **Appendix A**, all the forest patches, functional clumps for the corridors simulation, and sites generated as restoration candidates have some attributes, such as: unique ID and area, clump ID and area and adjacent fragments IDs and areas. Additionally to these attributes, others may be chosen depending on the goal considered, such as proximity to sites of interest, biological information for the target species, cost of restoration on each site, etc. Having the adequate information allows the protocol user (1) rank the fragments, clumps or restoration candidates by manipulating their attribute tables, and (2) select only the ones of interest or which fit the constrainer using a *definition query* within GIS tools.

3.3 Case Study

In order to demonstrate and evaluate the proposed methodology, each criterion is used for a different scale of analysis as follows: (I) legislation-based diagnosis for characterizing the entire *Atlantic Plateau of São Paulo region* and each of its 5^{th} order subwatersheds (SWSs) and (II) landscape-based to design sites for restoration within one of the SWSs. After the five landscape based criteria have been processed for this SWS, each resultant scenario is compared with the current forest cover scenario using landscape indexes. At last two different objectives and offers for restoration are simulated within this basin using some of the designed restoration candidates (**Figure 3.3**).

In order to process the data for this case study we used two input maps (SOS MATA ATLÂNTICA FOUNDATION; INPE 2010; KRONKA *et al.* 2005) to generate the forest cover map and five maps to generate the PPAs map: drainage and hydrography (Water and Electric Energy Department, São Paulo - DAEE), dams (BIOTA/FAPESP), elevation and slope (VALERIANO 2008). Prior to the processing all these data were projected to Albers projection and South America Datum 1969.

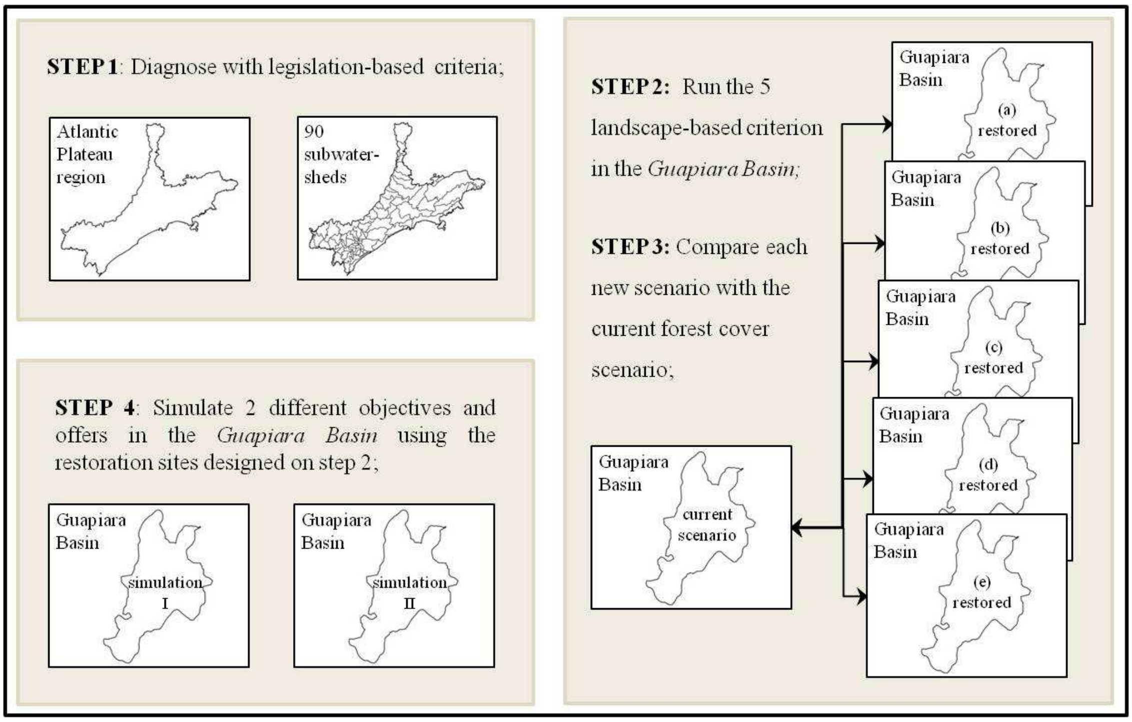

Figure 3.3 Scheme of the approach used in the case study to demonstrate the application of the methods developed for this protocol.

The SOS Mata Atlântica Foundation and INPE (2010) remnant forest map is a vector layer, produced by visual interpretation (scale 1:50 000) and manual edition over TM/Landsat 5 satellite images. In this map, all forest fragments larger than 3 ha within the Atlantic Forest domain are mapped. The State of São Paulo Forest Inventory natural vegetation vector map (KRONKA *et al.* 2005) has been produced by visual interpretation and manual edition over Landsat 5 and 7 images and aerial photographs, all from the years 2000 and 2001. The visualization scale was 1:35 000 and all natural vegetation of the Atlantic Forest and Cerrado within the State of São Paulo have been mapped. Since both maps seemed to underestimate the amount of Atlantic forest remnants on a visual analysis made over TM/Landsat-5 satellite images prior to processing, they were combined on a union basis, which means all the information contained in at least one of them was considered as forest cover in this research. The map called here *forest cover map* resultant from this combination showed less omission errors than the two previous ones and was used for all the geoprocessing described on this case study.

The drainage and hydrography 1:50 000 scale maps are a vectorized version of the official Brazilian charts database from IBGE (Brazilian Institute of Geography and Statistics) produced by DAEE (Water and Electric Energy Department, São Paulo)**.** The dams datum, from the BIOTA/FAPESP program is resultant from digitalization of the São Paulo State charts, on 1:50 000, from IBGE of 1972, and edition based on Landsat-5 and 7 satellite images of 1998 to 2000. Elevation and slope raster maps were obtained from the TOPODATA Project (VALERIANO 2008), which calculated local geomorphometric parameters, with 30 m spatial resolution, for the entire Brazilian territory from SRTM data (Shuttle Radar Topography Mission).

The Atlantic Plateau of São Paulo Region

An analysis is conducted over the entire *Atlantic Plateau of São Paulo* (~5 million ha) and its coastal areas with a buffer of 2 km, which included adjacent inland regions within the State of São Paulo. This whole region occupies approximately 6,1 million ha, within the São Paulo State (southeast of Brazil) from 21^{o}21S to 25^{o}18S and 44^{o}9W to 49^{o}19W, mostly within the *Atlantic Forest* domain, with some portions of *Cerrado*, the Brazilian savanna (**Figure 3.4**).

According to the Koeppen's classification system, the regional climate is humid-temperate, lacking a demarcated dry season. Precipitation ranges from 4,000 mm on the on the coastal escarpment, to 2,000 mm on the plateau, the relief varies considerably, from flat to very steep terrains and the elevation from sea level on the coastal parts to 2790 m.a.s.l. on the plateau (VALERIANO 2008). The most common vegetation formations at these elevations are ombrophilous dense forest on the coastal escarpment, and semidecidual interior forest at the plateau. (VELOSO *et al* 1991). According to Nalon et al (2008), the soils are predominantly Cambisols, Litholic neosols, Argisoil and Litosols.

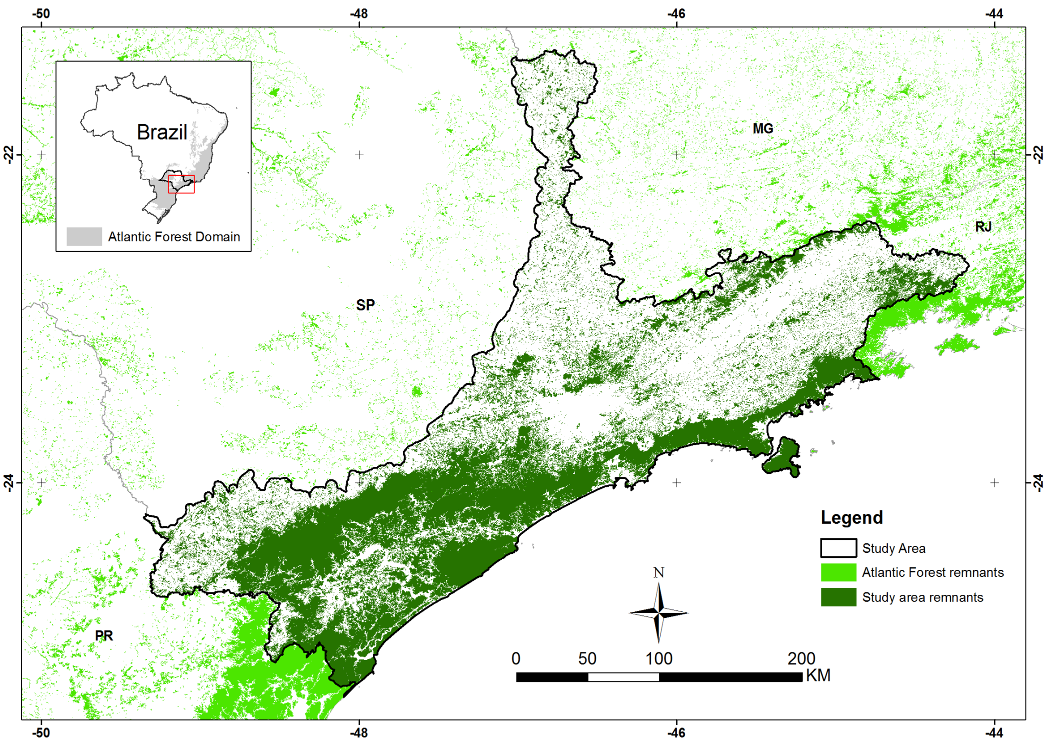

Figure 3.4 The *Atlantic Plateau of São Paulo* (~5 million ha) and its coastal areas with a buffer of 2 km, which included adjacent inland (whole region occupies approximately 6,1 million ha, within the Brazilian São Paulo State).

Additionally, the entire Atlantic Plateau of São Paulo has been divided into 90 5th order SWSs (PFASTETTER, 1987), which is proposed by Ribeiro *et al* (2011), and adopted by several Brazilian agencies (ANA, IBAMA and EMBRAPA) as a base unit for regional analysis and planning.

The Guapiara Basin

After diagnosing each SWS a finer analysis scale was used to run the methods on a SWS on the west of the study region, here named after *Guapiara Basin* (~150 thousand ha), located at 23^{o}55S to 24^{o}31S and 48^{o}24W to 48^{o}53W (**Figure 3.5**). A buffer of 20 km including the adjacent regions has been used in order to reduce edge effect influences in the analysis.

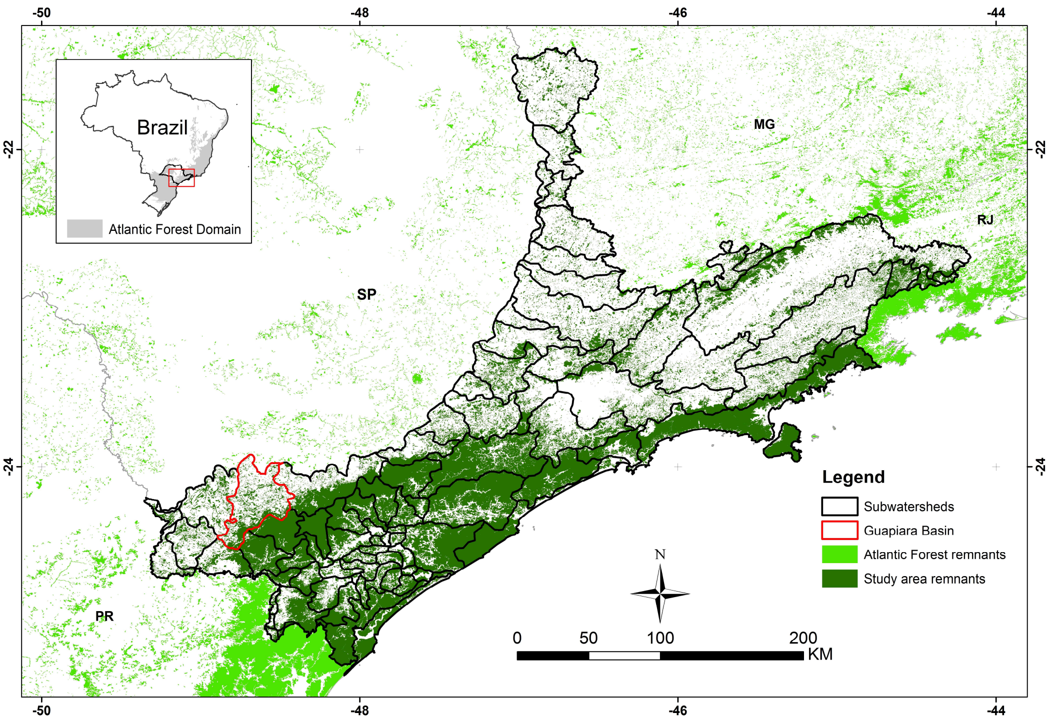

Figure 3.5 Ninety 5th order subwatersheds in the analysis region, and in red the one named in this research *Guapiara Basin* (~150 thousand ha), where part of the methods is run to demonstrate the use of the protocol.

Among the 90 SWSs present in the case study region, the *Guapiara Basin* has been chosen to run the restoration simulations because it has approximately 31% of its vegetation cover preserved, which is close to the 30% important threshold of vegetation cover on a landscape, as bellow this amount the arrangement of the remaining vegetation fragments become important (FAHRIG, 2003). Furthermore, when prioritization is necessary, it is reasonable to invest effort in regions that are degraded, but have a minimum potential of resilience, otherwise landscapes that are critically degraded might require great restoration effort to obtain the desired results, and on sites that are well preserved, conservation efforts, not restoration might be needed (PARDINI *et al*; 2010). Finally, this SWS is located between the preserved coast and degraded country, with characteristics of both, what constitutes a test for the performance of the methods in a heterogeneous site.

Prioritization

This chapter presents two simulations conducted to demonstrate and test the application of the proposed approach. Both were applied to the *Guapiara Basin*, but each one with different objectives and restoration offers (i.e. the amount of area to be restored). These and the restoration strategy adopted in each one are described next.

Simulation 1

Objective: Improve local biodiversity maintenance for long term.

Offer: restoration of 100 ha.

Strategy: structurally connect the fragments adjacent to the largest habitat patch in the region (i.e. the main biodiversity source area), focusing on those fragments no further away than 100 m. The prioritization was given by the options that resulted in the largest structurally connected areas (source area+corridor+fragments it connects) within regional scale: (a) first the potential sources in the region (source areas) were selected; (b) then all the corridors were identified which, if restored, would connect the neighbor fragments less than 100 m apart from the source areas and considered 30 m wide corridors, (c) if restoration offer remained, it has been used to thicken corridors width.

Processing steps:

1. Generate fixed width corridors for 100 m clumps;
2. Generate enhanced corridors for 100 m clumps;
3. Locate the largest forest fragment;
4. Extract only corridors that connect patches to this largest fragment;
5. Hierarch corridors by their area plus areas of the fragments each one connects;
6. Select priority corridors until offer is over.

Simulation 2

Objective: Select three underpass connections to be restored and that will connect relevant habitat patches located in both sides of the SP-250 state road. After improving these connections, enlarge the connected fragments which are located no more than two kilometers apart from the SP-250 road.

Offer: restoration of 300 ha.

Strategy: structurally connect the most important forest fragments located on both sides of SP-250 road of São Paulo state no further away than 100 m from one another and enlarge them until offer is over, prioritizing to improve the shape of the these fragments, in order to decrease the perimeter-area ratio.

Processing steps:

1. Generate fixed width corridors for 100 m clumps;
2. Generate enlargements, buffer 200 m negative buffer 201 m;
3. Clip both restoration options to the road two km buffer;
4. Extract only corridors overlapping the road;
5. Hierarch areas of fragments+enlargements each corridor connects;
6. Select the three largest couples of fragments+enlargements each corridor connects
7. Select larger enlargements of these patches until offer is over.

4 RESULTS AND DISCUSSION

Nowadays there are several examples of GIS tools in the field of conservation planning, such as MARXAN (BALL *et al* 2009), C-Plan (PRESSEY *et al* 2009) and Conefor Sensinode (SAURA & TORNÉ 2009), however there are few examples of its applications to restoration planning (MANSOURIAN *et al* 2005). To our knowledge, considering regional scale of analysis and processing, other researches had managed to highlight existing corridors (e.g. GUIDOS software - JRC 2011) and indicate corridors zones through moving windows (e.g. EWERS et al. 2010). The Corridor Designer Package (MAJKA *et al.* 2007) is suited for designing corridors between two blocks of habitat, in heterogeneous landscapes. With the sets of rules described in this paper, we managed to actually design, for whole landscapes, three options of corridors, and two options for the objectives not focusing on connectivity, but in incrementing area of existing fragments. Although Metapopulation theory explains that the risk of species disappearing is diminished by having more habitat patches, the creation of new patches is not attended by the protocol proposed here, but we acknowledge its importance and the need for improvements in the methodology to incorporate it.

Running the steps of these methods require a set of data and information. The quality of the input map is critical because it can significantly affect where and what kind of restoration sites are designed. The same is true for the input information (functional clumps size, PPAs width, source-areas cut-size, etc). If sufficient species and ecological data of the study area are available, the parameters can be chosen by relating the focal species or ecological processes more accurately to the selection of sites. While empirical models are probably more accurate than rule-based or literature-review based models, they require gathering a good set of field observations, which can take a considerable amount of time (BEIER *et al.* 2007).

4.1 Characterizing the Atlantic Plateau of São Paulo region

Considering the entire Atlantic Plateau of São Paulo region, there is 2,461,752 ha (40.35%) of remaining forest, of which 133,391 ha are located in PPAs (5,45% of the remaining forest), 716,720 ha (29%) in NRs and 1,611,642 ha (65,43%) were composed by forest fragments that could be included as LRs. Considering only the PPAs, 73.6% of their area wasn´t covered by vegetation (i.e. is degraded), and within the NRs, 8.56% of their area lack natural vegetation cover (**Table 4.1**). This means that: (1) there is a deficit of vegetation in PPAs, and (2) there is enough vegetation outside PPAs and NRs to fulfill the LRs demand. This vegetation offers for LRs is given to the large portions of vegetation remaining on the steep terrains along the coast, which are not protected by NRs yet. On this area lies the largest Atlantic Forest fragment, which alone covers an area of c.a. 1.1 million ha of continuous forests, representing 7% of what remains for Atlantic Forest domain (RIBEIRO *et al.* 2009) and thus, overcoming the deficit of vegetation in the country side of the study area.

Table 4.1 Proportion of Permanent Preservation Areas, areas apt to be regulated as Legal Reserves and Natures Reserves (preserved and not-preserved) in the *Atlantic Plateau of São Paulo Region*, which is composed of these and the water bodies (not shown in this table). In the deficit column, values with an asterisk (*) represent surplus of what should be preserved as regulated by the Brazilian Forest Act 4.771_15/1965 definitions.

VEGETATION & STUDY AREA	Total area (ha)	Area with remnants (ha)	Area without remnants (ha)	Remnants deficit (ha)
Permanent Protection Areas	506760,16	133391,28 (26,32%)	373368,89 (73,68%)	373368,89 (73,68%)
Legal Reserves	4709887,92	1611642,12 (34,22%)	3098245,80 (65,78%)	669664,53* (14,22%)
Nature Reserves	778089,82	716719,33 (92,11%)	61370,49 (8,56%)	61370,49 (8,56%)
STUDY AREA (TOTAL)	6101550,89	2461752,72 (40,35%)	3532985,18* (57,90%)	----

This scenario is far better analysed when we consider the SWSs scale, what suggests that the analysis of a large region is benefited with the use of sub-regions within it. The SWSs located on the coast have small deficit of PPAs, much of their NRs is preserved, and there is enough remaining vegetation to regulate LRs. However, on the country side, where agriculture dominates the economy (KRONKA *et al.* 2005), the SWSs tend to be in greater deficit of PPAs, NRs and vegetation apt to be LRs. The situation of the SWSs varied from being more than 70% preserved (27 of the 90 SWSs) to less than

30% preserved (26 SWSs). The *Guapiara Basin* is the 29th out 90 on a rank beginning from the less to the best preserved SWSs, with approximately 31% of its territory covered by Atlantic Forest remnants (see **Appendix B**, **Table B.1**).

4.2 Restoration sites design and analysis in the *Guapiara Basin*

The *Guapiara* SWS alone has 46,428 ha (30.96% of its area) of remnant forest, with 3,763 ha (8.1%) of it in PPAs, 1,984 ha (1.33%) in NRs and 40,637 ha (87.56%) apt to be LRs (**Table 4.2**). This vegetation is distributed in 1007 fragments, with a mean patch size of 196 ha (**Table 4.3** and **Figure 4.1**). After running the five landscape-based criteria for this subwatershed (**Figure 4.2**), a comparison using landscape indexes has been made to quantify the landscape changes if each of the criterion is fully implemented (i.e. restored).

Table 4.2 Proportion of Permanent Preservation Areas, areas apt to be regulated as Legal Reserves and Natures Reserves (preserved and not-preserved) in the *Guapiara Basin*, which is composed of these and the water bodies (not shown in this table). In the deficit column, values with an asterisk (*) represent surplus of what should be preserved as regulated by the Brazilian Forest Act 4.771_15/1965 definitions.

VEGETATION & Guapiara Basin	Total area (ha)	Area with remnants (ha)	Area without remnants (ha)	Remnants deficit (ha)
Permanent Protection Areas	12231,02	3762,76 (2,51%)	8468,26 (5,65%)	8468,26 (5,65%)
Legal Reserves	135060,64	40636,56 (27,11%)	94424,08 (63%)	13624,432* (9,09%)
Nature Reserves	2385,97	1984,09 (1,32%)	401,88 (0,27%)	401,88 (0,27%)
Guapiara Basin	149878,32	46427 ,60 (30,96%)	103480,88 (69,04%)	8870,14

Fixed width corridors and *enhanced corridors* had the same connectivity impact on the landscape, dropping the number of fragments from 1007 (current vegetation) to 719 (**Table 4.3** and **Figure 4.1**). This similarity had been expected, since the same clump size of fragments had been chosen to run both of them (100 m). Using the *fixed width* *corridors* methodology it is possible to connect patches through the shortest distance between them, and manipulating with precision the desired fixed width and maximum length sizes for the corridors. With this option it has been possible to make all the necessary connections with a minimum restoration effort: the bargain of approximately 66 ha restored, which means that all the fragments less than 100 m apart were connected. However, when processing the *enhanced corridors*, it also possible to choose the corridor maximum length, but only where connections can be enhanced due to the existence of large area of fragments facing each other, these corridors will be generated. This option demanded 1,523 ha of restored area to make all the connections in the *Guapiara Basin*. It enlarges interior areas in the corridors, thus creating a landscape with more core area within the fragments after restoration, what may benefit the habitat amount and flux of some interior species, as shown in the core area quantifications, which increased for 50 and 100 m, approximately 6.5 and 7.5% (**Table 4.3, Figure 4.3**). This menu of corridor options also includes the generation of non-preserved PPAs that constitute ecological corridors, excluding parts that do not link remaining forest fragments. Restoring all the *corridor PPAs* in the *Guapiara Basin* would increment 3,427 ha of vegetation area, with a major impact in connectivity, dropping the number of fragments of the landscape from 1007 to 170.

Any forest patch can be considered a source-area depending on the species, process and region considered (RODRIGUES *et al*, 2009). *Enlargements* and *resilience zones* are designed to optimize the distribution of area to be restored with the aim of incrementing vegetation area, in the first case, better shaping fragments, and both taking advantage of the potential source of fragments. Considering 50 m of edges, the current *Guapiara* Basin map has 31,973 ha (68.9%) of core areas and 14,427 ha (31.1%) of edge areas. For 100 m width edge half is found in edges and the other portion in core areas (**Table 4.3, Figure 4.3**). A total of 7,766 ha of restored area had been added to *enlargements* simulation, which increased the core areas approximately 37% and 54% for 50 and 100 m edge, respectively and the area-weighted mean shape index (AWMSI) from 7 to 3.3. For *Resilience Zones* simulation 2,864 ha of restored area has been added to the landscape, increasing core areas approximately 10% and 33% for 50 and 100 m edge, respectively and the AWMSI to 6.2 (**Table 4.3, Figure 4.3**).

Table 4.3 Area (in ha) and number of fragment patches (NP) per classes of size, mean patch size (MPS), area weighted mean shape index (AWMSI) and core and edge areas (in ha) for actual vegetation cover and the five simulated restoration options.

		Vegetation		Fixed Width Corridors		Enhanced Corridors		Enlargements		Resilience Zones		Corridor PPAs	
		area	NP	area	NP	area	NP	area	NP	area	NP	area	NP
Class of patch size (ha)	<50	8676.93	904	6216.90	625	6230.58	622	9381.80	888	8590.14	899	767.26	162
	50-100	3072.87	53	2661.64	47	2816.50	47	3795.89	60	3075.34	53	113.70	4
	100-250	4254.68	29	2226.30	21	2383.87	23	3400.40	27	4054.53	28	192.52	2
	250-500	4052.17	13	2885.12	11	3208.02	12	5992.24	18	3213.69	11	0.00	0
	500-1000	3884.38	6	6262.34	11	6632.95	11	5108.07	8	3884.38	6	0.00	0
	1000-2500	1179.48	1	3867.75	3	1546.54	2	2648.61	2	2482.39	1	1179.99	1
	2500-5000	0	0	0	0	2566.62	1	0	0	0	0	0	0
	5000-100000	0	0	0	0	0.00	0	0	0	0	0	0	0
	100000-250000	21307.10	1	22373.52	1	22565.23	1	23866.59	1	23992.02	1	47601.92	1
	MPS/ total NP	195.76	1007	279.54	719	282.99	719	210.47	1004	206.78	999	1408.32	170
AWMSI		7.00		8.64		8.05		3.33		6.23		66.68	
Edge width 50m	Core	31973.12 (68.9%)		31973.70 (68.8%)		33999.11 (70.9%)		43710.49 (80.7%)		35240.29 (71.5%)		31745.93 (63.7%)	
	Edge	14427.81 (31.1%)		14492.53 (31.2%)		13922.28 (29%)		10454.29 (19.3%)		14047.74 (28.5%)		18109.24 (36.3%)	
Edge width 100m	Core	23462.60 (50.5%)		23462.61 (50.5%)		25204.10 (52.6%)		36181.52 (66.8%)		31111.80 (60.8%)		22936.24 (46%)	
	Edge	22965.00 (49.5%)		23030.95 (49.5%)		22746.21 (47.4%)		18012.08 (33.2%)		20039.58 (39.2%)		26918.98 (54%)	

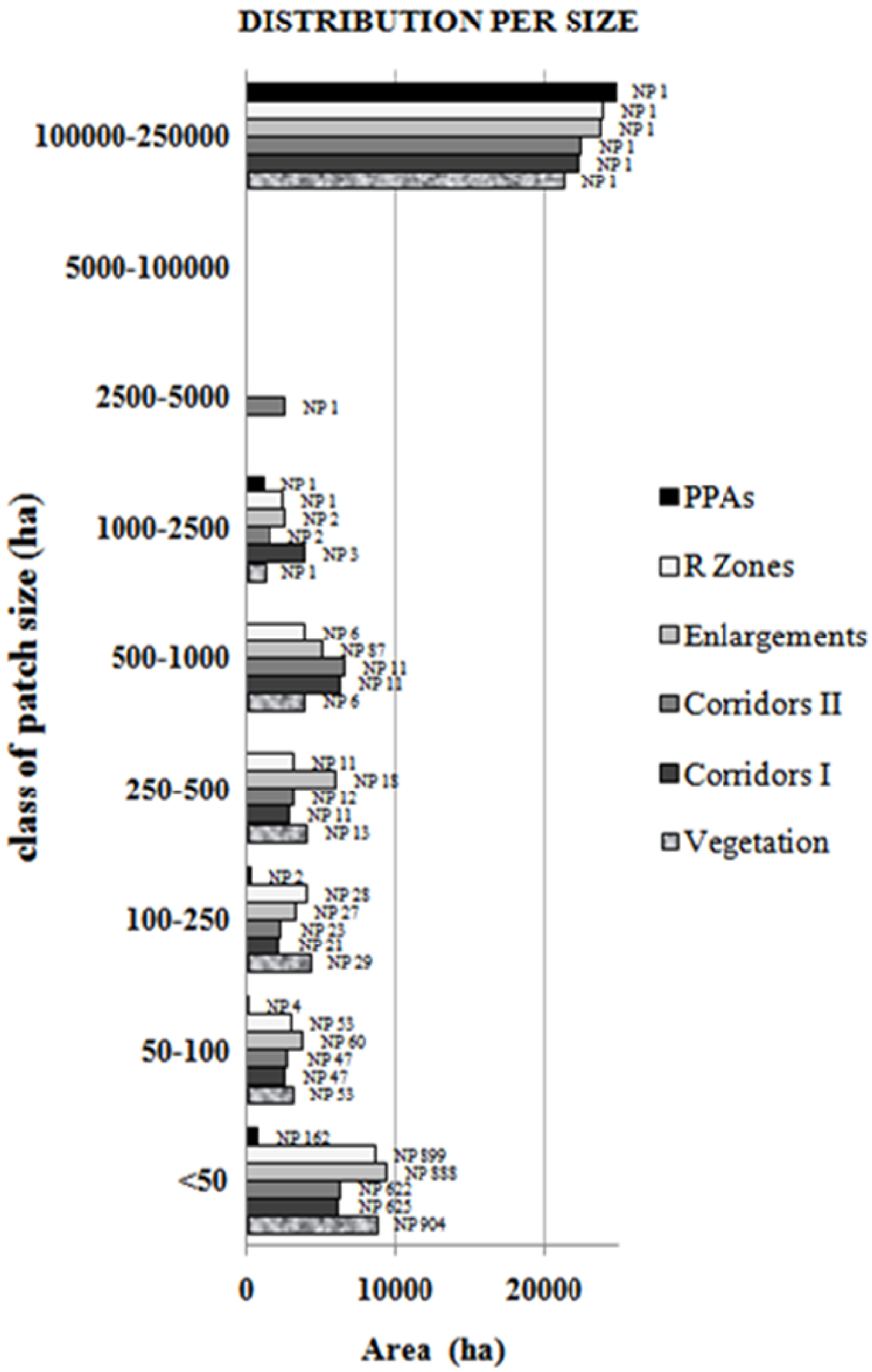

Figure 4.1 Distribution of the area of the remaining forest and simulated scenarios per class of sizes (ha) and number of patches (NP).

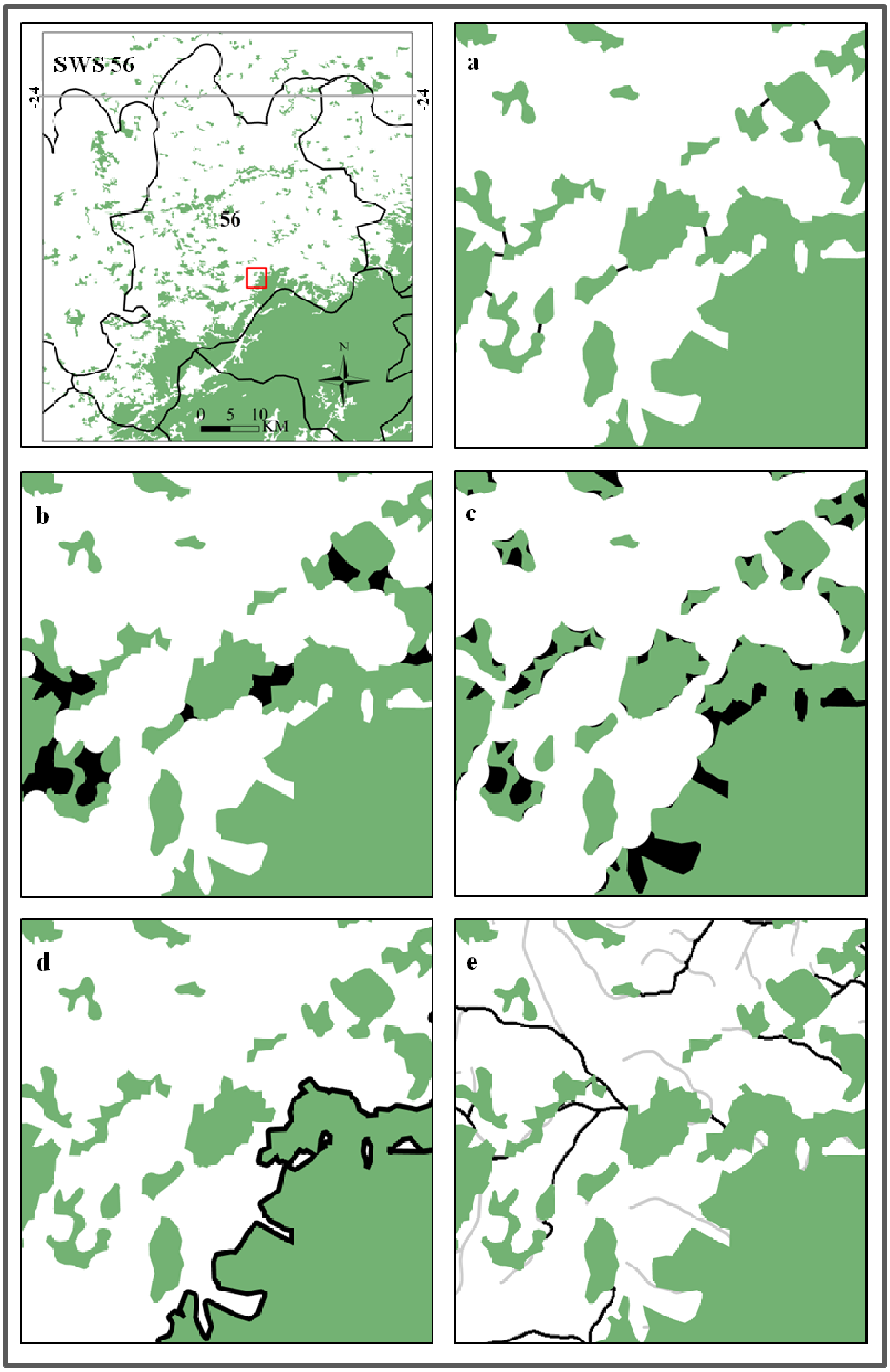

Figure 4.2 Guapiara Basin and a zoom on the detail (red square) with results for: a) fixed width corridors, b) enhanced corridors, c) enlargements, d) resilience zones and e) corridor PPAs (Atlantic Forest remnants in green and corridor candidates in black).

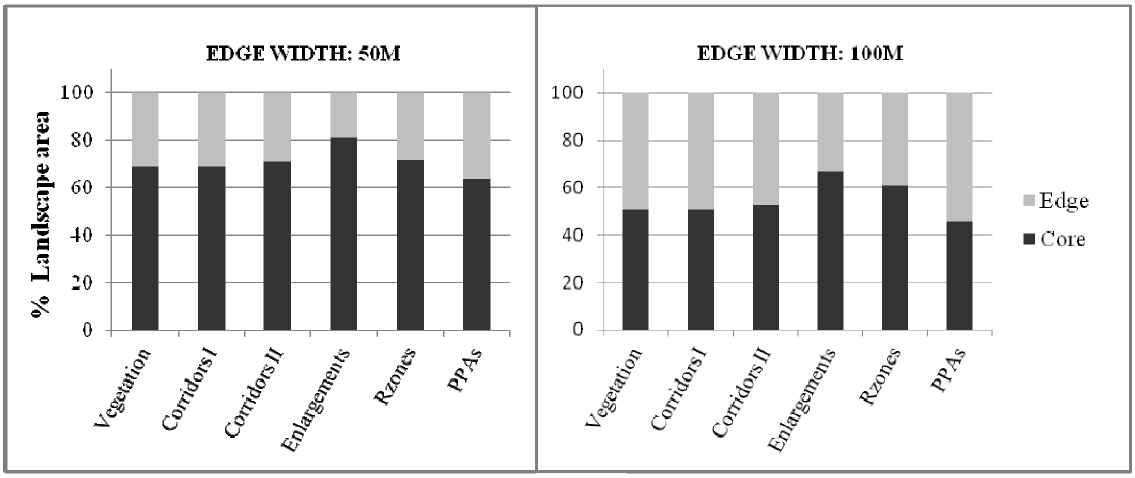

Figure 4.3 Percentage of remaining forest categorized as core and edge areas for 50 m and 100 m edge widths.

These proposed landscape-based criteria are able to support selection of areas to restore not only within the PPAs and LRs obtained with the legislation-based criteria described in this protocol. Other important projects that map areas for restoration in the Atlantic Forest can be benefited from our methodology as a complement of theirs. For example: the "Map of Potential Areas for Restoration in the Atlantic Forest" (RODRIGUES *et al*, 2009), identifies more than 17 million hectares of potential areas for restoration in the entire Atlantic Forest and the "Map of Priority areas for biodiversity restoration in São Paulo" (JOLY *et al*, 2010) prioritizes areas within this State in eight classes of importance for restoration. Both of these products support important decision making, but when prioritization needs to be done at a finer scale, within the polygons they select as important, other approaches are necessary to choose the sites, and the protocol proposed in this research offers the necessary tools for this finer scale of analysis.

Although the seven designed restoration options: (1) restoring PPAs, (2) restore within LRs, (3) fixed width corridors, (4) enhanced corridors, (5) enlargements, (6) resilience zones and (7) corridor PPAs, constitute computer processing elements, they are all supported by ecologically important theories that provide the base for applied landscape management in order to achieve spatio-temporal biodiversity maintenance, as shown below:

- *Island biogeography theory:* Large fragments are better than small ones (this supports options 2, 4 and 5, and to a lesser extent option 6); and connected (or near) fragments are better than far or unconnected ones (this supports options 1, 2, 3, 4 and 7).

- *Metapopulation theory* explains how to increase the likelihood that a fragmented population of a single species will persist. Given the vast array of species in remnant vegetation, this means that from a practical point of view it is only possible to consider one or two species that are believed to be significant. The theory suggests several ways in which a metapopulation of a single species can be secured, as follows: decrease local extinction rates which usually means making patches bigger (options 2, 4 and 5, and to a lesser extent option 6); increase between patch colonization rates which can be achieved through corridors (options 1, 2, 3, 4 and 7); and increase the number of patches occupied by any species. This rule would favour adding corridors (options 1, 2, 3, 4 and 7), or actively moving species from one habitat patch to another which might not a habitat restoration strategy. (POSSINGHAM 2001)

- There is also the empirically derived conservation rule that argues against habitat edges because they favour common species, and present management problems. Reserves with a low edge to area ratio are better than reserves with a high edge to area ratio. This argument would favour option 5 and to a lesser extent options 4 and 6.

4.3 Simulations

Appropriate management strategies for landscape mosaics will vary depending on the overall conservation goal (BENNETT *et al*, 2006). The strategy adopted in each simulation is one of the existing possible processes to solve the specific problems in question. For example, where the goal is to maintain the diversity of a taxonomic or ecological group, this may be achieved by managing the diversity of certain elements in the mosaic. Where the goal is the conservation of a particular species with specific habitat requirements, this may best be achieved by managing the overall amount of habitat for that species (LINDENMAYER *et al*, 2008). However it is important to consider that the approach adopted as strategy in the conducted simulations is one option among many possibilities and one had to be chosen.

Simulation 1

A total of fourteen fixed width corridors could make the planned connections and they can be fully restored, since their areas accounted for 3.46 ha (**Table 4.4**). This allowed restoration to be continued through enhanced corridors. Eight out of the nineteen were selected, since they accounted 96.07 ha (**Table 4.5**). Summing both restoration options a total of 99.53 ha were allocated. **Figure 4.4** illustrates the *Guapiara Basin*, and the details locate simulation I **Figure 4.5** and simulation II **Figure 4.6**.

Table 4.4 Fixed width (30 meters) corridors attributes showing only corridors adjacent to the largest patch in the landscape[1]. Areas of each corridor plus areas of the fragments it connects (ACC_CL0000) hierarchized prioritizing largest areas. Sum of all corridors areas (AHA_CO0030) is 3.46 ha.

FIXED WIDTH CORRIDORS ATTRIBUTES								
PID CO0030	**AHA CO0030**	**PID CL0000**	**PID CL00_1**	**ACL CL0000**	**ACC CL0000**	**PID CL0100**	**ACL CL0100**	**CNT CL0100**
272	0,23	799	1527	170707,26	170707,49	1033	172841,04	78
253	0,19	660	1527	170300,54	170300,72	1033	172841,04	78
290	0,29	757	1527	170154,41	170154,70	1033	172841,04	78
323	0,29	861	1527	170143,52	170143,81	1033	172841,04	78
329	0,27	879	1527	170120,64	170120,90	1033	172841,04	78
274	0,27	709	1527	170113,41	170113,68	1033	172841,04	78
265	0,12	693	1527	170113,25	170113,37	1033	172841,04	78
259	0,19	683	1527	170109,43	170109,62	1033	172841,04	78
328	0,20	873	1527	170108,93	170109,13	1033	172841,04	78
144	0,27	386	1527	170107,92	170108,19	1033	172841,04	78
192	0,30	505	1527	170106,66	170106,96	1033	172841,04	78
62	0,24	215	1527	170106,41	170106,65	1033	172841,04	78
137	0,31	366	1527	170105,90	170106,21	1033	172841,04	78
86	0,31	267	1527	170103,93	170104,24	1033	172841,04	78
	Total: 3,46 ha							

[1] **Table 4.4:** abbreviations definitions: PID_CO0030: ID of each corridor; AHA_CO0030: area (ha) of corridors; PID_CL0000 and PID_CL00_1: patch ID of the two fragments the corridors connects; ACL_CL0000: sum of the areas (ha) of the two patches corridors connect; ACC_CL0000: sum of areas (ha) of corridor and the two patches it connects; PID_CL0100: ID of the 100 m clump; ACL_CL0100: area of the 100 m clump; CNT_CL0100: number of patches in the 100 m clump.

Table 4.5 Enhanced corridors attributes showing only corridors adjacent to the largest patch in the landscape[2]. Areas of each corridor plus areas of the fragments it connects (ACC_CL0000) hierarchized prioritizing largest areas. Sum of corridors areas selected for restoration excluding overlapping fixed width corridors (AHA_noCorI) is 96.07 ha.

ENHANCED CORRIDORS ATTRIBUTES									
PID CO0130	**AHA CO0130**	**AHA noCorI**	**PID CL0000**	**PID CL00_1**	**ACL CL0000**	**ACC CL0000**	**PID CL0100**	**ACL CL0100**	**CNT CL0100**
459	24,77	24,77	799	1527	170707,26	170732,04	1033	172841,04	78
457	7,90	7,67	799	1527	170707,26	170715,16	1033	172841,04	78
452	9,45	9,27	660	1527	170300,54	170309,99	1033	172841,04	78
463	2,19	1,90	757	1527	170154,41	170156,60	1033	172841,04	78
468	8,36	8,07	861	1527	170143,52	170151,88	1033	172841,04	78
470	34,72	34,52	873	1527	170108,93	170143,65	1033	172841,04	78
471	6,96	6,69	879	1527	170120,64	170127,60	1033	172841,04	78
469	3,18	3,18	879	1527	170120,64	170123,82	1033	172841,04	78
454	6,54	6,42	693	1527	170113,25	170119,79	1033	172841,04	78
449	13,01	12,71	505	1527	170106,66	170119,67	1033	172841,04	78
447	6,65	6,07	366	1527	170111,90	170118,55	1033	172841,04	78
455	2,27	2,27	709	1527	170113,41	170115,68	1033	172841,04	78
456	0,97	0,70	709	1527	170113,41	170114,38	1033	172841,04	78
466	6,17	6,17	804	1527	170107,60	170113,78	1033	172841,04	78
453	4,17	3,98	683	1527	170109,43	170113,60	1033	172841,04	78
448	3,65	3,65	386	1527	170107,92	170111,57	1033	172841,04	78
450	1,95	1,95	640	1527	170109,15	170111,11	1033	172841,04	78
442	2,94	2,70	215	1527	170106,41	170109,35	1033	172841,04	78
443	4,66	4,42	267	1527	170103,93	170108,59	1033	172841,04	78
		Total: 96,07 ha							

[2] **Table 4.5:** abbreviations definitions: PID_CO0130: ID of each corridor; AHA_CO0130: area (ha) of corridors; AHA_noCorI: area (ha) of corridors minus the area of overlapping fixed width corridors; PID_CL0000 and PID_CL00_1: patch ID of the two fragments the corridors connect ; ACL_CL0000: sum of the areas (ha) of the two patches corridors connect; ACC_CL0000: sum of areas (ha) of corridor and the two patches it connects; PID_CL0100: ID of the 100 m clump; ACL_CL0100: area of the 100 m clump; CNT_CL0100: number of patches in the 100 m clump.

The restoration planner considered that the best strategy to improve regional biodiversity in the long term would be by connecting the very neighbor habitat patches to the larger source fragment, preferentially choosing fragments to be connected that structurally add more habitat to the source area. It will probably facilitate species movements between source (larger) and target (small) fragments, facilitating the target ones to be recolonized in case there are temporary local extinctions, in a metapopulation-like dynamic (HANSKI, 1994). A patch of habitat for a given species, or a patch of vegetation of any particular type, in both cases larger patches have been considered critical (LINDEMMAYER *et al*, 2008). One could have said that while large patches are important, many studies have shown that the ecological values of small- and medium-sized can be considerable (TURNER, 1996) and gotten to other conclusions. Furthermore, we acknowledge that patch size is relative; what constitutes a large patch of habitat for a species of beetle may be a small patch for a species of bird or mammal (LINDENMAYER *et al*, 2008). Anyways here it has been assumed that the benefits would be optimized by connecting adjacent fragments to the largest Atlantic Forest fragment (area of c.a. 1.1 million ha of continuous forests, see RIBEIRO *et al.* 2009), which is part of our study area.

Another smart strategy when no specific goal is required may be identifying disproportionately important species, processes and landscape elements. Some landscape elements may be disproportionately important because of their provision of key resources such as water or nutrients or for their spatial context in enhancing connectivity and gene flow. There may also be species of particular concern, either because of their relative scarcity due to landscape change or because of their disproportionate impact on an ecosystem (e.g. ecosystem engineers and keystone species). These are entities whose importance is often only recognized when problems arise (HOBBS *et al*, 2003).

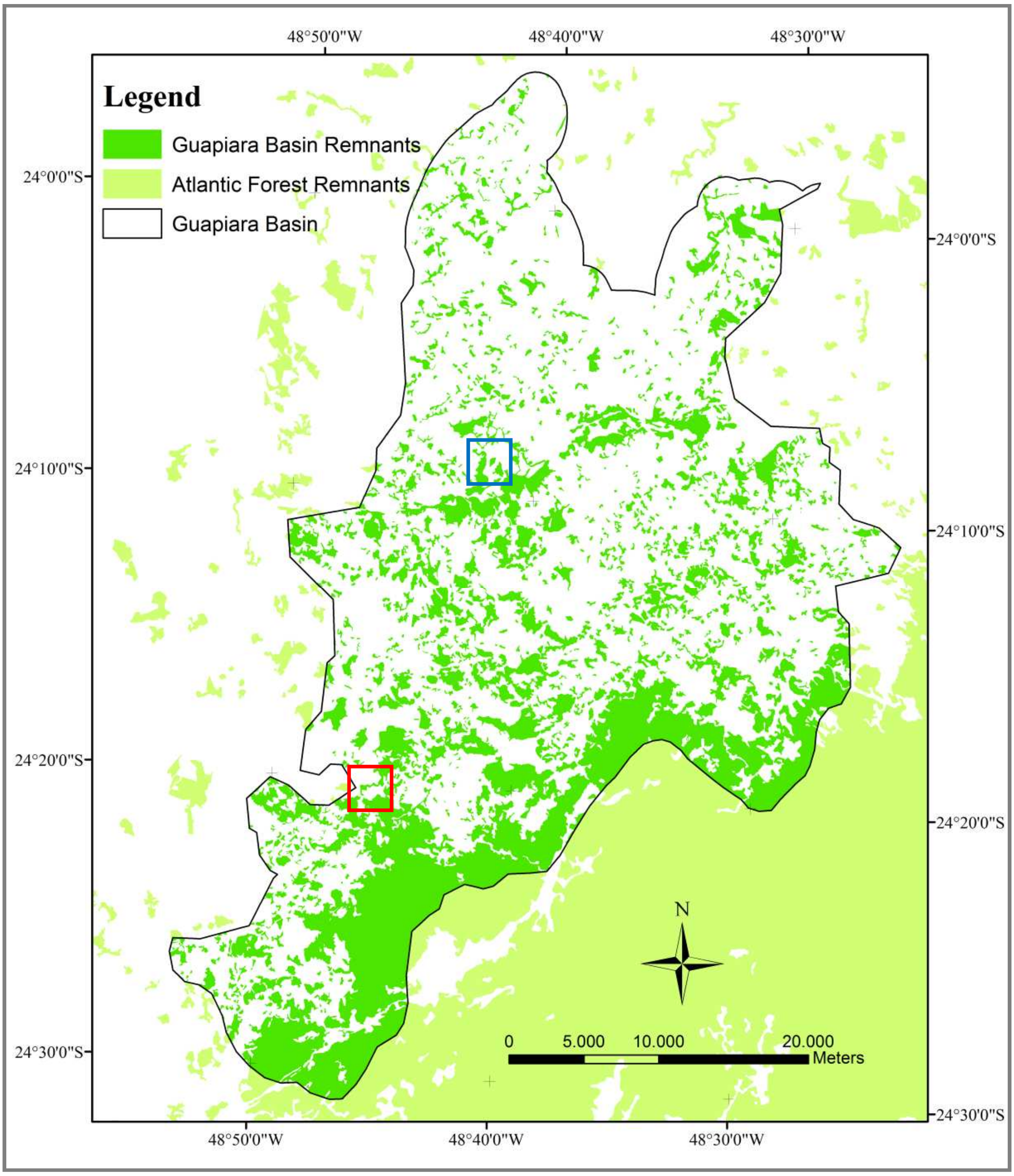

Figure 4.4 *Guapiara Basin*, on the southwest of São Paulo state, Brazil. Red square is the location of simulation I´s Figure 4.5 and blue square is the location of simulation II´s Figure 4.6 with the restoration options results.

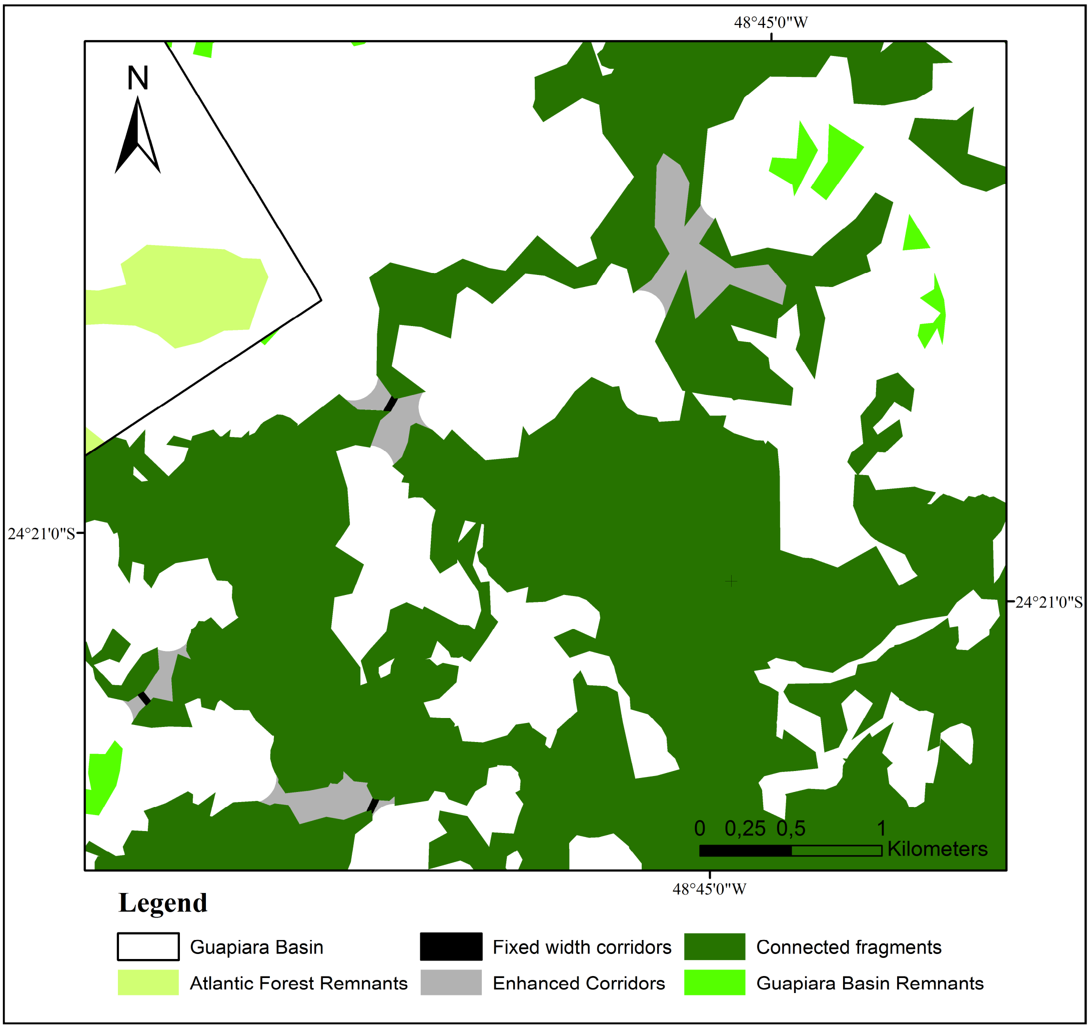

Figure 4.5 In black and grey we illustrate a subset of the selected restoration priorities to improve long term local biodiversity within the *Guapiara Basin* given a restoration offer constrainer. *Fixed width corridors* (30 meters wide) are in black and *enhanced corridors* in grey.

Simulation 2

Sometimes, the main goal of restoration might not be based on a biological or ecological process alone. In this case other interests of the restorationer must be taken into account, and still, it is important to conciliate them with logical biological or ecological processes. Simulation 2 presents a situation in which a road administrator needs to compensate an ecological passive and hires a restoration planner to find the best restoration sites. It would be the interest of this administrator to restore along the road for the logistical convenience, and furthermore, the marketing would be at sight distance of the guests (road users).

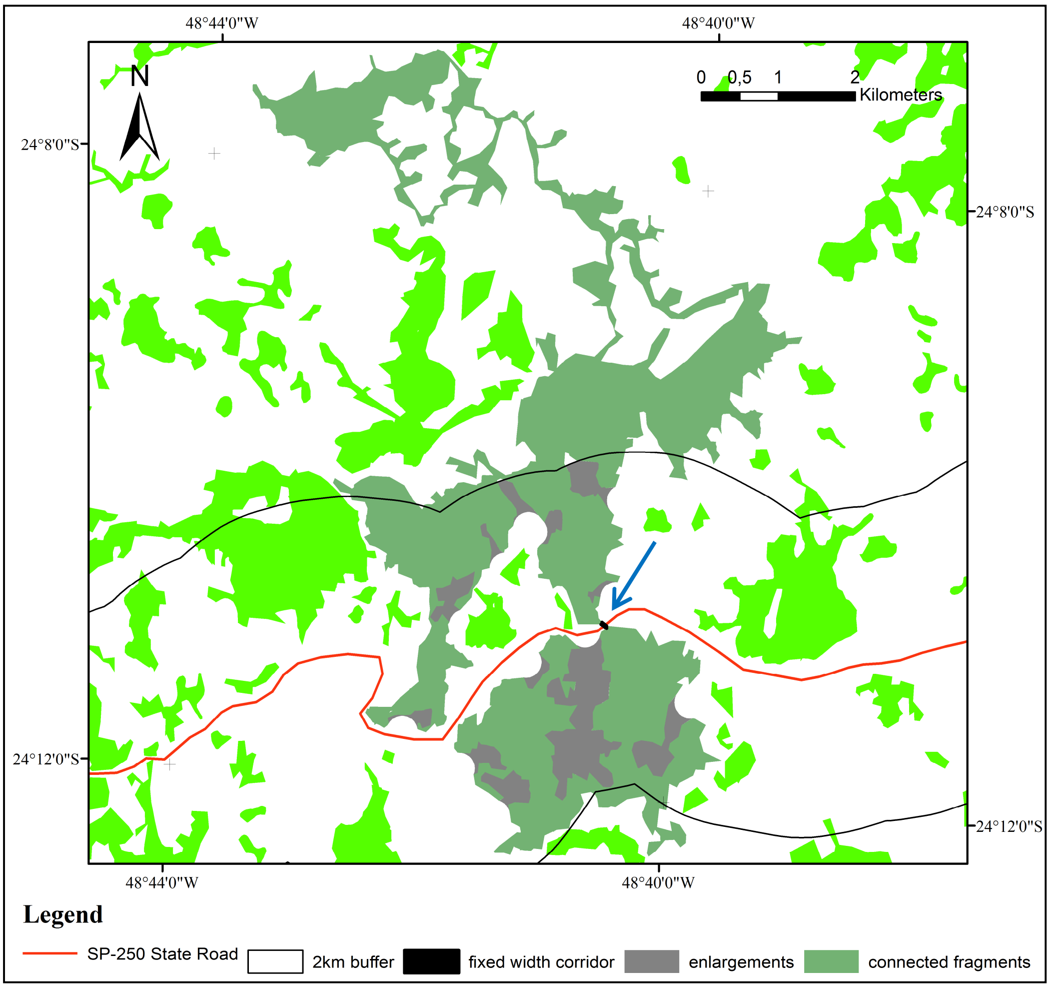

Figure 4.6 In black and grey a subset of the selected restoration priorities to comply with simulation II constrainers to restore along SP-250 State Road in the *Guapiara Basin*. 30 m wide *fixed width corridor* (shown by the arrow) is in black and *enlargements* in grey.

After applying the methodology and by considering only those patches far apart no more than 100 m, six potential corridors were found overlapping the road. Three of them were chosen which connected the largest couple of fragments separated by SP-250 road. Although some of the other ones might also be considered large fragments, they wouldn´t worth the connection to its neighboring much smaller patches. Since these three corridors accounted for 0.62 ha, the remaining restoration offer could be distributed on enlargements of the connected fragments (**Table 4.6**). Out of 116 enlargement polygons, 21 were selected, accounting for 299.36 ha (**Table 4.7**), which summed with the corridors area makes a total of 299.98 ha to be restored. **Figure 4.6** illustrates part of the suggested restoration sites (one of the underpasses connections and local enlargements), where one can observe that, if restored, the more relevant regional habitat patches will be connected, with its shapes more compact (smaller edge/core relationship) then the original scenario.

Table 4.6 Fixed width corridors attributes showing only corridors crossing the road[3]. Areas of the two patches plus its enlargements (AHA_EP0000 and AHA_EP00_1) each corridor connects hierarchized and prioritized by largest areas. Sum of selected corridors areas (AHA_CO0030) is 0.62 ha.

FIXED WIDTH CORRIDORS ATTRIBUTES											
PID CO0030	AHA CO0030	PID CL0000	AHA CL0000	PID CL00_1	AHA CL00_1	ACL CL0000	ACC CL0000	AHA EN0000	AHA EN00_1	AHA EP0000	AHA EP00_1
484	0,21	1315	435,95	1733	1179,48	1615,43	1615,64	169,03	74,22	604,98	1253,70
548	0,16	1495	14,63	1675	672,01	686,64	686,81	3,84	88,93	18,48	760,94
453	0,25	1235	39,87	1305	82,15	122,03	122,28	0,61	29,09	40,48	111,25
450	0,26	1229	10,58	1303	60,64	71,23	71,48	0,00	22,47	10,58	83,11
456	0,15	1238	231,48	1249	2,38	233,86	234,01	61,70	0,00	293,18	2,38
482	0,24	1315	435,95	1340	4,11	440,06	440,30	169,03	0,24	604,98	4,35
	0,62										

[3] **Table 4.6:** abbreviations definitions: PID_CO0030: ID of each corridor; AHA_CO0030: area (ha) of corridors; PID_CL0000 and PID_CL00_1: patch ID of the two fragments the corridors connects ; AHA_CL0000 and AHA_CL00_1: areas of the two fragments the corridors connects; ACL_CL0000: sum of the areas (ha) of the two patches corridors connect; ACC_CL0000: sum of areas (ha) of corridors and the two patches they connect; AHA_EN0000 and AHA_EN00_1: area of enlargements of the two fragments the corridors connects; AHA_EP0000 and AHA_EP00_1: sum of areas (ha) of the two patches corridors connect and their enlargements.

Table 4.7 Attributes of the enlargements of the selected fragments to be connected[4]. They have been hierarchized by area and prioritized from the largest to the smallest (AHA_EN0200). Sum of selected enlargements areas is 299.36 ha.

ENLARGEMENTS ATTRIBUTES			
PID_EN0200	AHA_EN0200	PID_CL0000	AHA_CL0000
5354	99,79	1315	435,95
5351	26,22	1315	435,95
8254	20,22	1675	672,01
8518	17,67	1733	1179,48
5338	16,53	1315	435,95
8497	15,93	1733	1179,48
8232	12,00	1675	672,01
5284	11,87	1305	82,15
5344	10,21	1315	435,95
8251	9,94	1675	672,01
8197	8,67	1675	672,01
8513	8,24	1733	1179,48
8221	7,67	1675	672,01
8508	6,21	1733	1179,48
8483	5,75	1733	1179,48
5359	4,53	1315	435,95
8240	4,18	1675	672,01
5280	3,85	1305	82,15
8506	3,77	1733	1179,48
8198	3,60	1675	672,01
5293	3,55	1305	82,15
8239	3,41	1675	672,01
8181	3,34	1675	672,01
8213	3,31	1675	672,01
8253	3,26	1675	672,01
5289	3,12	1305	82,15
6088	3,08	1495	14,63
8494	2,80	1733	1179,48
8487	1,98	1733	1179,48
	Total of selected: 299,36 ha		

[4] **Table 4.7:** abbreviations definitions: PID_EN0200: ID of enlargements; AHA_EN0200: area (ha) of enlargements; PID_CL0000: patch ID of the adjacent fragment;AHA_Cl0000: area of the adjacent fragment.

The conduction of the site selection in both simulations could have been different, for example: the strategy in simulation two could have considered the allocation of the underpasses in places adjacent to water bodies where they exist. This could be supported by the fact that most animals preferably move using riparian zones or swamps (LEEs; PERES, 2007), and these species are among the ones that present highest road kill rates everywhere (FAHRIG *et al*, 1995; SEILER, 2005). Such a fact suggests adoption of corridor PPAs as potential underpass connection points instead of fixed width corridors (see **Figure 4.7**).

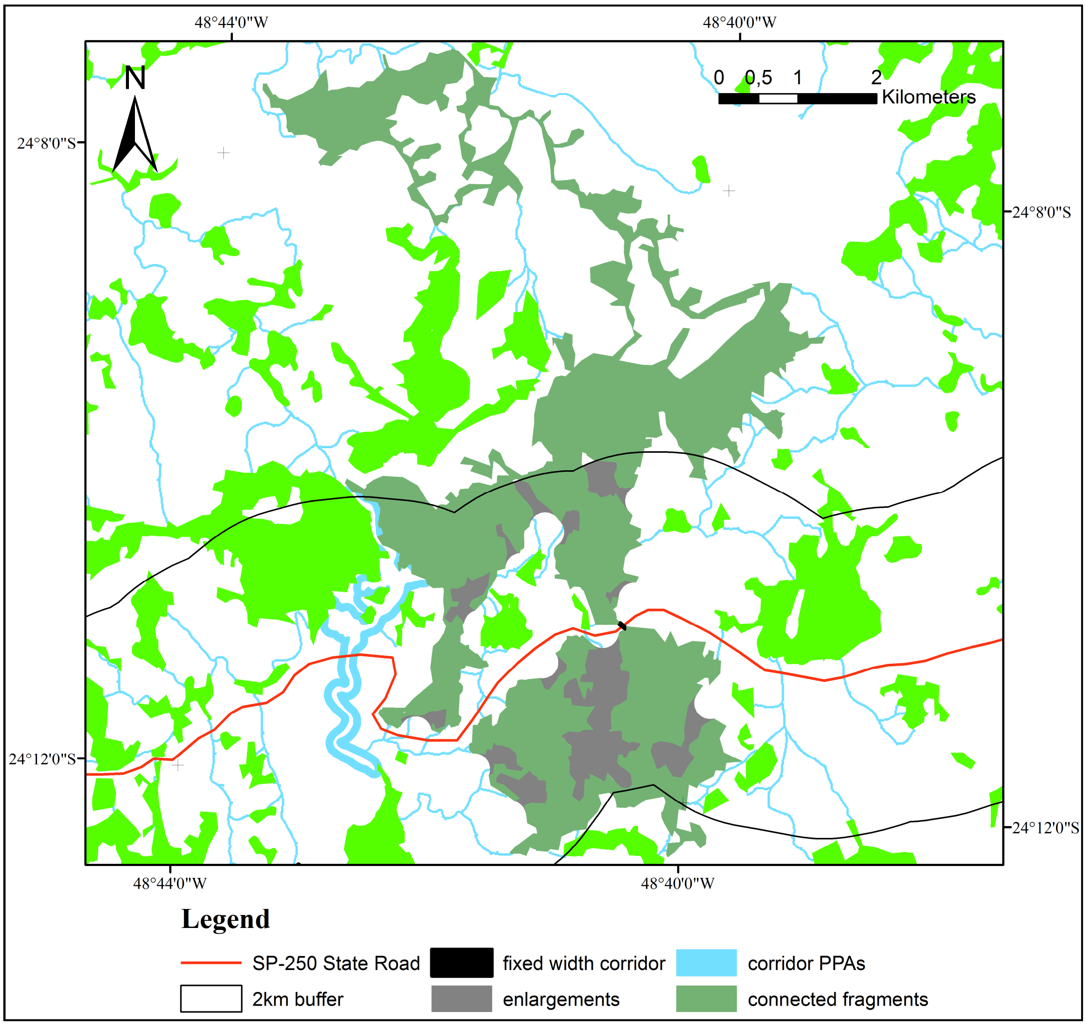

Figure 4.7 Simulation 2 alternative restoration strategy, considering establishment of the road underpasses on corridor PPAs.

5 RESTORATION HOTSPOTS TOOLBOX

The methods proposed and described in this research are apt to be implemented for semi-automatic processing in a GIS, such as in the format of a Toolbox in ArcGIS (ESRI, 2011). The conceptual model and the toolsets for the ArcGIS plug-in, here called "Restoration Hotspots Toolbox Bellow”, are detailed in this chapter. This tool would aid expert and non-expert users: 1) generate spatial and statistics data of forest quantification based on the Brazilian Legislation, 2) create restoration options addressed by several different approaches, 3) hierarch and 4) select some of the generated options according to a constrainer. These data can be obtained locally or regionally, which enables the application of the methodology in whole cities or states. In the Atlantic Forest it complements the array of restoration planning demands of the Atlantic Forest Restoration Pact, a group that aims to promote restoration of 15 million ha in this area until 2050 (CALMON *et al.* 2010).

Here this Toolbox, its toolsets, the scripts, and the interface of each script pop-up window are schematized. The vegetation polygon map is the necessary input to run the steps. If the user wants to run all the steps additional maps are needed: drainage, water bodies, head waters, slope, nature reserves and study area maps. The last maps are optional and needed in order to obtain PPAs and areas apt to be considered as LRs. The toolbox is composed of four toolsets, and the users may use them sequentially until desired outputs are achieved. Each toolset has different number of scripts, some of them optional. The scripts use the freeware language Python, version 2.4. The complete structure of the toolbox is presented in **Figure 5.1** and a full explanation of each Toolset part is given bellow.

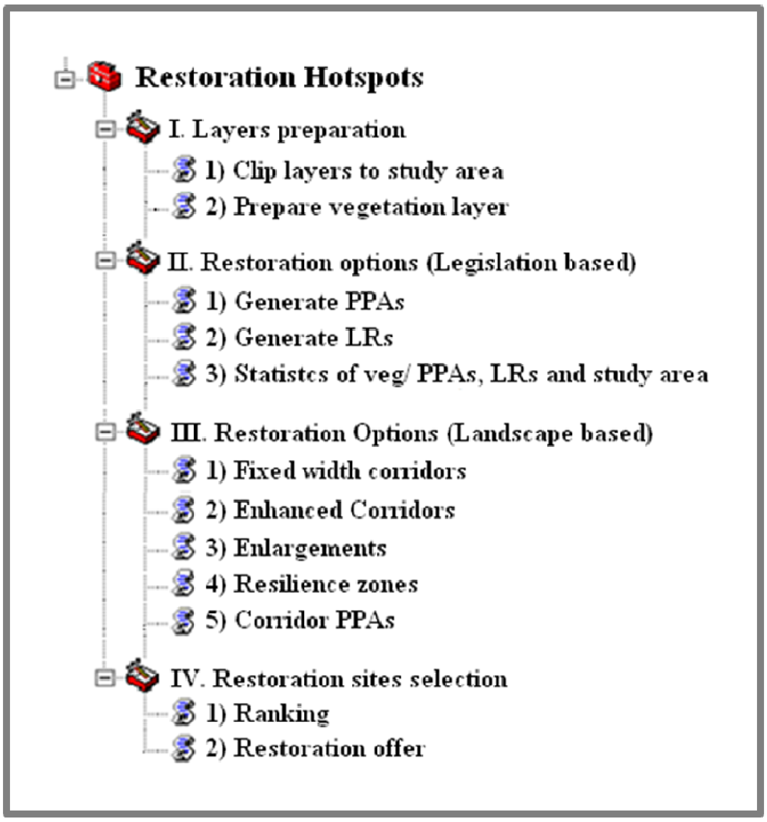

Figure 5.1 Scheme of the conceptual model we called "Restoration Hotspots Toolbox" and its toolsets, designed as an ArcGIS plug-in. The process may be used by a restoration planner sequentially in order to generate, prioritize and select sites for restoration.

I. Layers Preparation: Necessary step.

Outputs: Prepares all layers used in the entire processing to have the same area extent (1) and the necessary attributes (2). The windows for "Layers Preparation" toolset is presented in **Figure 5.2**.

1) Clip layers to study area

Necessary inputs: study area and vegetation (habitat and non-habitat) polygons shapefiles.

Optional inputs: drainage, water bodies and nature reserves polygons shapefiles; headwaters point shapefile; and slope rasterfile. Processing required prior to running Toolbox II or script 5 of Toolbox III.

2) Vegetation layers

Necessary input: vegetation polygon shapefile obtained in I. (1).

Optional inputs: functional clumps size (maximum length of corridors); required when running scripts 1 and 2 of Toolbox III.

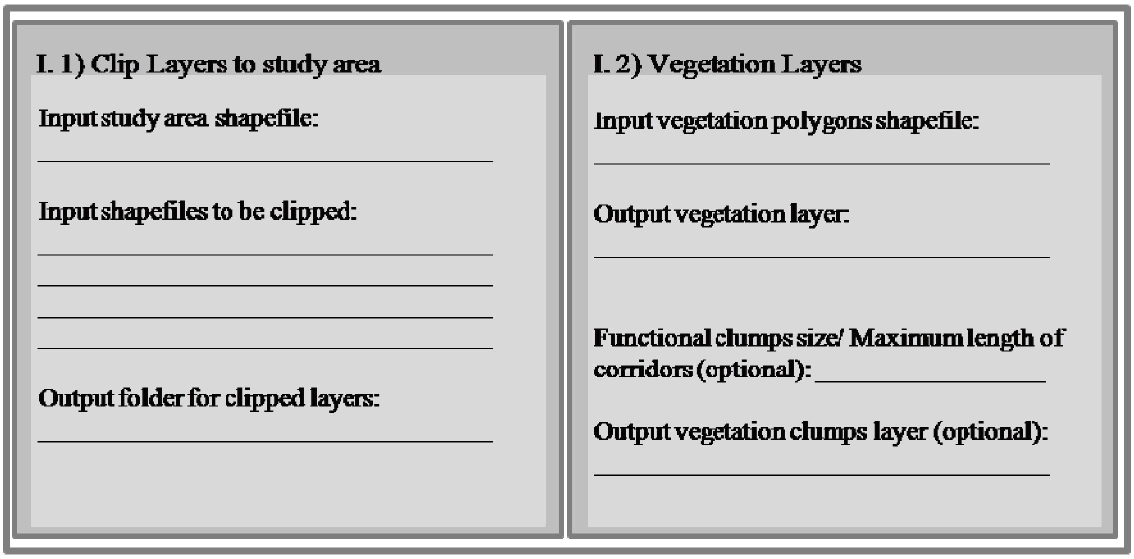

Figure 5.2 Windows for Restoration Hotspots Toolbox´s Toolset I: Layers Preparation.

II. Restoration Options (Legislation Based): Optional step.

Outputs: Generates restoration candidates based on the deficit of preserved PPAs (1) - required when running script 5 of Toolbox III - and areas apt to be used as LRs (2) according to the Brazilian legislation. Generates tables with statistcs of vegetation proportion in PPAs, areas apt to be used as LRs, study area and sub-study areas (3). **Figure 5.3** presents the set of windows for the legislation-based “Restoration Options" toolset.

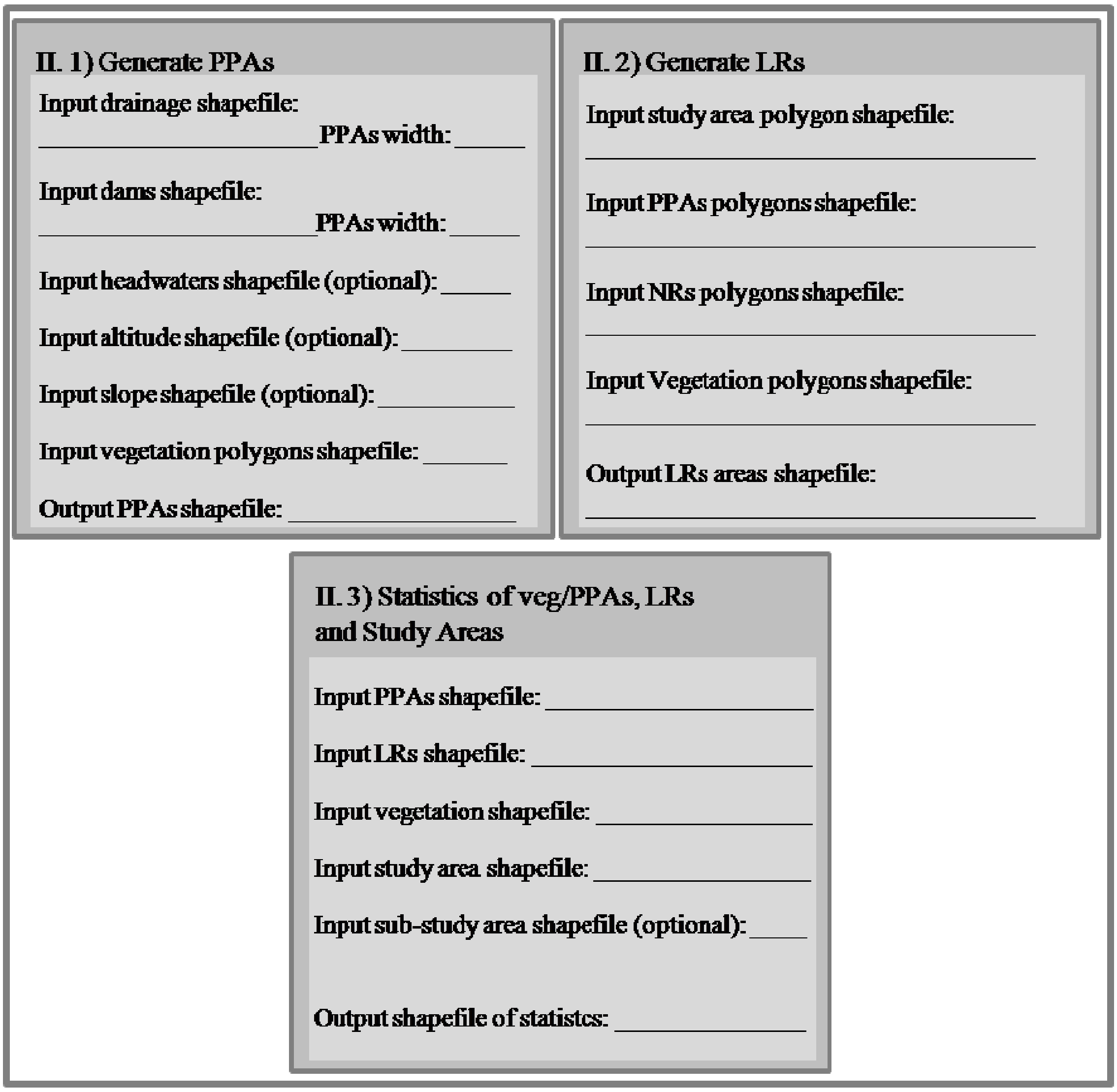

Figure 5.3 Windows for Restoration Hotspots Toolbox´s Toolset II: Restoration Options (Legislation Based).

1) Generate PPAs

Necessary inputs: drainage and water bodies polygons shapefiles, obtained in I. (1); inform PPAs width.

Optional inputs: headwaters point shapefile and slope rasterfile, obtained in I. (1).

2) Generate LRs

Requirements: have processed (1).

Necessary inputs: study area polygon shapefile; vegetation and nature reserves polygons shapefiles, obtained in I. (1); PPAs polygon shapefile obtained in II (1).

3) Statistics of veg/PPAs, LRs & SA

Requirements: have processed eighter (1) or both (1) and (2).

Necessary inputs: vegetation and nature reserves polygons shapefiles, obtained in I. (1); PPAs polygon shapefile obtained in II (1); LRs shapefile obtained in II (2); study area and sub-study areas polygons shapefile.

III. Restoration Options (Landscape Based): Optional step.

Requirements: The input vegetation layers must have been obtained at I (2).

Outputs: Generates restoration candidates based on landscape metrics and configuration, obtaining maximum ecological results per restoration effort. Generates corridors of maximum pre-determined lengh and fixed width (1) or enhanced by interior area (2). Enlarges forest fragments in strategic areas (3) or around fragments of desired cut-size (4). Selects PPAs that stablish corridors between existing forest fragments (5). See **Figure 5.4** for the windows that are included on landscape-based "Restoration Options".

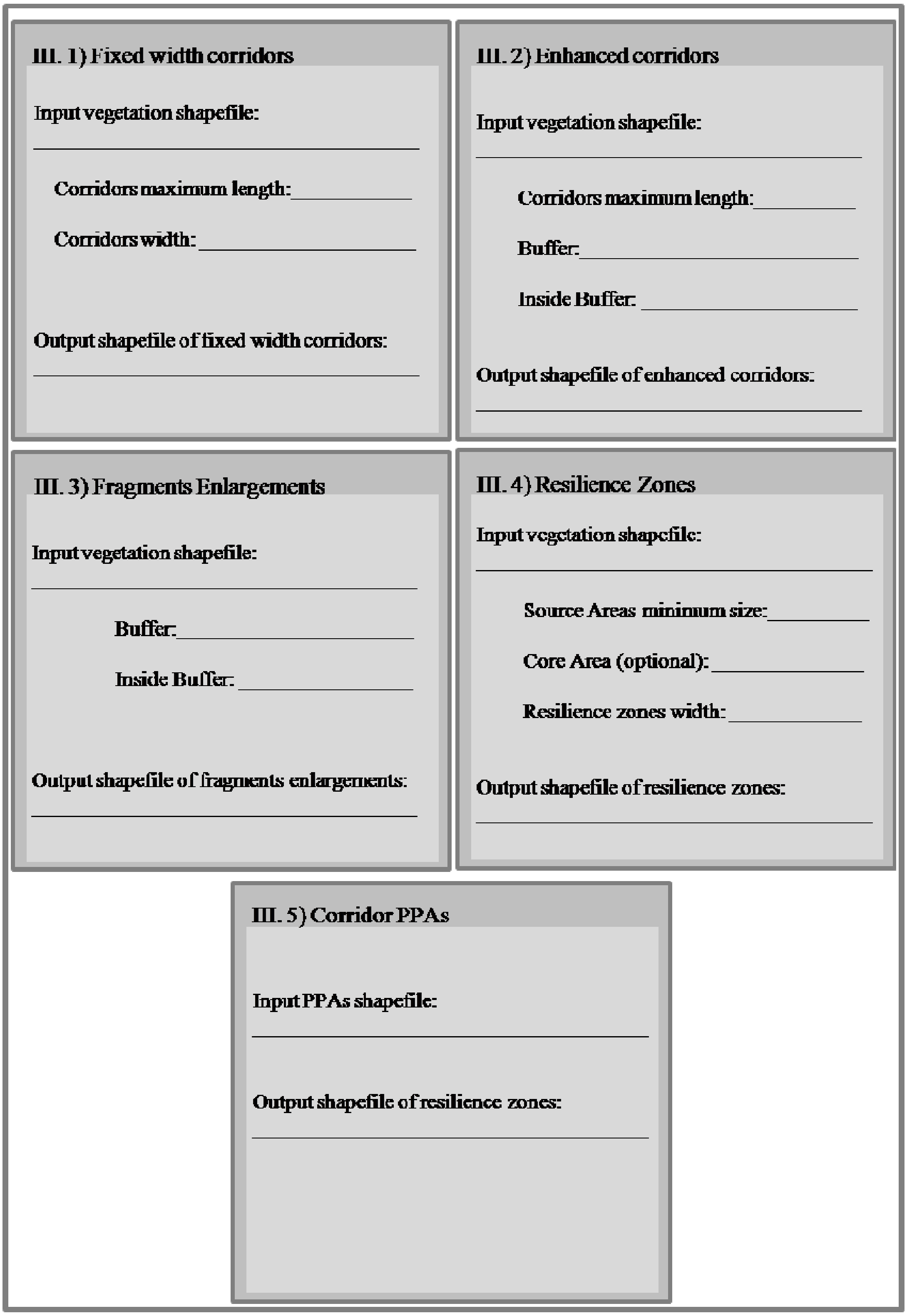

Figure 5.4 Windows for Restoration Hotspots Toolbox´s Toolset III: Restoration Options (Landscape Based).

1) Fixed width corridors

Necessary inputs: vegetation polygon shapefile with attributes of clumps size. Define corridors desired width.

2) Enhanced corridors

Necessary inputs: vegetation polygon shapefile with attributes of clumps size. Define buffer and inbuffer sizes (see Methods section).

3) Enlargements

Necessary inputs: vegetation polygon shapefile. Define buffer and inbuffer sizes (see Methods section).

4) Resilience zones

Necessary inputs: vegetation polygon shapefile. Define source-area cut-size and resilience zones width (see Methods section).

5) Corridor PPAs

Necessary inputs: vegetation polygon shapefile and PPAs polygon shapefile abtained in II (1).

IV. Hierarching Restoration Options: Optional step.

Requirements: Have processed at least one restoration option in II or III.

Outputs: Restoration options ranked in a prioritization order, based on sizes and/or locations of clumps and/or fragments (1); selects the priority sites until a restoration offer is finished (2). **Figure 5.5** shows the windows toolset for the restoration sites hierarchization.

1) Ranking

Necessary inputs: vegetation polygon shapefile with attributes of clumps size obtained in I. (1). Define functional clumps, fragments and location priority.

Optional inputs: layer of near features (e.g. a road, a city).

2) Restoration Offer

Necessary input parameter: area (in ha) to be restored.

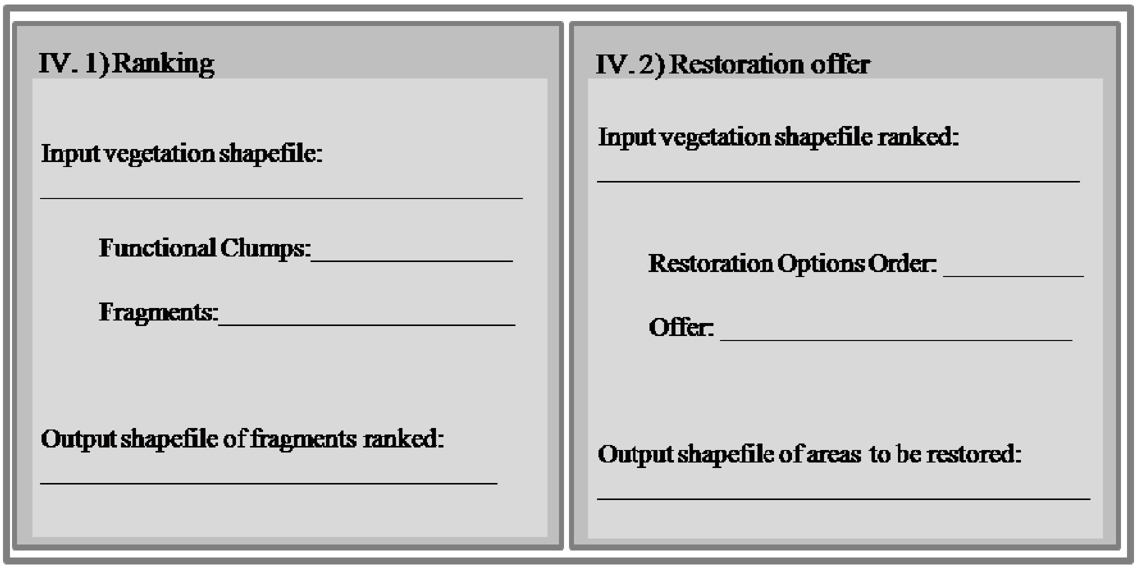

Figure 5.5 Windows for Restoration Hotspots Toolbox´s Toolset IV: Hierarching Restoration Options.

6 CONCLUSIONS

Currently there are several geoprocessing alternatives to aid conservation and only a few in the field of restoration planning, however the protocol proposed here is a decision modeling tool that constitutes a major step forward in systematic planning of ecological restoration within tropical forests, particularly in the Brazilian Atlantic Forest, which includes different alternatives to the user. It integrates a set of GIS tools, remote sensing derived products and landscape-based parameters. The legislation and landscape–based criteria can fully support the designing, prioritization and selection of sites for restoration after a clear objective is stated, or only parts of this methodology can be adopted to complement other products such as the "Map of Potential Areas for Restoration in the Atlantic Forest" (RODRIGUES *et al*, 2009) and the "Map of Priority areas for biodiversity restoration in São Paulo" (JOLY *et al*, 2010). Considering the set of alternative strategies for restoration site selection options described here even small offers for restoration can be optimized in order o attend a species demand, (re)establish an ecological process and/or fit to logistical constrainers.

The methods are composed of flexible rules that enable the user rank restoration possibilities and supply the demands of pre-defined goals. It allows the users or stakeholders to (1) generate alternatives which improve the flow of species; (2) to restore permanent preservation areas that promote structural connectivity; or (3) even enlarge cores areas to benefit edge sensitive species. A case study was conducted in order to illustrate the use of the protocol and evaluate the results, which accounted for improvements in landscape indexes with the restoration candidate sites implemented compared to the current forest cover scenario.

The proposed protocol is now ready to be applied in the real world, and its use will motivate improvements on the methodology, which should be implemented due to its flexibility and robustness. Ongoing tasks consider the implementation of the methodology in the software package currently called "Restoration Hotspots Toolbox", which will be freely available in the internet. Another aim is to integrate the set of proposed strategies with algorithms that evaluate the individual and combined contribution of each restoration site to local and overall habitat protection and connectivity increment. Future developments include geomorphometry features, information about regional-based resilience zone, type of matrix surrounding the habitat patches, and the time of anthropogenic land cover to be restored.

REFERENCES

ASTRIUM (Geo-information Services). **The SPOT satellites**. Available at: <http://www.spotimage.com/web/en/229-the-spot-satellites.php>. Visited on 01/Jul/2011.

BALL, I.R., H.P. POSSINGHAM, AND M. WATTS. Marxan and relatives: Software for spatial conservation prioritisation. Chapter 14: Pages 185-195 in Spatial conservation prioritisation: **Quantitative methods and computational tools.** Eds Moilanen, A., K.A. Wilson, and H.P. Possingham. Oxford University Press, Oxford, UK. 2009.

BENAYAS, J.M.R.; NEWTOM, A.C.; DIAZ, A.; BULLOCK, J.M. Enhancement of biodiversity and ecosystem services by ecological restoration: a meta-analysis. **Science**, v. 325, p. 1121–1124, 2009.

BEIER, P; MAJKA, D; JENNESS, J. **Conceptual Steps for designing wildlife corridors.** Available at: <http://corridordesign.org/downloads>. Visited on 01/Jul/2011.

BENNETT, A.F., RADFORD, J.Q.; HASLEM, A. Properties of land mosaics: implications for nature conservation in agricultural landscapes. **Biological Conservation**, v. 133, p. 250–264, 2006.

BROWN, J. H.; KODRICK-BROWN, A. Turnover rates in insular biogeography: effect of immigration on extinction. **Ecology**, v. 58, p. 445–449, 1977.

CALMON, M.; BRAANCALION, P.H.S.; PAESE, A.; ARONSON, J.L; CASTRO, P.; SILVA, S.C.; RODRIGUES, R.R. Emerging threats and opportunities for large-scale ecological restoration in the Atlantic Forest of Brazil. **Restoration Ecology**, v. 19, n. 2, p. 154–158, 2011.

CANASAT/INPE (Sugarcane mapping through Earth Observation Satellite Images/ National Institute for Space Research). **Sugarcane Maps download website.** Available at <http://www.dsr.inpe.br/laf/canasat/mapa.html>. Visited on 01/July/2011.

CBD (Convention on Biological Diversity). **Global Strategy for Plant Conservation.** Secretariat of the Convention on Biological Diversity, CBD, UMEP, Botanical Gardens Conservation International, Montreal: 2002.

CORRÊA, F. A reserva da biosfera da Mata Atlântica: roteiro para o entendimento de seus objetivos e seu sistema de gestão. **Série Cadernos da Reserva da Biosfera da Mata Atlântica**. São Paulo: 2ªed, 49p, 1996.

COWLING, R.M.; KNIGHT, A.T.; FAITH, D.P.; LOMBARD, A.T.; DESMET, P.G. Nature conservation requires more than a passion for species. **Conservation Biology**, v. 18, p. 1674–76, 2004.

DEAN, W. **With Broadax and Firebrand: The Destruction of the Brazilian Atlantic Forest.** California: University of California Press, 1996.

DEWALT, S.J., MALIAKAL, S.K., DENSLOW, J.S. Changes in vegetation structure and composition along a tropical forest chronosequence: implications for wildlife. **Forest Ecology and Management**, v. 182, p. 139–151, 2003.

DOBSON A P, BRADSHAW A D, A. BAKER J M. Hopes for the Future: Restoration Ecology and Conservation Biology. **Science**, v. 277, p. 515-522, 1997.

EORC, JAXA (Earth Observation Research Center, Japan Aerospace Exploration Agency). **ALOS Research and Application Project**. Available at <http://www.eorc.jaxa.jp/ALOS/en/index.htm>. Visited on: 01/Jun/2011. 2007.

ESRI (Environmental Systems Research Institute). **ArcGIS Software Details.** Available at: < http://www.esri.com/software/arcgis/index.html>. Visited on 01/Jun/2011.

EWERS, R.M..; MARSH, C.J.; WEARN, O.R. Making statistics biologically relevant in fragmented landscapes. **Trends in Ecology and Evolution**, Vol. 25(12): 699-704, 2010.

FAHRIG, L. Effects of habitat fragmentation on biodiversity. **Annual Reviews of Ecology and Systematics**, v. 34, p. 487-515, 2003.

FAHRIG, L.; MERRIAM, G. Habitat patch connectivity and population survival. **Ecology**, v. 66, p. 1762–1768, 1985.

FAHRIG, L.; PEDLAR, J. H.; POPE,S. E.; TAYLOR, P.D.; WEGNER, J.F. Effect of road traffic on amphibian density. **Biological Conservation**, v. 73, p. 177-182, 1995.

FAITH, D.P. Environmental diversity (ED) as surrogate information for species level diversity. **Ecography**, 26:374–79, 2003.

FISCHER, J.; LINDENMAYER, D.B.; FAZEY, I. Appreciating ecological complexity: habitat contours as a conceptual landscape model. **Conservation Biology**, v. 18, p. 1245–1253; 2004.

FORMAN, R. T. T. **Land mosaics: the ecology of landscapes and regions.** Cambridge University Press, Cambridge/New York: 632 p. 1995.

FRANKEN, R.J; HIK, D.S. Influence of habitat quality, patch size and connectivity on colonization and extinction dynamics of collared pikas Ochotona collaris. **Journal of Animal Ecology**, v. 73, p. 889–896, 2004.

GALBUSERA, P.; LENS, L; WAIYAKI, E; SCHENCK, T; MATTYSEN, E. Effective population size and gene flow in the globally, critically endangered Taita thrush, *Turdus helleri*. **Conservation Genetics**, v. 1: p. 45–55, 2000.

HAILA, Y. A conceptual genealogy of fragmentation research from island biogeography to landscape ecology. **Ecological Applications**, v. 12, n. 2, p. 321–334, 2002.

HANSKI, I. A practical model of metapopulation dynamics. **Journal of Animal Ecology** 63, 151-162, 1994.

HANSKI, I.; SIMBERLOFF, D. The metapopulation approach, its history, conceptual domain, and application to conservation. In: Hanski, I., Gilpin, M. (Eds.), **Metapopulation Dynamics: Empirical and Theoretical Investigations.** Academic Press, London: p. 5–26, 1997.

HITCHINGS, S.P.; BEEBEE T.J.C. Genetic substructuring as a result of barriers to gene flow in urban *Rana temporaria* (common frog) populations: implications for biodiversity conservation. **Heredity**, v. 79, p. 117–127, 1997.

HOBBS, R.J. Landscape ecology and conservation: moving from description to application. **Pacific Conservation Biology**, v. 1, p. 170–177, 1994.

HOBBS, R.; CRAMER, V.; KRISTJANSON, L.J. What happens if we cannot fix it Triage, palliative care and setting priorities in salinising landscapes. **Australian Journal of Botany**, v. 51, p. 647-653, 2003.

HOLL K.D.; AIDE T.M. When and where to actively restore ecosystems? **Forest Ecology and Management**, v. 261 (10), p. 1558-1563, 2011.

JOLY, C. A; CASATTI, L; BRITO, M. C. W; MENEZES, N. A; RODRIGUES, R. R; BOLZANI, V. S. Histórico do Programa biota/fapesp - O Instituto Virtual da Biodiversidade. p45-56. In: RODRIGUES, R.R; JOLY, C.A; BRITO, M.C.W; PAESE, A; METZGER, J.P; CASATTI, L; NALON, M.A; MENEZES, N; IVANAUSKA, N.M; BOLZANI, V; BONONI, V. L. R. **Diretrizes para conservação e restauração da biodiversidade no Estado de São Paulo.** Governo do Estado de São Paulo, São Paulo: 238p, 2008.

JOLY, C. A.; RODRIGUES, R. R.; METZGER, J. P. ; HADDAD, C. F. B.; VERDADE, L. M.; OLIVEIRA, M. C.; BOLZANI, V. S. Biodiversity Conservation Research, Training, and Policy in Sao Paulo. **Science** (New York, N.Y.), 328: 1358-1359, 2010.

JRC (Joint Research Center – European Commission). **Graphical User Interface for the Description of image Objects and their Shapes – GUIDOS software.** 2011. Available at: <http://forest.jrc.ec.europa.eu/download/software/guidos>. Accessed on 01/07/2011.

KIERULFF, M.C.M; BEISIEGEL, B.M; CARMIGNOTTO, A.P; COUTINHO, D.M; CIOCHETI, G; DITT, E.H; MARTINS, R.R; LIMA, F; NASCIMENTO, A.T.A; NALI, C; TAMBOSI, L. R; SETZ, E.Z.F; GOMES, M. T; MORATO, R.G; ALBERTS, C.C; VENDRAMI, J; FREITAS, S; GASPAR, D.A; PORT-CARVALHO, M; PAGLIA, A. Mamíferos. p72-76. In: RODRIGUES, R.R; JOLY, C.A; BRITO, M.C.W; PAESE, A; METZGER, J.P; CASATTI, L; NALON, M.A; MENEZES, N; IVANAUSKA, N.M; BOLZANI, V; BONONI, V. L. R. **Diretrizes para conservação e restauração da biodiversidade no Estado de São Paulo.** Governo do Estado de São Paulo, São Paulo: 238p, 2008.

KNUTSON, M.G.; SAUER, J.R.; OLSEN, D.A.; MOSSMAN, M.J.; HEMESATH, L.M.; LANNOO, M.J. Landscape associations of frog and toad species in Iowa and Wisconsin, USA. **Journal of the Iowa Academy of Sciences**, v. 107, p. 134–145, 2000.

KRONKA, F.J.N.; NALON, M.A.; MATSUKUMA, C.K.; KANASHIRO, M.M.; YWANE, M.S.S.; PAVÃO, M.; DURIGAN, G.: LIMA, L.P.R.; GUILLAUMON, J.R.; BAITELLO, J.B.; BORGO, S.C.; MANETTI, L. A.; BARRADAS, A.M.F; FUKUDA, J.C.; SHIDA, C.N.; MONTEIRO, C.H.B.; PONTINHAS, A.A.S.; ANDRADE, G.G.; BARBOSA, O.; SOARES, A.P.; JOLY, C.A.; COUTO, H.T.Z. **Inventário florestal da vegetação natural do Estado de São Paulo.** São Paulo: Secretaria do Meio Ambiente / Instituto Florestal, Imprensa Oficial. 200 p, 2005.

LEWINSOHN, T.M.; PRADO, P.I. How many species are there in Brazil? **Conservation Biology**, v.19, n.3, p. 619-624, 2005.

LEES, A. C.; PERES, C.A. Conservation Value of Remnant Riparian Forest Corridors of Varying Quality for Amazonian Birds and Mammals. **Conservation Biology**, v. 22, n. 2, p. 439–449, 2008.

LINDENMAYER, D.; HOBBS, R.J.; MONTAGUE-DRAKE, R.; ALEXANDRA, J.; BENNETT, A.; BURGMAN, M.; CALE, P.; CALHOUN, A.; CRAMER, V.; CULLEN, P.; DRISCOLL, D.; FAHRIG, L.; FISCHER, J.; FRANKLIN, J.; HAILA, Y.; HUNTER, M.; GIBBONS, P.; LAKE, S.;LUCK, G.; MACGREGOR, C.; MCINTYRE, S.; NALLY, R.M.; MANNING, A.; MILLER, J.; MOONEY, H.; NOSS, R.; POSSINGHAM, H.; SAUNDERS, D.; SCHMIEGELOW, F.; SCOTT

M.; SIMBERLOFF, D.; SISK, T.; TABOR, G.; WALKER B.; WIENS, J.; WOINARSKI, J. ZAVALETA, E. A checklist for ecological management of landscapes for conservation. **Ecology Letters**, v 11, n 1, p 78-9. 2008.

LOREAU, M. Are communities saturated? On the relationship of alpha, beta and gamma diversity. **Ecological Letters**, v. 3, p. 73–76, 2000.

LUDWIG, J., D. TONGWAY, D. FREUDENBERGER, J. NOBLE, AND K. HODGKINSON. **Landscape Ecology, Function and Management: Principles from Australia's Rangelands.** CSIRO Australia: 158 pp, 1997.

MAJKA, D; JENNESS, J; BEIER, P. **CorridorDesigner: ArcGIS tools for designing and evaluating corridors.** 2007. Available at: <http://corridordesign.org>. Visited on 01/Jul/2011.

MANSOURIAN, S.;VALLAURI, D.; DUDLEY, N.; eds. (in cooperation with WWF International). **Forest restoration in landscapes: beyond planting trees.** Springer, New York, 437p, 2005.

MARTENSEN, A.; PIMENTEL, R.; METZGER, J.P. Relative effects of fragment size and connectivity on bird community in the Atlantic Rain Forest: Implications for conservation. **Biological Conservation**, v. 141, p. 2184-2192, 2008.

METZGER, J.P. Estrutura da Paisagem e Fragmentação: Análise Bibliográfica. **Anais da Academia Brasileira de Ciências**, v. 71, p. 1-3, 1999.

______. Como restaurar a conectividade de paisagens fragmentadas? In: KAGEYAMA, P.Y; OLIVEIRA, R.E; MORAES, L.F.D; ENGEL, V.L; GANDARA, F.B. **Restauração ecológica de ecossistemas naturais.** Botucatu: FEPAF, cap.3, p.51 –76, 2003.

______. Conservation issues in the Brazilian Atlantic forest. **Biological Conservation**, v. 142, p. 1138-1140, 2009.

METZGER, J.P; GOLDENBERG, R; BERNACCI, L.C. Os caminhos da biodiversidade. **Ciência Hoje**, v. 25, n.146, p. 62-64, 1999.

METZGER, J.P; RODRIGUES, R.R. Mapas síntese de diretrizes para a conservação e restauração da biodiversidade no Estado de São Paulo. Pp. 130-136. In: RODRIGUES, R.R; JOLY, C.A; BRITO, M.C.W; PAESE, A; METZGER, J.P; CASATTI, L; NALON, M.A; MENEZES, N; IVANAUSKA, N.M; BOLZANI, V; BONONI, V. L. R. **Diretrizes para conservação e restauração da biodiversidade no Estado de São Paulo.** Governo do Estado de São Paulo, São Paulo: 238p, 2008.

MYERS, N.; MITTERMEIER R.A.; MITTERMEIER, C.G.; FONSECA, G.A.B.; KENT, J. Biodiversity hotspots for conservation priorities. **Nature**, v. 403, p. 853-858, 2000.

OUBORG, N.J. Isolation, population size and extinction: the classical and metapopulation approaches applied to vascular plants along the Dutch Rhine-system. **Oikos**, v. 66, p. 298-308, 1993.

PALMER, M.A.; AMBROSE, R.F.; POFF, N.L. Ecological Theory and Community Restoration. **Restoration Ecology**, v. 5, n.4, p.291-300, 1997.

PARDINI R, SOUZA S M, BRAGA-NETO R, METZGER JP. The role of forest structure, fragment size and corridors in maintaining small mammal abundance and diversity in an Atlantic forest landscape. **Biological Conservation**, v. 124, p. 253–266, 2005.

PARDINI, R.; BUENO, A.A.; GARDNER, T.A.; PRADO, P.I.; METZGER, J.P. Beyond the Fragmentation Threshold Hypothesis: Regime Shifts in Biodiversity Across Fragmented Landscapes. **PLOS One**, v. 5, p. e13666, 2010.

PETERS, R. **A Critique for Ecology.** Cambridge University Press, Cambridge: 1991.

PETERSON, G.D.,CUMMING, G.S.; CARPENTER, S.R. Scenario planning: a tool for conservation in an uncertain world. **Conservation Biology**, v. 17, p. 358–366, 2003.

PFASTETTER, **O. Classificação de bacias hidrográficas: método de Otto Pfastetter**, 16p, 1987.

PIRES, A.S., LIRA, P.K.; FERNANDEZ, F.A.S.; SCHITTINI, G.M.; OLIVEIRA, L.C. Frequency of movements of small mammals among Atlantic Coastal Forest fragments in Brazil. **Biological Conservation,** v. 108, p. 229–237, 2002.

POSSINGHAM, H.P. **The Business of Biodiversity: Applying Decision Theory Principles to Nature Conservation.** TELA Series No. 9. The Australian Conservation Foundation, Melbourne, Australia: 2001.

PRESSEY, R. L.; HUMPHRIES C. J.; MARGULES C. R.; VANE-WRIGHT R. I.; WILLIAMS P. H. Beyond opportunism: Key principles for systematic reserve selection. **Trends in Ecology and Evolution**, v. 8, n. 4, p. 124- 128, 1993.

RIBEIRO, M.C.; METZGER, J.P.; MARTENSEN, A.C.; PONZONI, F.J.; HIROTA, M.M. The Brazilian Atlantic Forest: how much is left, and how is the remaining forest distributed? Implications for conservation. **Biological Conservation**, v. 142, p. 1141–1153, 2009.

RIBEIRO, M. C.; MARTENSEN, A.C.; METZGER, J.P.; TABARELLI, M.; SCARANO, F.; FORTIN, M. The Brazilian Atlantic Forest: a shrinking biodiversity hotspot. IN: ZACHOS FE, HABEL JC. (Org.). **Biodiversity Hotspots. Distribution and Protection of Conservation Priority Areas**. Springer-Verlag Berlin Heidelberg, 1st Edition: 500p, 2011.

RIBEIRO, M.C.; MARTENSEN, A.C.; METZGER, J.P.; TABARELLI, M.; SCARANO, F.; FORTIN, M.J. The Brazilian Atlantic Forest: a shrinking biodiversity hotspot. In: **Biodiversity Hotspots**, F.E. Zachos and J.C. Habel (eds.). Springer-Verlag, Berlin and Heidelberg. DOI 10.1007/978-3-642-20992-5_21, 2011.

RODRIGUES, R. R. (Org.) ; BONONI, V. L. R. (Org.) . **Diretrizes para a conservação e recuperação da Biodiversidade no Estado de São Paulo.** 1. ed. São Paulo: Imprensa Oficial: v. 1. 248 p, 2008.

RODRIGUES, R.R; JOLY, C.A; BRITO, M.C.W; PAESE, A; METZGER, J.P; CASATTI, L; NALON, M.A; MENEZES, N; IVANAUSKA, N.M; BOLZANI, V; BONONI, V. L. R. **Diretrizes para conservação e restauração da biodiversidade no Estado de São Paulo.** Governo do Estado de São Paulo, São Paulo: 238p, 2008.

RODRIGUES, R.R; BRANCALION, P.H.S; ISERNHAGEN, I. **Pacto pela restauração da mata atlântica: referencial dos conceitos e ações de restauração florestal.** São Paulo: LERF/ESALQ: Instituto BioAtlântica: 256p, 2009.

RODRIGUES, R.R.; GANDOLFI, S.; NAVE, A.G.; ARONSON, J; BARRETO, T.E.; VIDAL, C. Y.; BRANCALION, P. H.S. Large-scale ecological restoration of high-diversity tropical forests in SE Brazil. **Forest Ecology and Management**, v.261, n. 10, p. 1605-1613, 2010.

RODRIGUES, R.R; GANDOLFI, S. Conceitos, tendências e ações para recuperação de florestas ciliares. In: RODRIGUES, R. R; LEITÃO-FILHO, H. de F. (eds.). **Matas ciliares: conservação e recuperação.** São Paulo: EDUSP, p235-247, 2004.

SAUNDERS, D.A.; HOBBS, R.J.; MARGULES, C.R. Biological consequences of ecosystem fragmentation: a review. **Conservation Biology**, v. 5: n. 18-32, 1991.

SAURA, S; TORNÉ, J. Conefor Sensinode 2.2: a software package for quantifying the importance of habitat patches for landscape connectivity. **Environmental Modelling & Software**, v. 24: p. 135-139, 2009.

SEILER, A. Predicting locations of moose–vehicle collisions in Sweden. **Journal of Applied Ecology**, v. 42, p. 371–382, 2005.

SER (Society for Ecological Restoration International Science & Policy Working Group). **The SER International Primer on Ecological Restoration.** www.ser.org & Tucson: Society for Ecological Restoration International, 15p, 2004.

SHARKOV, E. A. **Remote sensing of tropical regions** - Chichester, England: John Wiley & Sons, 1998. 310306743 (Wiley-Praxis Series in Remote Sensing).

SILVA, J.M.C & C.H.M. CASTELETI. Status of the biodiversityof the Atlantic Forest of Brazil. In: C. Galindo-Leal & I.G.Câmara (eds**). The Atlantic Forest of South America: biodiversity status, trends, and outlook.** p. 43-59. Center for Applied Biodiversity Science e Island Press, Washington, D.C: 2003.

SOS ATLANTIC FOREST FUNDATION /NATIONAL INSTITUTE FOR SPACE RESEARCH (INPE). **Atlas dos Remanescentes Florestais da Mata Atlântica, período: 2005-2008.** 2009. Available at: <http://www.sosma.org.br>. Visited on: 10 feb. 2010.

STOTZ D. F; FITZPATRICK,J.W.; PARKER III, T.A.; MOSKOVITS, D.K.; **Neotropical Birds: Ecology and Conservation**. 478 pp, ISBN 0 226 77630 1 University of Chicago Press: 1996

TEWS, J., BROSE, U., GRIMM, V., TIELBORGER, K., WICHMANN, M.C., SCHWAGER, M., JELTSCH, F. Animal species diversity driven by habitat heterogeneity/diversity: the importance of keystone structures. **Journal of Biogeography**, v. 31, p. 79–92, 2004.

TURNER, I.M. Species loss in fragments of tropical rain forest: a review of the evidence. **Journal of Applied Ecology**, v. 33, p. 200–209, 1996.

URBAN, D.L; SHUGART, H.H. Avian demography in mosaic landscapes: modeling paradigm and preliminary. In: Verner, M.L; Morrisson, M.L; Ralph, C.J. Wildlife 2000 **– Modelling habitat relationships of terrestrial vertebrates.** Madison, The University of Wisconsin Press, p.273-279, 1986.

VALERIANO, M.M. **TOPODATA: guia para utilização de dados geomorfológicos locais.** São Jose dos Campos: INPE-15318-RPQ/818, 44p. 2008.

VELOSO, H.P.; RANGEL FILHO, A.L R & LIMA, J C A. **Classificação da Vegetação Brasileira, adaptada a um sistema universal.** MEFP/IBGE/DRNEA, Rio de Janeiro, 123p, 1991.

WIENS, J.A; SCHOOLEY, R.L; WEEKS, R.D. JR. Patchy landscapes and animal movements: do beetles percolate? **Oikos**, 78:257-2641997.

WILCOX, B.A.; MURPHY, D.D. Conservation strategy: effects of fragmentation on extinction. **The American Naturalist**, v. 125, p. 879– 887, 1985.

WILLIAMS, P.H; MARGULES, C.R; HILBERT, D.W. Data requirements and data sources for biodiversity priority area selection. **Journal of Biosciences**, v. 27, p. 327-338, 2002.

WU, J. Scale and scaling: a cross-disciplinary perspective. In: **Key Topics in Landscape Ecology**. Eds WU, J.; HOBBS, R.J. Cambridge University Press, Cambridge, pp. 115–142, 2007.

XAVIER, A. F; BOLZANI, B. M; JORDÃO, S. Unidades de Conservação da Natureza no Estado de São Paulo. p.23-44. In: RODRIGUES, R.R; JOLY, C.A; BRITO, M.C.W; PAESE, A; METZGER, J.P; CASATTI, L; NALON, M.A; MENEZES, N; IVANAUSKA, N.M; BOLZANI, V; BONONI, V. L. R. **Diretrizes para conservação e restauração da biodiversidade no Estado de São Paulo.** Governo do Estado de São Paulo, São Paulo: 238p, 2008.

APPENDIX A

Details for corridor generation (item 2.2 in Material and Methods Section)

a) Corridors with fixed width

To define the corridors generate a new map with the intersections of each buffered patch. From these intersections generate points that are half way between each two fragments separated by one another no more than 200m, which means these points are no further than 100m from each patch. Give each point an ID and make a buffer of 110 meters making sure that all the generated circles intersected at least two forest patches. Again isolate the intersections and generate points from each of them. Each couple (or group) of points generated from the intersection of the same circle with the neighbouring patches will carry the same Point ID. Lines are created linking these points with same ID, and from now on any width of corridor can be created by buffering these lines by half the desired width. Since we decided on having 30 wide corridors in the case study, we carried 15m buffer in each line. Intersections of corridors and patches must be erased, and added the following attributes to each corridor: Corridor unique ID (PID_CO0030), area (AHA_CO0030), IDs of the two patches it connects (PID_CL0000 and PID_CL00_1), sum of the areas of these two patches (ACL_CL0000), ID of the clump it was part of (PID_CL0200), and area of this clump (ACL_CL0200). At last, when more than one corridor is generated between same patches, erase the largest one.

(b) Enhanced connections

Buffer the vegetation whatever size larger than 2/3 of the clump fragments maximum distance dissolving by the PID of the clump adopted. The next step is making a negative buffer at least one meter larger than the buffer. After several trials we noticed that if a buffer is at least 2/3 the maximum distance between the fragments we want to connect, the important connections will not the omitted after the negative buffer, and most all of the thin ones (which connect thin "strip parts" of fragments will). Additionally, when the negative buffer is a minimum size larger than the buffer, fewer artifacts appear around the fragments. Here we define as artifacts all the polygons created in the process that are not corridors. The next step is to erase the "buffered-inbuffered" layer with the vegetation map, which will result in a layer with the corridors and artifacts filling the irregular vegetation polygons. We used a buffer of 130m and a negative buffer of 140m for the case study. After a Spatial Join (join one to one) with the vegetation layer, erase all the artifacts and keep the corridors only. The attributes created for these corridors are: unique ID (PID_EN0130), area (AHA_BU0100), IDs of two patches it connects (PID_CL0000 and PID_CL00_1) – it might connect more than one, number of patches it connects (CNT_Frags), ID of the clump it was part of (PID_CL0200), and clumps areas (ACL_CL0200).

c) Enlarge forest patches

Buffer the vegetation map, then apply a negative buffer the same size or larger; erase vegetation and use the transformation Multipart to Singlepart Features. This processing might need some testing by the user since larger buffers and smaller negative buffers will create larger increments. For our case study, 200m buffer and 201m negative buffer allowed us have satisfactory results. Finally append to each feature its ID (PID_EN0200) and area (AHA_EN0200), ID of the adjacent fragment (PID_CL0000) and area (AHA_CL0000).

d) Resilience zones

(a) Identifying source-areas

In our case study, we assumed that patches larger than 1000 ha are better to maintain the maximum biodiversity and should be considered as "source-areas" of propagules and of fauna species, but other source-areas sizes might be necessary at different sites.

(b) Generating Resilience Zones

Within the Brazilian Tropical Forest vegetation propagules can easily reach 50 m from source areas within the landscapes (e.g. Haugaasen *et al* 2011; Boscollo *et al* 2008). Thus, we set a 50 m buffer (resilience zone) from the source areas that will be beneficiated by the presence of resources from these forest patches which favour regeneration if no agriculture or pasture management occurs. However we acknowledge that depending on the species, process or site analysed the buffer width might vary.

e) Corridor Permanent Preservation Areas

(1) Extracting corridor PPAs

The PPAs layer had been merged with the vegetation layer and the resultant map converted to a raster grid, with 10m resolution. We used GUIDOS 1.3 software (Joint Research Center – European Commission 2011) to identify the corridors which connect two or more habitat patches. An 3 pixel edge were setup in GUIDOS to individualize each corridors.

APPENDIX B

Table B.1 Area of the subwatersheds in the study area (*The Atlantic Plateau of São Paulo Region*) and amount of vegetation present in each one. Information of the *Guapiara Basin* are on line of ID 56.

SUBWATERSHEDS			**VEGETATION**	
ID	**Area (ha)**	**% of the study area**	**Area (ha)**	**% of the subwatershed**
1	4977,05	0,08	2705,25	54,35
2	3261,56	0,05	2998,70	91,94
3	3613,96	0,06	1180,06	32,65
4	93197,91	1,53	84326,42	90,48
5	6138,64	0,10	1930,56	31,45
6	37655,17	0,62	27255,59	72,38
7	66812,35	1,10	43484,55	65,08
8	57685,37	0,95	37344,68	64,74
9	13624,93	0,22	10146,63	74,47
10	4390,28	0,07	3361,82	76,57
11	10984,47	0,18	6705,31	61,04
12	40353,92	0,66	20828,94	51,62
13	2621,98	0,04	755,77	28,82
14	8469,02	0,14	4779,85	56,44
15	15525,10	0,25	10349,93	66,67
16	5318,88	0,09	2988,15	56,18
17	17472,17	0,29	10200,96	58,38
18	16465,31	0,27	12352,42	75,02
19	18928,10	0,31	6247,19	33,00
20	26259,08	0,43	17657,43	67,24
21	18293,14	0,30	8323,87	45,50
22	12650,08	0,21	6651,84	52,58
23	13521,86	0,22	6482,31	47,94
24	13568,61	0,22	5456,94	40,22
25	9771,87	0,16	4940,40	50,56
26	4706,33	0,08	2693,25	57,23
27	26588,62	0,44	22910,34	86,17
28	7472,20	0,12	3189,20	42,68
29	4384,36	0,07	1017,39	23,20
30	60364,28	0,99	23314,51	38,62
31	17125,09	0,28	12694,90	74,13
32	5224,99	0,09	2986,02	57,15
33	119990,05	1,97	97159,99	80,97
34	43002,63	0,70	24805,91	57,68

35	58310,49	0,96	50297,89	86,26
36	9562,63	0,16	3972,32	41,54
37	44260,20	0,73	8467,42	19,13
38	70503,78	1,16	60441,59	85,73
39	69822,70	1,14	16609,18	23,79
40	38730,64	0,63	38520,80	99,46
41	56199,23	0,92	54537,05	97,04
42	14390,43	0,24	10118,70	70,32
43	37722,14	0,62	30558,49	81,01
44	28415,67	0,47	20117,70	70,80
45	4054,27	0,07	147,09	3,63
46	33046,01	0,54	28380,29	85,88
47	16510,19	0,27	5106,39	30,93
48	177784,40	2,91	141532,03	79,61
49	46697,35	0,77	41788,58	89,49
50	19664,78	0,32	6046,67	30,75
51	66237,27	1,09	59610,19	89,99
52	95443,23	1,56	86065,96	90,18
53	108490,04	1,78	23865,75	22,00
54	33764,22	0,55	29800,21	88,26
55	147149,12	2,41	66361,04	45,10
56	149878,32	2,46	46397,44	30,96
57	57750,36	0,95	40954,73	70,92
58	184411,49	3,02	156847,58	85,05
59	61749,94	1,01	23497,96	38,05
60	58100,59	0,95	16319,21	28,09
61	160573,67	2,63	58184,24	36,24
62	103786,44	1,70	30182,60	29,08
63	57623,89	0,94	18054,43	31,33
64	31606,78	0,52	5304,72	16,78
65	270667,73	4,44	52096,88	19,25
66	247977,62	4,06	198271,87	79,96
67	137468,41	2,25	54251,66	39,46
68	165022,51	2,70	19626,95	11,89
69	81924,11	1,34	23216,12	28,34
70	98237,34	1,61	32911,88	33,50
71	92406,54	1,51	17202,73	18,62
72	14260,69	0,23	10213,05	71,62
73	30896,43	0,51	1973,52	6,39
74	11152,62	0,18	6496,08	58,25
75	175692,90	2,88	45405,55	25,84
76	273844,36	4,49	49751,49	18,17
77	34206,77	0,56	23448,34	68,55
78	257818,72	4,23	41014,91	15,91
79	38833,56	0,64	13383,50	34,46
80	20114,27	0,33	9219,43	45,84
81	120085,87	1,97	10973,03	9,14
82	4127,84	0,07	1082,71	26,23

83	78093,54	1,28	6289,15	8,05
84	632296,62	10,36	121447,17	19,21
85	114889,48	1,88	10565,13	9,20
86	30401,74	0,50	4600,69	15,13
87	26095,37	0,43	2630,26	10,08
88	70432,89	1,15	8702,98	12,36
89	219538,33	3,60	26626,90	12,13
90	2405,01	0,04	2373,58	98,69