Biodiversity and land use systems in the fragmented Mata Atlântica of Rio de Janeiro

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PREFACE

The contributions of this volume are based on the research project BLUMEN (‘Biodiversity in integrated land use management for economic and natural system stability in the Mata Atlântica of Rio de Janeiro’). Its aim is the interdisciplinary analysis of different land use systems in the remnant forest fragments of the Brazilian Atlantic forest in the region of Rio de Janeiro state. Within this project, the ecosystem’s exceptional biodiversity is treated as an *explanandum* and research is directed towards the investigation of the importance of biodiversity for the stability of the entire ecosystem, with special focus on the impact of land use systems. Thereby, prerequisites for the application of sustainable land use systems in the survey area were identified. However, the scientific foundation for the question as to whether and how humid ecosystems can be utilised sustainably is still lacking. Therefore, an interdisciplinary approach is needed to explain the complex human-technology-environmental systems. This approach set the objectives of the BLUMEN project (2002-2006), which was carried out by the following institutions under the coordination of ITT: University of Bonn, University of Leipzig, Federal University of the State of Rio de Janeiro, Federal Rural University of Rio de Janeiro, Federal University of São Carlos, Foundation Institute Osvaldo Cruz, and National Institute of Technology of Brazil.

One essential goal of this project was the assessment of biodiversity in remnant forest fragments within the study area. This assessment builds the basis to identify relevant attributes of the fragments, such as resilience, connectivity, and successional stage. A second important goal was the assessment of land use change under current conditions at different locations within the study area. A further goal was the identification of direct and external effects of land use systems. Therefore, new methods for rapid assessment of ecological potentials of different vegetation and landscape types, such as 'ecovolume' and 'agroclimax', had to be found. Based on these results, scenarios of different land use systems dynamics were developed. These were included into a regional integrative and ecological-economical modelling approach to determine and predict adequate controlling measures for varying conditions. Thus, the principal aim was the merging of biodiversity and land use systems research and combining all findings into the development of a concept for sustainable land use, which on one hand considers local culture and production systems and on the other hand meets future requirements.

Due to the emigration of the Brazilian partners to a different federal state, the project was terminated after the first project phase. Although the complex interdisciplinary research questions could not be fully answered, several studies were finished and will be presented in this volume. A serious loss for the project was the death of our colleague Prof. Dr. Morawetz, Professor of Systematic Botany at the University of Leipzig. Together with his colleagues, Prof. Dr. Morawetz was responsible for a considerable part of the project's success. Prof. Dr. Morawetz, with his indispensable knowledge of the Neotropical flora in combination with his classical education and his appreciation of interdisciplinarity in scientific research, inspired fruitful discussion within the team. His death cast a shadow on the project, still, the conviction to continue with BLUMEN project was not compromised.

In spite of the termination of the project, the long-term objectives of the project remain essential and the German researchers found new partners to realise the required research. The BMBF supports the follow-up project entitled ‘Climate change, landscape dynamics, land use, and natural resources in the Atlantic Forest of Rio de Janeiro’ (DINARIO). Exceeding the goals of BLUMEN project, DINARIO explores the impact of further factors such as climate change, migration, global market and tourism dynamics on the region. Based on dynamics and on current mitigation processes of different land use systems, scenarios will be developed to determine and predict controlling measures for various conditions found within the study area. Controlling measures will be identified by the development of a regional, integrated modelling approach. A new partner, who will combine all disciplines represented in the project, was recruited for the integrated modelling: the Institute of Geoinformatics of the Friedrich-Schiller-University Jena. The project's survey areas will differ from BLUMEN project's area and their selection is bound to landscape units, for land use systems as well as for forest fragments. Biodiversity within forest fragments is explored with the main focus being on the role of biodiversity for the entire system.

The reduction of biodiversity loss is a main issue of the seventh ‘Millennium Development Goal’ (MDG). The MDGs were issued by the UN member states in 2001, and the inclusion of biodiversity into the MDGs highlights the importance of the ‘Convention on Biological Diversity 1992’ and further clarifies the connection between species protection and development. Biodiversity, or biological diversity, decreases by anthropogenic impacts: the growing world population must be fed and needs agrarian raw materials. Ecosystems, subject to their sensitivity, suffer by overexploitation and by utilisation, which is not adapted to the specific sites. Regrettably, land use competes with natural forests and climax vegetation, in particular in tropical and subtropical countries, because population growth imposes high pressure on land resources.

For all ecosystems, such development induces growing pressures, even in regions that were deemed marginal in the context of land use, in particular mountainous regions. The discrepancy between land use and fragile ecosystems becomes more apparent, the warmer and wetter the ecosystems are and the faster the biological processes can take place (in the humid tropics, these processes proceed ca. 100 times faster than in the temperate zones). Therefore, tropical rainforests are recognised as especially endangered ecosystems. Humid woodlands are ecosystems of exceptional biodiversity, which were displaced by deforestation and converted into land use systems. The legitimate demands for income of the farmers led to market-orientated production systems with increasing productivity (and therefore value) and in parallel, with increasing risk for extant forest fragments. But the importance of these fragments is increasing too, because the value of the stabilising functions of ecosystems, or ecosystem services, are coming more and more into focus. Such ecosystem services are biodiversity, water balance, air filtration, and aesthetic services, such as the value of recreation areas. Taken together, the sustainability of ecosystems includes various aspects. The essential question, which is still pending scientific examination, is whether ecosystems in the humid mountainous regions are useable in a sustainable way, without destroying the natural resources and associated ecosystem services.

In the years between 2000 and 2005, the estimated annual net deforestation amounted to ca. 7.3 millon ha. However, forests harbour about 80% of terrestrial biodiversity. More than 1.6 billion people (thereof one billion poor people according to UN-statistics 2007) are dependent on forests and their produce for their sustenance. Another three billion people are dependent on marine biodiversity. Biodiversity is - and has always been - an invaluable reservoir for use by humans. With increasing mechanisation of agriculture, land use is being concentrated on fewer and fewer plant and animal species. For millennia, more than 7,000 plant species have been cultivated, but today only about 150 crop species remain. Of these, ten to twelve are predominantly used, hence agrobiodiversity, in parallel to biodiversity, has experienced an enormous loss over the last decades, too.

The demand for environmental goods implies high income elasticity, i.e. there is a positive correlation between the protection of resources and economic development. Accordingly, integrated research projects with the aim of implementation of the project's findings in the long run, are important for the future of the region. All the more, if regionally and locally acting stakeholders (farmers, residents, government employees, regional administration staff, etc.) are integrated into the project. Ultimately, the overall aim of a site-adapted, sustainable and environmentally suitable use of natural resources implies the reconcilability of maintaining or restoring abiotic and biotic fundamentals of ecosystems with economically driven land use systems.

Hartmut Gaese

PART I

Introduction

CHAPTER 1

THE DYNAMIC OF THE MATA ATLÂNTICA

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Abstract: Ongoing deforestation causing fragmentation and habitat loss is a typical phenomenon occurring in all tropical forests around the globe. For the originally contiguously forested Brazilian Atlantic coast, fragmentation and habitat loss are particularly serious due to the long settlement history and to the current high population density. This leads to continuing overexploitation of natural resources, not only in the form of further deforestation, but also erosion of biodiversity, degradation of soil and water quality, water shortage and elevated levels of greenhouse gas emissions. Today, deforestation in the Atlantic forest is mainly caused by the conversion of forest into agricultural land, resulting in further intensification of the already shattered mosaic of forest fragments and matrix areas. Different land use systems in these matrix areas, depending on their sustainability, imply varying potentials to act as benefiting matrix area connecting forest fragments. A concept for biodiversity conservation in such a mosaic landscape cannot solely rely on the protection of single areas of biodiversity, but has to integrate all aspects of the complex human-ecological system, to safeguard biodiversity in accordance with the well-being of local human communities. A

promising approach is the establishment of ecological corridors, which includes matrix areas and forest fragments to improve connectivity of entire regions. For the success of these corridors, the shift towards sustainable land use systems in matrix areas is essential, both for the conservation of biodiversity and for profitable long-term land use. However, implementation of such comprehensive concepts is difficult and necessitates further interdisciplinary and transdisciplinary research combining expertise of all fields related to human-ecological systems.

Introduction

The Atlantic Forest, or Mata Atlântica, is one of the world's most outstanding and most threatened ecosystems (Myers 1990, Myers et al. 2000, Mittermeier et al. 2004, 2005). On the one hand, it hosts an enormous structural, floristic and faunal diversity comprising a high degree of endemism at all levels of organism organisation (e.g. Fonseca 1985, Fonseca et al. 1999, 2004, Kinzey 1981, Morawetz & Krügel 1997, Morawetz & Raedig 2007, Mori et al. 1981, Prance 1987). On the other hand, its destruction since the beginning of the colonisation of South America has led to a dramatic reduction and fragmentation of the ecosystem (e.g. Bertoni et al. 1988, Dean 1996, Leitão Filho 1987). Between the five South American biodiversity hotspots, the Atlantic Forest is the most densely populated one and comprises the one of the smallest portions of protected areas (Mittermeier et al. 2004). Today some of the biggest Brazilian urban agglomerations and agricultural landscapes with different land use types are embedded in the area once almost continuously covered by the Mata Atlântica.

The reduction and fragmentation of natural ecosystems by anthropogenic impacts have elevated the rate of species extinction by thousand times the natural background rate (Pimm et al. 1995). But also physical and chemical qualities of landscapes are affected by the destruction and fragmentation of natural habitats and unsustainable land use practices. Soil erosion and landslides certainly are natural processes, but they are intensified by man-made degradations (e.g. Augustin 2001, Coelho Netto 2003, Figueiredo & Guerra 2001). Other parameters affected by anthropogenic landscape transformations are soil and air quality as well as surface and groundwater availability and quality. In turn, negative effects of man-made habitat destruction impair the productivity of land use systems. In spite of this, the importance of ecosystem services is not sufficiently recognised and appreciated by society (Tonhasca Jr. 2005).

Accelerated anthropogenic climate change will undoubtedly magnify the effects of habitat destruction and fragmentation (Thomas et al. 2004). Its specific effects on biodiversity have yet to be assessed for most of the biodiversity hotspots (Midgley et al. 2002). In general, ongoing climate change affects the vulnerability of ecosystems and land use systems on economic, social and environmental levels (e.g. Felgentreff & Glade 2007, Parmesan & Yohe 2003, Rahmstorf & Schellnhuber 2007). Therefore, the evaluation of related risk and resilience potentials considering climate change scenarios is indispensable for development concepts, strategies and instruments for sustainable natural and agricultural resources management and conservation. One of the most crucial questions in this context is how the vulnerability and resilience of eco- and land use systems vary in response to changes in human-environmental interactions (interactions between ecosystem and economic, political and social factors and processes) caused by climate change.

There is an ongoing public and political debate over climate change. In the context of the intensive public and political attention paid to the climate change problem, it has to be emphasised that a reflection of climate change detached from other social, ecological and economic problems cannot achieve success. Climate mitigation and adaptation measures are not per se socially and/or ecologically suitable. Therefore, these measures and strategies have to meet the demands of the sustainability concept. This implicates the need for interdisciplinary and integrated approaches in assessment, data management, modelling and planning. Additionally, it is necessary to consider spatial and temporal dynamics and interrelationships between the different elements and units of the systems, regions or landscapes to be assessed, modelled and planned. As different elements present different dynamics, individual interrelationships differ in their spatial and temporal dimensions. Thus all approaches have to be multi-scalar and versatile.

The highly fragmented and intensively used landscape of the Mata Atlântica represents an outstanding challenge of modern nature conservation, land and resource use planning and management. The proposed project is designed to face these challenges and to meet the demands for a sustainable, climate efficient rural development in this threatened ecosystem.

Biodiversity and landscape fragmentation

The Brazilian Mata Atlântica is a unique series of South American rainforest ecosystems. The Atlantic Forest has been considered one of the world's biodiversity hotspots ever since Myers (1990) first selected 18 priority regions for the conservation of vascular plants. The ecosystem presents not only a very diverse flora, but also an elevated number of endemic plants. More than 8,000 of an estimated 20,000 species of plants (40%) are thought to be endemic (Brooks et al. 2002, Fonseca et al. 2004, Mittermeier et al. 2004, 2005). Especially tree species show an exceptionally high degree of endemism. The estimates for this ecological group vary from 53% (Mori et al. 1981) to about 70 % (Gentry 1992). However, also other plant groups, such as Bromeliaceae (Smith 1955), ferns (Tryon & Tryon 1982) and bamboos (Soderstrom et al. 1988), present high percentages of species that are restricted to the region. Since Myers' analysis (1990), several databases and estimates about the diversity and endemism rates of different animal groups have been published (e.g. Brown & Freitas 2000, Duellman 1999, Fonseca et al. 1999, Stotz et al. 1996, Sazima 2001, Sazima et al. 2001) and have corroborated the inclusion of the Mata Atlântica in the list of the 34 biodiversity hotspots (Brooks et al. 2002, Myers et al. 2000, Mittermeier et al. 2004, 2005).

The high biodiversity and endemism rates found in the Atlantic Forest can be explained at least partly by historical vegetation dynamics and the related speciation processes as well as by the latitudinal, altitudinal and continentality gradients and the resulting environmental diversity (Almeida 2000, Prance 1989, Thomas et al. 1998, Tonhasca Jr. 2005). On a large scale, different vegetation formations can be recognized and were classified along these gradients (e.g. Joly et al. 1991, Lombardi & Gonçalves 2000, Morellato & Haddad 2000, Oliveira-Filho & Fontes 2000, Rambaldi et al. 2003, Rizzini 1954, Scarano 2002, Veloso et al. 1991, Viana et al. 1997). Several studies from other ecosystems demonstrate that small scale environmental heterogeneity influences the diversity and species composition patterns. This may allow distinguishing different vegetation types within large scale formations (e.g. Dempewolf 2000, Paulsch 2001, Tuomisto et al. 1995, 2002, 2003, Tuomisto & Ruokolainen 2005, Vormisto et al. 2000, Wesenberg et al. 2001). In the Atlantic Forest, small scale floristic differentiation is poorly studied for most of the vegetation formations and was part of the investigations realised in the BLUMEN project (Engelmann 2005, Engelmann et al. 2006, Seele 2005, Seele et al. 2006, Wesenberg et al. in prep.).

Due to the exploration and deforestation of the Atlantic Forest during the last centuries (Almeida 2000, Dean 1996), its forest area is reduced to 5-12% (depending on definition of its inland borders) of its original extent today (Lombardi & Gonçalves 2000, Mittermeier et al. 2004, 2005, Morellato & Haddad 2000, Oliveira-Filho & Fontes 2000, Ranta et al. 1998, Saatchi et al. 2001, Scarano 2002, Viana & Tabanez 1996). The biggest part of this remaining forest consists of comparably small and only partially protected fragments (Lima & Capobianco 1997, Gascon et al. 2000).

The fragmentation of landscapes has severe effects on the function of ecosystems. Habitat reduction, for instance, results in local species loss (Pitman et al. 2002, Silva & Tabarelli 2000, Stratford & Stouffer 1999, Williams-Linera et al. 1998). Furthermore, vegetation structure and dynamics can change due to promotion of invasive species and/or limitation of the regenerative capacity of many species (Benitez-Malvido 1998, Kapos et al. 1997, Laurance 1991, Laurance et al. 1998a, 1998b, 2000, Lovejoy et al. 1986, Tabarelli et al. 1999, Timmins & Williams 1991). The latter is mainly caused by shrinking populations of forest species and splitting of formerly connected populations, respectively. This type of habitat fragmentation also causes interruptions of migration routes for animals. As a consequence, this leads to interruptions of pathways and vectors for pollen and seed dispersal and hence to genetic exchange restrictions (Benitez-Malvido 1998, Hamilton 1999). In addition, former inner forest areas are transformed to more or less exposed forest edges. Consequently, this so-called ‘edge effect’ is of increasing ecological importance. Several gradients in microclimate, floristic composition or biological interactions can be observed between the edge and interior of the forest fragments (Foggo et al. 2001, Galetti et al. 2003, Kapos 1989, Laurance 1991, Murcia 1995, Stevens & Husband 1998, Young & Mitchell 1994). All these effects of fragmentation lead to a progressive erosion of biological diversity (Pimm et al. 1995, Terborgh & Winter 1980, Tilman et al. 1994, Wilson 1988). Consequently, several Atlantic Forest species from different taxonomic groups are considered to be threatened with extinction nowadays, mainly because of their endemism and habitat degradation (e.g. Bergallo et al. 1999, Brooks & Rylands 2003, Câmara 1983, Fonseca et al. 1994, Ibama 1992, Stattersfield et al. 1998). According to the summarising results of Brooks et al. (2002), the percentage of critically endangered species in different groups vary from at least 1% (plants) up to about 10% (mammals, birds). However, since the current distribution patterns of many species in the Mata Atlânatica are only insufficiently known, these numbers could be much higher.

The destruction and fragmentation of the natural habitats and accelerated species extinction are coupled to several direct and indirect negative consequences for the human population. Flora and fauna provide a great variety of primary resources (e.g. Capobianco 2001, Dean 1996, Tanizaki-Fonseca & Moulton 2000, Jacobs 1988, Kunin & Lawton 1996, Simões & Lino 2002, McNeely et al. 1990, Myers 1988, Prance 1998, Whitmore 1998). The major part of the natural resources that sustained the Brazilian economy during the last 500 years came from the Atlantic Forest (Almeida 2000). However, their overexploitation and habitat destruction do not only affect their actual availability. By destroying this vast genetic storehouse (Myers 1983), we are also eliminating future resource-use options. Furthermore, degradation is prejudicial to the great number of free services provided by ecosystems, such as climate and water regulation, soil formation and protection, nutrient cycling, flood and erosion protection, biological pest and disease control, pollination and recreation. Their intrinsic economic values often exceed the value of the direct use of biological resources many times (e.g. Balmford et al. 2002, Costanza et al. 1997, Ehrlich & Ehrlich 1981, Heal 2000, Ricketts et al. 2004, Tonhasca Jr. 2005). Last, but not least, nature is an integral part of the fabric of all human cultures (Wilson 1984, Wilson & Kellert 1993). Idealistic values can be attributed to nature that represent non-utilitarian reasons for biodiversity and ecosystem conservation (e.g. Dearden 1995, Janzen 1988).

Central issues to counteract the ongoing isolation of forest remnants are the protection of existing corridors and the preservation of natural connective attributes of the landscape matrix. Instruments to reduce isolation and negative effects of landscape fragmentation are reforestations and the establishment of ecological corridors (e.g. Castro & Fernandez 2004, Hilty et al. 2006, Laurance 2004, Laurance & Laurance 1999). These enlarge forest habitats, increase habitat connectivity and reduce edge effects as well as ameliorate physical characteristics of the landscape such as soil quality and water balance. Furthermore, growing forest being important CO_2 sinks are relevant factors in the context of global climate change. In a biodiversity hotspot such as the Mata Atlântica, it is desirable to promote the use of native species for reforestation and moreover to select adequate species for each specific habitat to be restored (Almeida 2000, Reis et al. 1999). This requires a profound knowledge of the regional habitat variability and the related floristic composition and vegetation dynamics (especially of successional processes) as well as of the autecological characteristics of the species. Yet not only ecological criterions are important. Since most of the land in the Mata Atlântica is private property and the income of the farmers depends on agricultural production, disregarding socio-economical aspects will lead to a failure of all conservation and restoration efforts. Therefore reforestations and the establishment of silvopastoral and agroforestry systems, which open alternative income sources, can be successful concepts to bring together the ecological and socio-economical interest (Almeida 2000, Harvey & Haber 1998, Leakey 1999). In this context, native species with economic value (e.g. medical plants, ornamentals, fruit plants, fibre plants) deserve particular attention in the selection of species to be used in reforestations.

Once chosen as adequate species, the selection of suitable seeds for sapling production is another ecologically and economically important aspect. One of the negative effects of the genetic isolation of fragmentised populations is the possible minor fitness of the propagules (e.g. Koenig & Ashley 2003, Smouse & Sork 2004). Therefore, the origin and characteristics of seed are relevant factors for the success of reproduction and sapling production (e.g. Chacón & Bustamante 2001, Cordazzo 2002, Navarro & Guitián 2003).

Agriculture and biodiversity

Until recently, agricultural land was not regarded as important for biodiversity conservation and conservation activities almost entirely focused on the protection of natural areas. However, an appreciation of the importance of farming activities for biodiversity is emerging (Feehan 2001). Agro-biodiversity or the diversity of cropping systems, crop species and farm management practices has received increasing attention in recent years as a way of spreading risk and supporting food security in resource-poor farming systems (Tengberg et al. 1998). On-farm conservation is a special form of in situ conservation based on the groundwork of traditional farming and gardening methods (Hammer 2004). Management practices that increase the spatial and temporal diversity within fields can enhance production and reduce the environmental impacts of crop production (Bezdicek & Granatsteis 1989, George 1971, Kort 1988, Olson 1995, Pohlan 2002).

The effects of agriculture on biodiversity are of considerable importance because farming is the human activity that occupies the largest share of the total land area in the Mata Atlântica. Even for some regions where the share of agriculture in total land area is smaller, agriculture can contribute to biodiversity conservation by increasing the diversity of habitat types. The expansion of agricultural production and intensive use of inputs over recent decades in the Mata Atlântica Region are considered major contributors to the loss of biodiversity. At the same time, certain agricultural ecosystems create conditions to favour species-rich communities and thus serve to maintain biodiversity. These systems might be endangered if altered to a different land use, such as agroforestry. Agricultural food and fibre production is also dependent on many biological services. These include the provision of genes for development of improved crop varieties and livestock breed, crop pollination and soil fertility provided by micro-organisms (Parris 2001).

First research results in the study area in the municipality of Teresópolis show that favourable economic, geographical and environmental conditions for agriculture increase crop monoculture systems, which dominate the landscape (Torrico 2006). Crop land and cattle range land compete with preservation and reforestation strategies. The degradation of land is a average feature of the municipality. It is evident that in the last 50 years water discharge has decreased to 50 %, due to deforestation and loss of many small springs (1/6 in this survey) (Torrico et al. 2006). Ecological farming systems, such as agroforestry and silvopastoral systems, as well as the cultivation of perennial crops contribute to reduce this pressure on fragments and deforested areas (Torrico 2006). These systems play a key role in linking and buffering fragments and in improving both agro-diversity and biodiversity in the Atlantic rainforest (Torrico et al. 2005). Furthermore, ecological farming systems present the largest value of sustainability in ecological terms and pose the capacity to produce and to save great quantities of biomass in the system. In addition, ecological farming systems need fewer economical resources and more natural renewable resources, which eventually guarantee its sustainability (Torrico 2006).

Obstacles and requirements for conservation

A fundamental goal of modern nature conservation is the preservation of biological diversity. In this context the fragmented landscape of the Mata Atlântica represents an outstanding challenge for modern nature conservation management. A major obstacle to effective conservation is insufficient knowledge of ecosystems, their elements as well as their dynamics.

In the fragmented Mata Atlântica, the remaining natural habitats, which are mostly forest fragments, often differ in terms of species composition, diversity and structure. Thus, the results of our investigation in the Mata Atlântica of Rio de Janeiro showed that selected forest fragments were floristically dissimilar, although they were located in spatial proximity (Thier 2006). On the one hand, these differences are caused by the natural environmental variability of the landscape. Yet on the other hand, they are also the result of anthropogenic influences. They reflect the historical and actual land use intensity in the fragments and their surroundings (which influences the disturbance and succession processes), the spatial arrangement of landscape units and the connectivity of the forest remnants.

A basic precondition for the modelling of development scenarios and for planning and executing effective and sustainable conservation activities is profound knowledge of the species and the structural diversity of a landscape, both current status as well as historical development. This also includes knowledge about environmental, spatial and anthropogenic causes. Furthermore, it requires the analysis of structural and functional characteristics of landscape connectivity and limiting factors at different spatial scales. For this reason, only an integrated and multidisciplinary approach at landscape scales, taking into account the mentioned factors can lead to reasonable results. This implies cross-linking classical methods of ecological analysis with methods of landscape ecology. So far, such integrated studies have been rarely practiced in the Mata Atlântica (Almeida 2000).

Because of the elevated species richness and the complexity of tropical ecosystems, census investigations in these regions are very costly, both in terms of labour and time. Therefore, a detailed investigation of all forest remnants within a large area is almost impossible. Considering the rapidly proceeding destruction of tropical forests and the associated loss of species (Brooks et al. 2002, Henderson et al. 1991, Pitman et al. 2002), there is an increasing need for the development of rapid and applicable methods to evaluate vegetation and its developmental potential. One methods introduced in recent years is the identification of indicator species (Frahm & Gradstein 1991, Kessler & Bach 1999, Tuomisto & Ruokolainen 1994, Tuomisto et al. 1995). Presence/absence data and abundance data of such indicator species are used to assess floristic and environmental associative patterns.

The inclusion of tree demographic and population data facilitates additional prognoses of developmental trends of the forest remnants (Odgen 1970, Thier 2006). One possibility for the rapid assessment of forest structural data is the use of optical instruments (Breda 2003, Brown et al. 2000, Cournac et al. 2002, Ferment et al. 2001, Leblanc et al. 2002, Whitmore et al. 1993). Such technical methods are suitable and useful to analyse the spatio-temporal variability and heterogeneity of comparable, large forest areas (Dignan & Bren 2003, Frazer et al. 2000, Hale 2001, Halverson et al. 2003, Trichon et al. 1998). In addition, these methods yield rapid and exact structural data which allows for conclusions on light availability, microclimate, ecophysiological processes and natural forest regeneration (Chen et al. 1991, Fassnacht et al. 1994, Hubbell et al. 1999, Kuppers et al. 1996, Lieberman et al. 1995, Midgley et al. 1995, Sattler & Lindner 2006, Sattler et al. 2007, Stenberg et al. 1994, Whitmore et al. 1993). These large scale structural data are of exceptional value with regard to mainly short term and "snapshot" data, mostly presented from tropical rain forests (Trichon et. al. 1998, Wasseige et. al. 2003).

A better scientific understanding of ecosystem processes, dynamics, functions and vulnerabilities related to current and future environmental impacts are important objectives of conservation. Moreover, conservation efforts also have to focus on socio-economical and socio-cultural aspects. Especially ecosystems dominated by agricultural production such as the Mata Atlântica require the elaboration and the establishment of ecological and socio-economical sustainable land use systems. Important reasons for the unsustainable use of ecosystems are the immediate economic benefits for individuals who use the ecosystem and exploit natural resources. Any attempt to conserve biodiversity will be perceived as superfluous costs by those involved in the exploitation, both in terms of absent benefits and actual conservation costs (Groombridge & Jenkins 1996). Moreover, the sustainability of extractivism is prevented by factors such as price fluctuations, transport and storage difficulties, the seasonality of production and the insidious action of intermediaries (Prance 1997, Shanley et al. 2002). Additional obstacles are insufficient knowledge about the used species and the low value generally attributed to the biological resources (Klink 1996).

In this context, the assessment of indirect use values and non use values of ecosystems and their public appreciation remains a sensitive issue. (Müller 1997, Tonhasca Jr. 2005). According to estimates from Constanza et al. (1997), the global annual value of ecosystem services added up to 33 billions of dollars, which nearly equalled the global Gross Domestic Product of that time. Although some authors argue against the financial analysis of nature (Heal 2000), economical approaches of valuing ecosystems (e.g. Balmford et al. 2002, Constanza et al. 1997, Ehrlich & Ehrlich 1981) are important for conservation efforts, because they are based on the same utilitarian arguments that are used by the critics of conservation (Tonhasca Jr. 2005).

And finally, conservation is also hindered by the limited knowledge and understanding of ecosystems by their human inhabitants. According to Quintela (1996) more than 90% of the inhabitants of the Mata Atlântica region ignore their existence and importance. Neither laws nor international appreciation could preserve the Atlantic Forest, if Brazilian society does not respect the Mata Atlântica as their cultural, esthetical, biological and also economical heritage, which has to be used in a sustainable manner (Tonhasca Jr. 2005). Therefore, environmental education and sensitisation play important roles in the context of conservation efforts. For farmers, the forest fragments mainly represent their water sources and are considered as very less important for logging or supply of other by-products such as fruits or medicines (Torrico et al. 2006).

Potential of biodiversity conservation in agricultural landscapes

Conservation of biodiversity is particularly difficult when mosaic landscapes are dominated by agricultural use. Some agricultural systems contribute more to the degradation of natural ecosystems. In contrast, others positively contribute to the recuperation of degraded ecosystems. This is true for agroforestry systems, silvopastoral systems, ecological farming systems and related systems. (Laurance 2004, Schroth et al. 2004). These systems could play a role in helping to maintain higher levels of biodiversity in the forest fragments, both within and outside protected areas. Where landscapes have been denuded through inadequate land use or where degraded agricultural areas have been abandoned, revegetation in combination with agroforestry practices can promote biodiversity conservation (Schroth et al. 2004).

Agroforestry systems, silvopastoral systems and ecological farming systems reduce the pressure on land that was deforested for agriculture. Such land still provides habitat and resources for partially forest-dependent native plant and animal species (Laurence 2004). In tropical land use mosaics, agroforestry elements positively influence ecological processes related to water and nutrient fluxes, microclimate, pest and disease dynamics, and the presence and dispersal of fauna and flora (Schroth et al. 2004, Thurston et al. 1999, Torquebiau 1992). The indirect value of agroforestry systems provides further environmental benefits, such as carbon sequestration, watershed maintenance, and buffering against climate change biome shifts. Besides this, nutrient cycling in adjacent natural forest systems is enhanced. Nutrients are kept in the system and quickly and efficiently recycled, whereas in agricultural systems, there is often a prevalence of high nutrient losses (Gascon et al. 2004).

Benefits from corridors are various. They facilitate faunal movements and plant dispersal (Bennet 1990, Forman & Deblinger 2000) and provide habitats for resident species of plants and animals (Laurance & Laurance 1999). They are important constraints for the spread of diseases, weeds, and undesirable species (Hess 1994) and contribute to the ecosystems resilience process and the increase of habitat quality (Henein & Merriam 1990).

Opportunities for conserving agro-biodiversity in situ could offer solutions to these concerns within regions that are marginal for agricultural production (Bardsley 2003, Smale et al. 2002).

Carbon in tropical systems

A significant part of greenhouse gas (GHG) emissions in tropical countries is caused by land conversion and high deforestations rates (Brown et al. 1996a). Tropical forest systems act as sinks for atmospheric CO_2 in form of large volumes of biomass per hectare (Lugo & Brown 1992). Land clearing often causes the burning of forest biomass and leads to net emissions of carbon dioxide and other GHGs (López & Galinato 2005).

Carbon sequestration is now a recognised forest management strategy with enormous economic implications, primarily due to the advent of "carbon credits." Carbon credits are awarded to entities ranging from companies to countries. It offers the possibility to trade C sinks established in the landscape in exchange for correspondingly large above-limit C emissions emitted somewhere else (Silver et al. 2000). At the moment, there is little information on carbon fluxes in tropical systems. For a more efficient trade, there is an urgent need for better estimates of the actual biomass of a vegetation system, including the herbaceous biomass as well as the small woody species with DBH smaller than 10 cm (Janssens et al. 2006).

Actual tropical land use has a significant impact on the global carbon cycle through increased rates of C emissions to the atmosphere and the loss of above- and belowground C accumulation and storage capacity. Current estimates suggest that approximately 1.6 (± 0.5) Pg (petagram = 1015 g) of C are lost annually from the conversion of tropical forests (Brown et al. 1996b). In their aboveground biomass, secondary forests accumulate approximately 94 Mg C ha-1 (30 years old and 20 m high) (Puig 2005). Tropical secondary forests have been reported to accumulate up to 5 Mg C ha-1 yr-1. During the first 10 to 15 years of regrowth, its sequestration capacity is estimated at 2 to 3.5 Mg C ha-1 yr-1 (Brown & Lugo 1990). Rates of above-ground C accumulation in plantations range from 0.8 to 15 Mg C ha-1 yr-1, during the first 26 years following establishment (Lugo 1988).

In Brazil, even eight years after reforestation, previous intensive pasture management resulted in lower soil C pools than sites that were less intensively used (Buschbacher et al. 1988). The effects of climate on soil C accumulation after reforestation are not well known. In mature tropical forests, soil C pools tend to decrease exponentially as the ratio of temperature to precipitation increases, corresponding to decreasing soil C pools along a gradient from dry to wet forests (Brown & Lugo 1982).

In total, tropical forests store approximately 206 Pg C in the soil (Eswaran et al. 1993). For the Mata Atlântica region, it was demonstrated that natural systems have a high potential to sequestrate carbon (Torrico & Janssens 2006). The mature forest of the National Park "Serra dos Órgãos" (Atlantic Forest), stores 272 Mg C ha-1 while the secondary forest fragments stores only 87.3 Mg C ha-1. The total dry phytomass in Corrego Sujo (53 km2) counts a stock of 386844 tons. The same area will produce annually 20478 tons dry matter representing 2.28E14 Joules. The forest fragments and the forest areas in regeneration accumulate more than 92% of biomass within the system. Horticulture can end up producing more phytomass (27.8 Mg C ha-1) (Torrico & Janssens 2009).

Carbon sequestration by forest systems is a finite process. Biomass eventually reaches a maximum sequestration potential and then no longer reduces the amount of CO_2 in the atmosphere. The required time period is not well known, but it has been suggested that such a limit is reached in the first 50-100 years following forest establishment (Silver et al. 2000).

Agricultural land needs to be considered a candidate for carbon trading in the future (Puig 2005). According to Schimel et al. (2001), there are several possible mechanisms for enhancing C uptake by agricultural systems: Regrowth on abandoned agricultural land, fire prevention, longer growing seasons and organic fertilisation by increased concentrations of carbon dioxide and nitrogen.

Development perspectives for sustainable agriculture

The World Commission on Forests and Sustainable Development (WCFSD 1999) has called attention to the global need to restore the functional integrity of nature. The Sustainability Impact Assessment of economic performance, environmental quality, and social conditions has become a central requirement for policy design. These three dimensions are inherently merged and subject to trade-offs. Quantification of trade-offs for policy decision support requires numerical models in order to systematically assess the interference between economic performance, environmental quality, and social conditions (Böhringer & Löschel 2006)

Agricultural systems are complex systems. None of their fundamental processes can be successfully addressed in isolation. Innovative and interdisciplinary research is needed for integration, verification and transformation of knowledge to the diverse areas of agricultural science to assure global access to sufficient food. This is the objective of agricultural science: Continuous re-examination and integration of knowledge about complex natural systems to balance food production with environmental constraints (Langensiepen et al. 2004).

The model of sustainable development, on which the international community agreed at the 1992 United Nations Conference on Environment and Development in Rio de Janeiro, aims at the reconciliation between the improvement of the economics and social living conditions and the long-term conservation of the natural resources. This is the only way to offer future generations suitable opportunities of development (Schulze-Weslarn 1997). The important related topics are (i) Policy and management; political discussion including economical, cultural and social issues, population control policy. (ii) Energy and inputs: energy resources, fertilizers, plant protection, ecological farming, science, research and technology. (iii) Genetic resources: identification, evaluation, and utilization of plant genetic resources. (iv) Climate: constrain and impacts. (v) Soil and water: resource and requirements (El Bassam 1998).

The conventional «one problem, one solution approach» is no longer adequate. It must be replaced by a system analysis that considers man as integral to the environment. The estimation of long-term economic performance and ecological sustainability of a given agricultural system requires careful consideration of origin and quality of energy and material inputs used to increase crop yields. This also includes economic and labour efficiencies. New accounting procedures are needed that consider production efficiency in its economic, ecological and social context. These contexts are not generally considered jointly in economic analyses of agricultural systems.

Agricultural land implies the option to act as potential carbon sink (Lal 1997). Agriculture can provide carbon sequestration services if management practices are altered to increase soil carbon (Antle & Capalbo 2003). This includes alternative agricultural tillage, crop rotations, livestock waste disposal, and other practices (Tweeten et al. 1998, 2000).

Furthermore, links between the agricultural sector and the Millennium Development Goals (MDGs) at household level have to be established. These links are (i) to ensure environmental sustainability. (ii) to assess whether agriculture practices are direct causes of or important immediate solutions to environmental degradation (direct link), and (iii) to foster more productive agricultural technologies and to aim at a withdrawal of agriculture from marginal, sensitive environments, to more profitable agricultural sectors, (iv) therefore to reduce migration to urban slums (indirect link), (v) to improve behaviour with nature. First, the agricultural sector is likely to cause more negative consequences for the environment than positive ones. Unprofitable agricultural systems tend to unsustainably consume environmental resources. Second, a declining environmental resource base erodes the foundation of the agricultural economy. Finally, (vi) an important additional requirement is the minimisation of negative environmental impact from agricultural investments, under participation of the human community into planning processes. This should also include a relatively equitable distribution of agricultural assets across the human population and the incorporation of environmental costs caused by agricultural production into economic assessments of production systems (MDGs 2006).

The importance of accounting for nature's services is gaining wide acceptance (Daily 1997, Holliday et al. 2002). It is taking shape with new methodologys, which take into account natural services, such as emergy or agro-climax, in evaluating and designing the agricultural production systems. This is necessary as the neoclassical economy does not have the capacity to overcome its deficiencies in measuring sustainability (Ulgiati & Brown 1998, Torrico 2006) and because of emerging global problems such as the loss of biodiversity and the energy crisis.

The agro-climax methodology combines methods of energy and emergy evaluation, systems analysis, agro-biodiversity, and socio-economic analysis. Agro-climax identifies tradeoffs and synergies from the agricultural systems on farms, at local as well as regional levels. This assessment allows decision makers to decide in favour of sustainable and profitable land use systems and to formulate policies that contribute to achieving the goals of sustainable agriculture.

Soil and water

For understanding of landscape evolution and development of future land use and conservation strategies in the Atlantic forest of Rio de Janeiro, the young Quaternary landscape history under changing climates and human impact are of outstanding importance. Scientific research in the Mata Atlântica and the Serra dos Órgãos has been carried out in different related fields. Soil sciences and geomorphologic research has focussed on landscape evolution as well as natural and man-made degradation processes, in particular soil erosion and landslides.

Older geomorphological works include King´s theory of pediplanation and the postulation of three main erosion cycles for Southeast Brazil (1956) and geomorphologic theories, which underline the importance of climate change for Quaternary landscape evolution in the tropics. Studies in Southeast Brazil by Ab´Saber (1956, 1964), Tricart (1960), Bigarella (1961, 1964), Bigarella & Becker

(1975), Bibus (1983) and Bork & Rohdenburg (1983) see the Quaternary climate change, with forested periods under warm and humid climate conditions and open grassland in drier (semi-arid to arid) periods, as the main reason for the stepped topography of Southeast Brazil as well as an important factor for soil formation. Pollen analyses from different locations (Barros 2003, Behling 1993, 1995, 2002, Behling & Lichte 1997, Ledru et al. 1998, Scheel-Ybert et al. 2003) confirm the change of the vegetation cover in the mountain ranges of the Serra do Mar and Serra da Mantiqueira during the late Pleistocene and Holocene.

Based on the works of Ab´Saber (1956, 1964) and Bigarella (1961, 1964), research on Brazilian geomorphology has drawn special attention to slope processes, which are of particular importance not only for the understanding of landscape evolution, but also for erosion prevention and land use planning. Meis et al. (1975), Meis & Machado (1978) and Meis & Moura (1984) carried out investigations in the valleys of the rivers Paraiba do Sul and Doce, where they identified three periods of high erosion rates in the Pleistocene and Holocene, and in contrast to that, periods of high stability. The term "rampa-complex" as the characteristic form of the South Brazilian crystalline, traces back to Meis´ works. Further investigations in that field were undertaken by Moura (1990) and Avelar & Coelho Netto (1992). In younger works, Dantas & Coelho Netto (1995) and Coelho Netto (1997, 1999) point out the human impact on landscape evolution and degradation in Southeast Brazil. They underline the influence of different degradation cycles, which are related to the historical land use, such as sugar cane and coffee plantations.

Many investigations published in the past years are related to soil erosion and landslides and particularly to the question of natural and man-made degradation or disasters. Some works focus on the development of gullies in Pleistocene depressions or depending on geological structures and hydrological conditions (Coelho Netto 2003, Coelho Netto & Fernandes 1990, Oliveira & Meis 1985, Oliveira et al. 1994), others on human impact (Augustin 2001) or on both, natural and human influence (Figueiredo & Guerra 2001, Peixoto et al. 1999). The importance of late Pleistocene landslides for landscape evolution is pointed out by Modenesi-Gauttieri (2000). In recent history, landslides are becoming a serious problem, leading to material damage and sometimes human loss. Investigations concerning risk potentials and modelling of landslides were carried out in the Tijuca massif in Rio de Janeiro by Coelho Netto et al. (1999), Cruz et al. (1999) and Fernandez et al. (2004).

In the field of soil sciences, a first soil map for the state of Rio de Janeiro was generated at a scale of 1,000,000 (Projeto Radambrasil 1983). In 2001, a new map was published at the scale of 1:500,000 (Projeto Rio de Janeiro 2001). Soil studies are rare and if carried out at all, mainly as part of geomorphologic investigations. In the Serra dos Órgãos, Nehren (2008) and Nehren & Heinrich (2007) ascertained that soils have been directly influenced by humans in most parts of the mountain range due to deforestation and land use intensification. Only on steep slopes in montane and high montane rainforests, untouched soils can be found. Furthermore, the degradation of landscapes and soils is strongly related to the type, intensity and duration of land use. While the coastal plains and lowlands have already been used by prehistoric and indigenous slash-and-burn agriculture and cultivated by European settlers since the 16th century, first settlements in the mountains date back to the late 18th century. Therefore, anthropogenic degradation there is relatively young and less severe as compared to the lowlands. Finally, Nehren (2008) stresses the interrelations between regional development, land use practices, deforestation and landscape degradation. This work can be seen as a basis for further investigations particularly in the field of landscape evolution and restoration purposes.

The ability to predict the future development of a landscape under continuation or change of land use practices requires general knowledge about soils. This knowledge comprises the characteristics of natural and anthropogenic soil evolution and the status quo of soil development in the study area. The evaluation of soil quality parameters enables the scientist to deduce and model consequences for geo-ecology. In return, recommendations can be made towards changes in land use practices under consideration of sustainability and global climate change. This is applicable for both on-site and off-site effects. This also forms the very link between soil science and the water supply of a landscape. Quantity and quality of both surface water and groundwater bodies are influenced by the land use pattern in a catchment. For instance, unsustainable land use is often associated with high surface runoff and water discharge high in suspended load and solubles (importance of DOC, dissolved organic carbon, in tropical environments). Therefore, to achieve sustainable improvement of water resources it is required to establish a land use management in the corresponding catchments.

A river system can be assumed to consist of compartments such as water column and sediment, pelagial, hyporheic and riparian zone, and flood plain (Reichert et al. 2001). There are processes that take place in different compartments as well as interaction between compartments. Compartments can contain substances such as algae, nitrogen, phosphorous, dissolved oxygen and carbon dioxide, which are transformed by various processes. These are divided into three groups (Chapman 1996): (i) physical and exchange processes such as convection, advection and sorption, (ii) biological processes and (iii) chemical processes. River water quality modelling takes these processes into account and simulates the changes in the substances according to input loads and system parameters.

Catchment water resources are determined by the hydrology of the catchment, which, in turn, is influenced by the land use practices within the catchment. It is equally true that land use is constrained by the available water resources. Therefore, it is important to be aware of the potential impacts on the hydrology of a catchment when formulating land use policies (Batchelor et al. 1998). Linking hydrological models with land use practices and their pressures on the environment supports the estimation of the likely impacts on the water bodies. This information can be fed back into the decision-making process and ultimately contribute to a better and more effective environmental policy.

The study area

The main research activities of the BLUMEN project were concentrated in the municipality of Teresópolis (latitude -22°24´43.2, longitude 42°67´), which has a total area of 849.6 km² (Appendix 1: Map 1 and Map 2). The basin where most of the studies were concentrated was Córrego Sujo (5323 ha), further subdivided into 86 "micro-basins" (Appendix 1: Map 3 and Map 4). Digitalization of the images "Iconos" enabled the land use divisions to be presented in Figure 1 and Appendix 1: Map 5).

In general the relief of the mountainous area is dominated by three components (Figure 2): the first are fragments of the Atlantic forest that extend into the higher parts or on steep slopes; the second are composed of hillside pastures where *Brachiaria* dominates, and in some cases covers complete hills; and the third encompasses agriculture in the river-beds. Many grass swards are actively regenerating and eventually develop into bush (*Capoeiras*). The most important land covers are described in the Table 1.

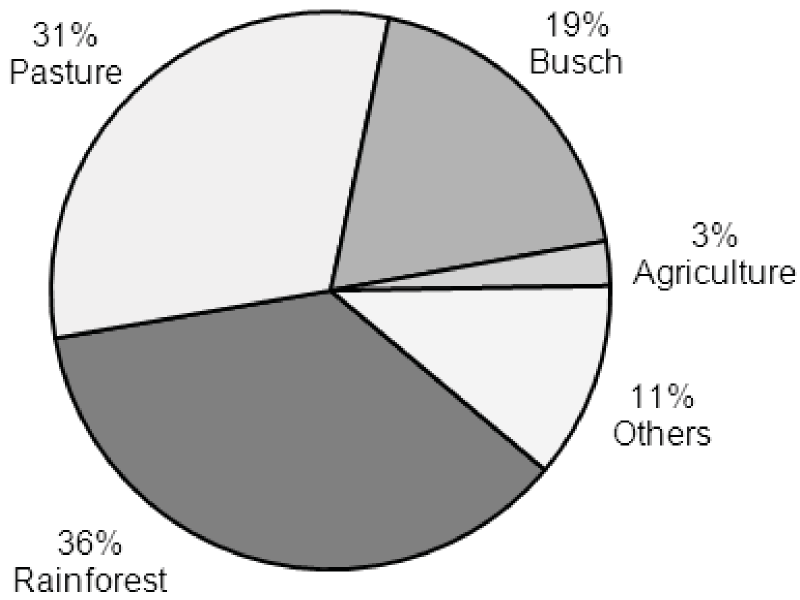

Figure 1. Share of different land use types for the Côrrego Sujo.

More than 80% of the establishments in Teresópolis have positive conditions for agricultural production, with enough manpower (three people per farm unit) to increase the cultivation area or to intensify production.

The property holding on average is 6.8 ha, where 66% of the proprietors have more than 17 ha and 54% less than 1 ha ("*mediators,*" i.e. landless workers sharing half of the harvest with the land owners). The production units with an agricultural speciality have on average 33% forest area, 22% horticultural cultivation, and 14% pasture.

(a)

(b)

(c)

(d)

Figure 2. Landscapes components in the study area. (a) General landscape overview of grass, fragments and crops; (b) mountainous relief; (c) intense horticultural production (d) pastures

Table 1. Land cover description.

Land Cover	Description
Developed forest	Presence of species older than 30 years, high presence of epiphytes and lianas, and the canopy is closed. This kind of vegetation cover is predominant in the national park and some fragments.
Forest of intermediate development	Semi-arboreal and bush species prevail; arboreal vegetation begins to show predominance, little presence of epiphytes. Mostly in the small fragments.
Forest in initial development	Lack of epiphytes, gramineous cover prevails, bushes and herbaceous plants can reach up to 4 meters high. In many abandoned pastures with more than 5 years in so far not burnt.
Grasses and bushes	Presence of clean areas with gramineous plants for sheep herding in some cases with thin bushes.
Agricultural	Horticulture predominates, also areas with citrus
Vegetation of waterlogged areas	*Typha domingensis* predominates; characteristic waterlogged land. Besides these conservation units and the National park, around 212 fragments which have an area average of 12.8 ha are observed in the region

The agriculture in the region is characterized by intensive, small (less than one ha) but often irrigated horticultural production systems. These horticultural systems have little or no interaction with the cattle and forest subsystem. Inputs such as organic and inorganic fertilizers are introduced to the system. Plants are produced in the region using good quality seed. Most of the young plantlets are produced locally in specialized nurseries. The products of the system are marketed through different channels, mostly dominated by middlemen who take the production to the surrounding markets. The productive units generally opt for diversification market strategies, since prices fluctuate throughout the whole year.

Out of 1793 ha under agricultural production, 74% (1327 ha) are devoted to cattle production and 2% to sylvopastoral systems. The average animal load is 11 animals pro 10 ha. Extreme values of 2 up to 67 animals pro 10 ha were found. In the humid season the average milk production is 7.5 l d^{-1}, and in the dry season, 4.5 l day^{-1}. After 40 months of fattening the meat livestock produces approximately 165 kg of clean meat/head that are marketed through middlemen and sold in bordering markets. The remaining 24% of agricultural land is occupied mainly by horticultural systems.

The intensive horticultural systems are the most important economic activity and occupies circa 403 ha. Five main types of horticultural systems exist in the region: (i) leafy vegetable systems (58% of all units), i.e. all leafy cultivation with a cycle shorter than 5 months: such as for example, lettuce, cabbage, spinach (ii) fruit vegetable systems (20%) with a cycle longer than 5 months: such as vegetable pear, lady fingers, squashes, cucumber, tomato, *Solanum gilo* (iii) mixed fruit and leafy vegetable systems (15%) that combine both the leafy vegetable system and the fruit vegetable system: for example, vegetable pear with lettuce, (iv) perennial cultivation system (5%) with a perennial cycle: such as for example mint, tangerine, and finally (v) ecological production systems that are very rare (<2%).

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CHAPTER 2

FOREST FRAGMENTATION IN THE SERRA DOS ÓRGÃOS: HISTORICAL AND LANDSCAPE ECOLOGICAL IMPLICATIONS

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Abstract: In this article we give an overview of the historical development and related deforestation and landscape degradation processes in the Serra dos Órgãos region. The history of forest fragmentation is analysed from prehistoric colonisation to the present by interpreting archaeological, anthropological and historical literature, historical sources as well as remote sensing data. Landscape degradation processes, investigated by Nehren (2008) on the basis of geomorphological and pedological field work and laboratory analyses, are reflected in a historical context. As a result, characteristic land use and degradation patterns are shown for different time periods and at different spatial scales. Furthermore, driving forces for recent degradation processes are pointed out and risks of further deforestation and landscape degradation are assessed.

Keywords: forest fragmentation, Serra dos Órgãos, landscape history, landscape ecology.

Introduction

The Serra dos Órgãos in Rio de Janeiro State (RJ) is the northernmost branch of the "Serra do Mar" mountain range, which extends from Santa Catarina in South Brazil towards the northeast over more than 1,000 km. The corresponding biogeographic corridor represents relatively extensive remnants of the Atlantic Forest (*Mata Atlântica*), characterised by high biodiversity and endemism. Due to its high level of endemism on the one hand and high anthropogenic pressure on forests on the other hand, the Brazilian Atlantic Forest biome is considered a hotspot of biodiversity (Myers 1990, Myers et al. 2000).

Deforestation in the Atlantic Forest has a long history which is closely linked to overexploitation and unsustainable land use (Dean 1995). Nevertheless, the Mata Atlântica region was the birthplace of the Brazilian country, and today the Southeast with its triangle of São Paulo, Rio de Janeiro and Belo Horizonte is the economic heart of the country. Thus, landscape degradation must primarily be seen against the background of colonisation and subsequent agricultural, infrastructural and industrial development.

Today about 93% of the former Atlantic Rainforest is destroyed (Galindo-Leal 2003), but the remaining forest fragments are still among the most diverse ecosystems on earth. They play an important role for biodiversity conservation and serve as migratory corridors for animals and plants. But moreover, they are also vitally important to protect water and soil resources and help to stabilise the local climate.

The Serra do Mar corridor with the Serra dos Órgãos is one of the biologically richest areas within the Atlantic Rainforest with a forest land cover of about 30% (Galindo-Leal 2003) and a high proportion of endemic species (Costa et al. 2000). To protect these forests, conservation strategies have been developed and as a main result, an extended conservation corridor with a network of protected areas has been implemented. However, population growth and economic development, accompanied by infrastructural projects, urban sprawl and agricultural intensification put high pressure on the remaining forest patches.

To better understand the ongoing land use intensification and related forest fragmentation and landscape degradation processes in the Serra dos Órgãos, the landscape history of the region is reconstructed. With this knowledge the impacts of previous land use practices on landscape evolution can be assessed, the present appearance of landscapes be explained, and even forest ages and human influence on different patches be estimated.

For the municipality of Teresópolis in the mountain region, the younger land use history and present processes in the landscape system are analysed. This includes the identification of main human impacts, driving forces, system responses, and the consequences for further land use management.

Study area and methods

The landscape history of the region is reconstructed on basis of archaeological, anthropological and historical literature, historical sources, such as written documents, maps, paintings and photographs, as well as remote sensing data in different spatial scales. While the pre-colonial history is discussed for Southeast Brazil, the younger development since the European colonisation is analysed for Rio de Janeiro State under special consideration of the Serra dos Órgãos mountain region.

The pilot region of the BLUMEN project (Appendix 1: Map 1) was the study area for a landscape ecological investigation undertaken by Nehren (2008). In his research, the geomorphological and pedological methods applied are described in detail. Within the study area, the modern land use intensification process as well as forest fragmentation and landscape degradation coming along with it were analysed for the municipality of Teresópolis. Detailed geomorphological and pedological studies were carried out in the small catchment area of the *Corrego Sujo* (54 km²), a small creek of 15.6 km length (Appendix 1: Map 3). Furthermore, different forest stands in the National Park "Serra dos Órgãos" and four forest fragments with sizes ranging from 8.9 to 58.5 ha in the rural hinterland of Teresópolis were studied with respect to soil conditions and human influence. In this contribution some results of his work are reflected in the historical context.

Results and discussion

Pre-historical colonisation: Sambaqui societies in Southeast Brazil

Archaeological, anthropological and palaeo-environmental studies prove a long and intensive anthropogenic influence in South and Southeast Brazil. According to Schmidt Dias (2004), the oldest human traces in South Brazil were found in Arroio dos Fósseis, Rio Grande do Sul (12,770 ±220 BP). Slightly younger are the human skeletons of Lagoa Santa in Minas Gerais (12,070±170 BP; Barbosa & Schmitz 1998). In contrast, human evidence in the present-day state of Rio de Janeiro is considerably younger (8,100 ±75 BP; Beltrão et al. 1986, Schmidt Dias 2004).

There are numerous signs of human presence all along the Brazilian coast from the early and mid-Holocene on, particularly more than one thousand shell mound locations of the Sambaqui culture [the term "Sambaqui" is derived from the Tupi language and means shell mound], which are recorded in the national register of archaeological sites (Gaspar et al. 2008). While in most cases, archaeological findings argue against dwellings and sustained domestic activity of the Sambaqui societies (Gaspar et al. 2008), a few sites in RJ indicate permanent settlements of these fishing-collecting groups around lakes at Boa Vista Island, Cabo Frio (Barbosa et. al 1994). According to Barbosa et al. (2004), these sites were discontinuously occupied during two distinct periods between 4,000-3,300 and 2,000-1,500 BP.

Other investigations in RJ also date shell mounds with artifacts or skeletons mainly between 4,000 and 1,500 BP (Beltrão 1978, Mendonça & Godoy 2004, Marinho et al. 2006, Mendonça et al. 2006), but there are also some older and younger datings. Beltrão (1978), for example, dated some hills between 1,500 and 500 BP, but also one mound in Magé between 6,000 and 10,000 BP. However, from today's perspective, the dating method with fossil sediments must be seen as relatively imprecise. Nevertheless, younger studies corroborate earlier findings that the oldest shell mounds originate from the early Holocene. At present, the earliest dates of 9,200 BP are small shell mounds along the Ribeira do Iguape valley in São Paulo state, some 30 km inland (Figuti et al. 2004).

Very few studies focus on the ecological impact of Sambaqui societies. Many, especially older, studies associate Sambaquis with hunting and gathering economies which depended primarily on mollusc collecting and fishing. Therefore, the ecological impact was seen as very low or not even worth being discussed. But some younger investigations state that at least from 5,000 BP on, Sambaqui societies intensified fishing and started to use nets in lagoons and mangrove areas (Gaspar et al. 2008). Apart from marine food, also plant resources such as roots were important for human diet (Scheel-Ybert 2001). The author documents for the southeastern coast of RJ that in the Late Holocene the region was covered by different plant associations. The Sambaqui societies living there already gathered plant food such as palm fruits and collected wood and thereby influenced the distribution of plants. Tenório (1991, cited in Gaspar et al. 2008) even goes a step further and suggests management of tree species and potentially garden horticulture.

Pre-historical colonisation: Tupi Societies in Southeast Brazil

Pre-historic Tupi tribes inhabited Rio Grande do Sul and Paraná about 2,200 years ago and arrived in present-day RJ at approximately 1,800 BP (Silva Noelli 2008). There is a long and controversial discussion within the archaeological and anthropological community about the chronology and migration routes, discussed in Fausto (2006) and Silva Noelli (2008), among others. At this point, only some important aspects will be mentioned.

Regarding origin, migratory patterns and land occupation, consensus only exists with respect to a common centre of origin and differentiation through historic and cultural processes (Silva Noelli 2008). Some authors presume the centre of origin somewhere in the Amazon, from where a first territorial expansion may have started about 2,500 years ago (Meggers & Evans 1973, Brochado 1984). The movement south probably took place inland along the main rivers Madeira, Guaporé and Paraguai and from there into smaller tributaries (Brochado 1984). In a second migration period between 800 and 1,000 AC, the Tupi moved from the Paraná-Paraguai basin northwards along the coast (Brochado 1984). In sharp contrast to that hypothesis, Métraux (1927, cited in Fausto 2006) and other authors see the origin of the Tupi-Guarani in the Paraná-Paraguai basin itself, from where the tribes moved northwards along the coast up to the Amazon basin. According to that hypothesis, the disjunction of the Tupi and Guaraní should have taken place already in the Paraná-Paraguai basin. Gaspar et al. (2008) assume that early Tupi communities may likely have inhabited former Sambaqui territories. At any rate, no co-existence of Tupi and Sambaqui tribes has been proven.

Against the background of landscape history and deforestation, population dynamics and lifestyle are of particular interest. Concerning this matter, Dean (1995) collected numerous data for the whole Mata Atlântica region, published in his book "*With broadax and firebrand: the destruction of the Brazilian Atlantic forest.*" Accordingly, Tupi tribes inhabited the coastal zone in a band up to 500 km wide. Due to the barrier of the coastal ranges, the stripe was considerably smaller in present-day RJ compared to other coastal regions. The tribes practiced *coivara*, the traditional slash-and-burn agriculture which is still prevalent in rural areas, and cultivated corn, manioc, and other crops. In addition, they were fishermen and hunters and collected forest products.

According to historical chronicles mainly from the 16h century, settlements consisted of a central place surrounded by four to eight *malocas* (community houses). The population of these settlements varied between 500 and 3,000 people. A village controlled approximately 70 km² of land on which the *coivara* was practised (Drummond 1997).

On basis of historical documents, Dean (1995) made an interesting calculation: with an estimated average village population of 600, 70 km² cultivated land and a deforestation rate of 0.2 ha per person and year; the whole primary forest of a village territory would have been cleared within only 55 years. Thus, with a hypothetical colonisation of 1,000 years, the territory would have been completely burned not less than 19 times.

For the coastal zone of RJ and São Paulo, Dean (1984) estimated a population density between 4.8 and 5.3 inhabitants per km² before the European colonisation. Taking into account the population concentration in the flat littoral zone and people of other ethnic groups, a total number of 150,000 inhabitants seems to be coherent. Since these people not only practiced *coivara* but also used firewood for cooking as well as timber for house and ship building and for weapons, larger forest areas must have already been degraded. Drummond (1997) estimated that about 10% of the coastal region was already deforested with the arrival of the Europeans in the early 16th century – and this does not mean that the remaining 90% were primary forests. This hypothesis is supported by documents of land grants in Rio de Janeiro (1590), whereby almost all estates were described as *matos maninhos* (cultivated forest land) and only a few as *matos verdadeiros* (real forests)

(Dean 1995). It would be unlikely to find such a rapid deforestation and cultivation by Europeans in less than 90 years.

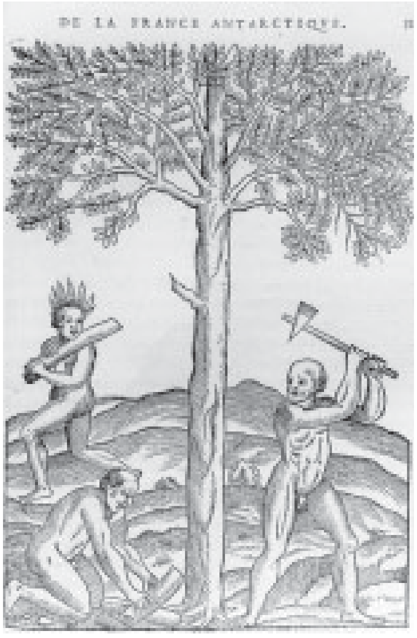
In contrast to Drummond (1997), Fundação S.O.S Mata Atlântica/INPE (1993) estimated the forested land of RJ to 97% for the year 1500. Taking into account the low population density of about 5 inhabitants per km², the pre-historical forest degradation can be seen as moderate, since regeneration phases were long enough to ensure an ecological sustainable system. This includes the maintenance of soil fertility as well as an exchange of the genetic pool, so that secondary forests still were likewise as diverse as primary forests. However, even though the influence of prehistoric land use practices on coastal forests in Southeast Brazil can be estimated as more or less important, the image of unspoiled coastal primary forests before the European arrival must be revised.

The European colonisation

While indigenous populations used fire to clear areas of tropical forest for agriculture in the coastal plains, they expanded into mountain rainforests only for hunting. As old trails testify, they even crossed the main ridge of the massif, but there is no evidence that they burned rainforests for cultivation in the Serra dos Órgãos mountain ranges. This changed dramatically with the arrival of the first European settlers.

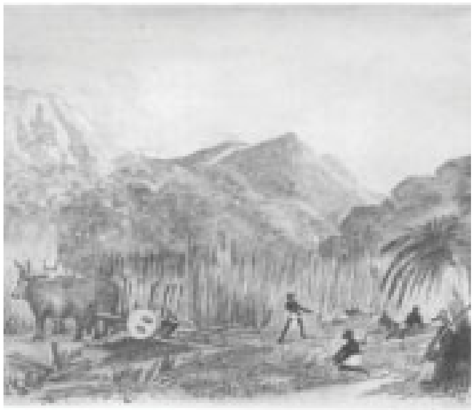
Historical documents prove rapid deforestation rates in the coastal region of Southeast Brazil after the European arrival. As stated by Nehren (2008), the development in the coastal plains of Rio de Janeiro can be divided into four main exploitation cycles:

1. Selective cutting of the precious brazilwood (*=pau-brasil; Caesalpina echinata*) started at the beginning of the 16th century. The extensive felling of the trees was possible with the increased arrival of European settlers and African slaves from 1565 on. In Europe, the brilliant red pigment called *brazilin* was used for dyeing luxury clothes, and apart from that, bows for string instruments were made of the dense heartwood. The economic exploitation of brazilwood was the initial step for the large-scale destruction of the Mata Atlântica forests (Drummond 1997, Homma 2003). Today, the tree species is nearly extinct in its original habitat and cited in the official list of endangered flora of Brazil as well as listed as endangered in the IUCN list of threatened species (IUCN 2009).



Picture 1: André Thevet: Cutting Brazilwood (from: Les singularitez de la France Antartique, Paris 1557)

2. The first sugar cane plantations in the coastal area of RJ were established around 1560, some decades later than in Salvador do Bahia (Dean 1995). In the following years extensive clearings for cultivation, energy generation (charcoal), and pastures for workhorses were made in the lowlands. Already in the mid-17th century the forests in the Guanabara Bay were cut down, with the consequence that firewood for charcoal production became scarce (Dean 1995). In the lower mountain region of the Serra dos Órgãos first sugar cane plantations are recorded in the municipality of Magé for the late 17th century (Drummond 1997).



Picture 2: Sugar cane cultivation in Frechal in the lower ranges of the Serra dos Órgãos (detail), painting of an unknown artist (1839), collection Gilberto Ferrez

3. The "Gold routes" (*Caminhos do Ouro*) from the gold mines in Minas Gerais to the ports of Rio de Janeiro at the end of the 17th century followed old Indian trails, crossing the forested mountain ranges of the Serra do Mar. The oldest route connected Vila Rica (today Ouro Preto) in Minas Gerais with the port of Parati in the South of RJ. In 1720, a new route, known as *Caminho Novo da Estrada Real*, was created. This trail crossed the westernmost part of the Serra dos Órgãos and led to Porto da Estrela in the Guanabara Bay (IBAMA 2006).

Picture 3: Cobblestones of the old gold route near Parati (Photo: Nehren)

With the new connection, the rise of the "Imperial city" Petrópolis in the Serra dos Órgãos began. According to Nehren (2008), the gold routes were the initial step for the opening and development of the Serra dos Órgãos mountain region.

4. In the 19th century, large areas of Atlantic forest were replaced by coffee plantations throughout Southeast Brazil (Dantas & Coelho Netto 1995, Guerra & Botelho 2001). The clearings caused soil erosion and water problems and even dry spell periods in winter (Dantas & Coelho Netto 1995). In contrast to sugar cane, coffee was also planted on steep slopes, for example in the Tijuca massif in the metropolitan area of RJ and locally in the Serra dos Órgãos with the result of erosion and landslides. In the mid-18th century the population of RJ grew fast and had to be supplied with water.

Picture 4: Coffee harvest in Rio de Janeiro (Rugendas); Source: A. Gomes Mathias: História Ilustrada do Rio de Janeiro

Finally, the high water demand of the coffee plantations caused water scarcity, so that in 1860 the governmental authorities decided to expropriate local coffee farms and establish an official reforestation programme (Dantas & Coelho Netto 1995). From there on, the coffee plantations moved westward to São Paulo and only a few survived in RJ. Drummond (1997) estimated that between 1790 and 1860 about 25,000 km² of forest land had been cleared in RJ, which was about 60% of the state's territory.

In 1888, the *Lei Aurea* (Golden Law) abolished slavery in Brazil and therewith the organisational structure of coffee production changed fundamentally. From there on, more European immigrants, particularly Italians, worked on the plantations (Prutsch 1996). After the world economic crisis in 1929, coffee prices collapsed and most of the few remaining coffee plantations in the western part of RJ were converted into pastures (Coelho Netto 1999).

There are no documents that specifically source the distribution of coffee cultivation in the Serra dos Órgãos. However, it is unquestionable that coffee was extensively planted in the lower ranges (Drummond 1997), where coffee trees still occur in secondary forests. In spite of the climatic disadvantages with occasional frosts, coffee was also locally planted in the higher ranges, particularly in Petrópolis and Teresópolis. Today, coffee plants can still be found in forest fragments. However, there are no documents proving large-scale coffee plantations in the higher ranges.

Apart from the main exploitation cycles mentioned above, other land uses caused high losses of forested land. Thus, in the west of RJ cattle ranching was established already in the mid-16th century. In 1808, historical sources prove that 450,000 furs were exported from RJ. This suggests a pasture land of about 36,000 km² (Dean 1995).

Development of the Serra dos Órgãos: the municipality of Teresópolis as example

First settlements in the lower mountain range, in today's municipality of Magé, are dated to 1567. In 1696, Magé received its town charter, and in the 17th and 18th century other villages came into existence (Drummond 1997). In the early 18th century first *fazendas* were founded in the higher ranges (Oscar 1991).

The city of Teresópolis developed from a small settlement on the path between Magé and Sapucaia, which was already recorded in a map of Baltasar da Silva Lisboa from 1788 (Vieira 1942). In 1818, the British settler George March established a *fazenda* close to the present-day city of Teresópolis (Ferrez 1970). Parts of the current city were built on the former *fazenda*, which practiced agriculture and animal husbandry and already advanced summer tourism (Rahal 1991). Other *fazendas* were set up in the following years (Oscar 1991). Finally, the town was founded in 1855, and the municipality in 1891.

Important milestones for the city development were the completion of the first telegraph line to Magé (1898) and the railroad from Porto da Piedade in the Guanabara Bay to Várzea in Teresópolis (see picture 5), which was officially opened in 1908 (Viera 1934). In 1939, President Vargas inaugurated the road from Itaipava to Teresópolis (Vieira 1940), which was the shortest connection to Rio de Janeiro until 1959. In the same year, the National Park 'Serra dos Órgãos' was founded. Twenty years later, President Kubitschek opened the direct road from Teresópolis to Rio de Janeiro, which cuts through the National Park. Two years before, the tracks of the railroad had been removed. The rail traffic has not been restarted since that time. In 1974 the connection between Teresópolis and Porto Novo da Cunha as a part of the highway to Bahia was completed, and finally, in the same year the RJ-130 between Teresópolis and Nova Friburgo was bituminised and enlarged.

Picture 5: Railway Teresópolis - Leopoldina (postcard)

For the region between the two cities, road upgrading was of outstanding importance for both, agricultural and tourism development. Thus, the transport time for agricultural products from the hinterland of Teresópolis to Rio de Janeiro was significantly shortened and moreover, larger trucks could be used. The road is an important development axis, where old villages expanded and new villages were founded. Furthermore, many tourism facilities, such as hotels, *pousadas* (guest houses), golf courses and horse ranches, as well as small to large scale *condominios* evolved along the scenic road. Currently, the tourism development in the region is still growing.

Simultaneously with the infrastructural development, the population in the Serra dos Órgãos region grew notably. Thus, the population density in the municipality of Teresópolis increased from 45 persons per sq. km at the census 1950 to 179 at census 2000. In 2007, about 150,000 people lived in the municipality (IBGE 2000). The population development in the other municipalities of the Serra dos Órgãos such as Petrópolis and Nova Friburgo is comparable; in Magé the growth rates are even higher.

Modern history of land use and deforestation in Rio de Janeiro State

There are some interesting figures that reflect the younger history of deforestation in RJ. According to Duarte de Barros (1956: 246), in 1911 an area of 35,980 km² in RJ was forested, which was about 85% of the total land surface. In the following years by far the greatest part of the forests were cut off, so that in 1947 only 3,480 km² remained, which was about 8.2% of the total land area. In that time, deforestation in RJ was closely linked to an active immigration policy, which caused a rapid expansion of agricultural land and pastures as well as industrialisation and urban sprawl. Thus, in 1913 the highest immigration rates in the state's history were reached (Prutsch 1996).

In addition to the land use activities of the new citizens and the general population growth, also the infrastructural and industrial development put high pressure on forests. Particularly for the new railways and factories, a large amount of timber was needed. Therefore, already in 1904 the railway companies started to plant Eucalyptus for charcoal production (Dean 1995). Furthermore, numerous roads were constructed, which made formerly remote areas accessible, and in 1903 Rio de Janeiro started an urban renewal with the slogan 'Rio Civilizes Itself!' As a consequence, poorer population groups were forced to move from the inner city to the outskirts, were they populated numerous formerly forested hills, the characteristic *morros* (Prutsch 1996).

In the 1950s and 60s, the South-Southeast axis of Brazil emerged as the economic engine of the country – and Rio de Janeiro and São Paulo took the leading role. Between 1950 and 1970 the population in RJ increased from 4.7 to 9.0 million, with annual growth rates of more than 3% (Fundação CIDE 2007). Many immigrants came from the poor Northeast, searching for better living conditions.

However, the economical and population development were not accompanied by higher deforestation rates. On the contrary, Fundação S.O.S Mata Atlântica/ INPE (1993) presented numbers whereby in 1960 about 25% of the total land area of RJ was forested, notably more than in 1947. With the removal of the capital from Rio de Janeiro to Brasilia in 1960, the city lost most of its political and economic power and São Paulo took the leading role in economy. As a consequence, population growth in RJ dropped from 2.3% (1970/1980) to 1.15% (1980/1990) and 1.3 % (1990/2000) (Fundação CIDE 2007).

There are no deforestation rates known for the time between 1960 and 1990. However, during that period many new roads and highways were built or enlarged in the whole state, which caused massive cutting effects and noise exposure in the remaining forest patches, such as those of the NP 'Serra dos Órgãos'.

Precise land use data were analysed for the time between 1994 and 2001 by Tribunal de Contas do Estado do Rio de Janeiro (2005). According to these data, the area of closed rainforests in RJ decreased from 16.6 to 9.6% within that period. Simultaneously pasture land increased from 44.5 to 49.4%, *Capoeira* (secondary bush vegetation) from 15.5 to 18.5% and populated area from 4.2 to 6.3%, reflecting a trend of growing animal husbandry and urbanisation in RJ State, at the expense of closed forest patches.

Forest fragmentation and agricultural development in Teresópolis

Nehren (2008) analysed the land use history and landscape degradation patterns in the municipality of Teresópolis giving special attention to the forests in the NP 'Serra dos Órgãos' and the fragmented landscape north of Teresópolis. In the following some of the main results are presented.

In contrast to the coastal zone, deforestation and landscape degradation in the mountainous municipality of Teresópolis and its neighbouring counties concentrates on the last two centuries. There are no historical documents or studies on how the infrastructural and agricultural development in the Serra dos Órgãos affected forest ecosystems quantitatively and qualitatively. Therefore, landscape history was reconstructed based on different sources, particularly historical documents, interviews and surveys, while human impacts were analysed and evaluated by means of geomorphological and pedological field studies.

As a main result for the protected rainforests of the National Park it can be stated that there are many traces of human activity in the lower ranges and foothills, while the influences in the rainforests above 1,000 m a.s.l. are relatively low. There were some tourism activities in the higher ranges already starting with the foundation of *Fazenda March* in 1818, but until 1939 no larger deforestation and land use activities are known, most likely because of the difficult access with very steep slopes. With the establishment of the National Park in 1939, the necessary infrastructure, such as park roads, buildings, water pipes, and transmission lines had only limited impacts on the surrounding forests, but three fires in the north-eastern part of the Park in 1949, 1955 and 1959 caused serious damage. The historical findings are reflected by soil profiles, which contain burned branches and many charcoal pieces and show increased soil displacement. Moreover, deep black termite mounds and a high fraction of palm trees - few species which are characteristically for secondary forests - were found in these locations. By contrast, undisturbed profiles usually do not contain charcoal pieces and possess a high erosion resistance due to a very dense root system. As a basic principle, undisturbed profiles also show acidification and accumulation of humus in the topsoil, accompanied by relatively higher nutrient contents.

As already mentioned in the previous chapters, in former times the forests of the mid and lower ranges on the Atlantic side (from 50 to 1,000 m a.s.l.) were partially used for sugar cane and coffee plantations as well as for firewood production. Other uses include the extensive plantation of *Chinchona* within the present-day National Park, mainly in the municipality of Guapimirim. In the mid-19th century, the bark of the *Chinchona* tree was used as a malaria treatment. The construction of the railway with its several bridges in the late 19th century and of the main road from Rio de Janeiro to Teresópolis in the mid-20th century led to high deforestation rates and other disturbances along the routes. Although conclusions for the whole park cannot be drawn, neither from historical documents nor from random soil samples (which often show colluvial accumulation and high contents of charcoal pieces), it can be presumed that wide parts of the rainforests in the lower and mid ranges of the NP are secondary forests.

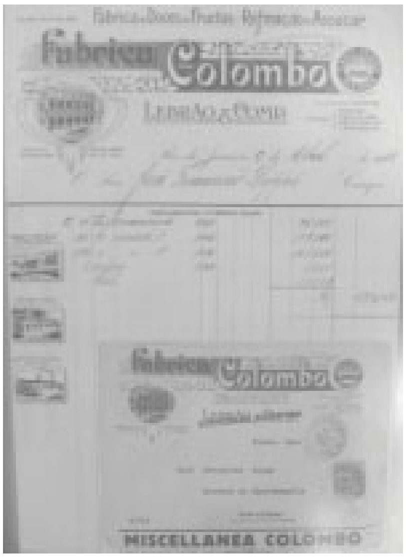
Picture 6: (left): Alpinist climbing the Dedo de Deus in the 1930s (Archive Centro Excursionista Brasileiro)

Picture 7: Transport path within the present-day NP (Archive Aderito A. Alves).

Picture 8: Construction of a reservoir in the NP in the 1940s (Archive Aderito A. Alves).

Today, the rural area north of Teresópolis presents itself as a mosaic of pastures, agricultural land, *capoeiras* and forest fragments. Archaeological findings suggest that Indian tribes already explored the area in prehistoric times, but there are no remains of pre-colonial settlements or evidence for slash-and-burn agriculture. In contrast to the coastal zone the agricultural development started late in the 19th and 20th century and is not characterised by exploitation cycles. Quite the contrary, the colonisation and land use patterns were very heterogeneous. First *fazendas* were established in the late 19th century between Teresópolis and Nova Friburgo. For this time, the cultivation of sweet potato and beans is known from the region west of Nova Friburgo. Around 1880 many families from Italy settled in the region of Venda Nova / Bom Successo, attested by the family names Gallo, Lippi, Granito or Dallia (information by Mr. Eduardo Ponte, Agricultural School of Venda Nova). Other nationalities such as Spaniards and Greeks followed and with them their traditions, culture and knowledge of agriculture, which was not always adapted to the conditions in the Serra dos Órgãos.

Historical documents and pictures show that land use on the *fazendas* was very heterogeneous in both type of use and intensity. However, coffee cultivation did not play an important role, in fact, traditions and experiences from the mother countries were transferred to the new environment. For example the *Fazenda Lippi*, founded in 1885, managed an area of 340 ha north of Venda Nova. In the first years very different agricultural products were brought to the local market (=*Venda*). In 1910 the large-scale production of quinces was started. The fruits were transported to Rio de Janeiro by donkeys, where the jam processing took place. But after a ruinous pest in 1935 the production was stopped, and from there on mixed agriculture, mainly different vegetables, and animal husbandry were practiced.



Picture 9: Account of quince trade from 1927 (Archive Museo Lippi).

Picture 10: Venda Nova in the early 1930s. In the background: A characteristic, partially deforested hill (Archive Museo Lippi).

Another estate, the *Fazenda Conceição*, was founded in 1950. The property included the Corrego Sujo catchment area, where detailed landscape ecological studies were carried out. The *fazenda's* electricity was generated by hydro power. Therefore a small tributary of the Corrego Sujo was impounded, which can be seen in the topographic map of 1983. Today the dam and lake do not exist any more. Until 1970 the land was not cultivated and the property was used for land speculation. Then the *fazenda* was dissolved and split into numerous so called *micrositios*, which were sold on the market. From there on the lots with an average size of three to four hectares were used mainly by peasants who planted vegetables in the floodplains and citrus fruits on the slopes. By now most of the land is used as pasture.

Current land use patterns, degradation and driving forces

Nehren (2008) analysed different types of land degradation in the municipality of Teresópolis and drew the conclusion that the following seven types are the most important ones:

1. Land consumption and soil sealing by urban sprawl, tourism and agricultural activities;
2. Burning of forest and bush land for agriculture and land speculation;
3. Soil erosion as a result of non-suitable agricultural and silvicultural land use practices;
4. Landslides along roads due to natural and technical hazards as well as in *favelas* (= shanty towns) situated on steep hills as a consequence of high population pressure;
5. Bank erosion and floods due to reduced water storage capacity and accelerated runoff after heavy rainfalls mainly as a result of deforestation, melioration, and soil sealing;
6. Melioration and intensive agriculture in floodplains associated with a loss of biodiversity;
7. Complete landscape and soil transformation by agricultural intensification and tourism.

If we look at these degradation types from a historical point of view, we can assume that – in contrast to the coastal zone – the most serious problems in the municipality of Teresópolis arose in modern times, mainly in the last 50 years. With focus on suburbanisation processes, picture 11 shows that a strong development took place since the mid 1980s. Because of the relief with steep slopes to the south, the city expanded to the west, north and east, with characteristic patterns, following the main roads along the valleys and from there further forward into the side valleys. The urban sprawl must be seen in the context of the high population growth in RJ as well as in the increasing attractiveness of the city itself, which was vitally advanced with the construction of the direct road to Rio de Janeiro in 1959. With its favourable climatic conditions, beautiful landscapes and closeness to Rio de Janeiro, Teresópolis became a popular location for secondary residences and tourism. In addition, high crime rates in Rio de Janeiro induced wealthy citizens to buy properties in the mountain region and "escape" for weekends and holidays.

But with the growing prosperity, also *favelas* developed, so that in the year 2000 already 24.0% of the population lived in the shantytowns, which is the second highest rate in RJ (IBGE 2000). Due to limited land resources and high prices in the city, these settlements often illegally "climbed up the hills" and destroyed protected forests (picture 12). Furthermore, houses were constructed along the rivers, where they are highly at risk to bank erosion and floods (picture 13). In addition, untreated sewage from these households seriously threatens the water quality of the rivers and creeks.

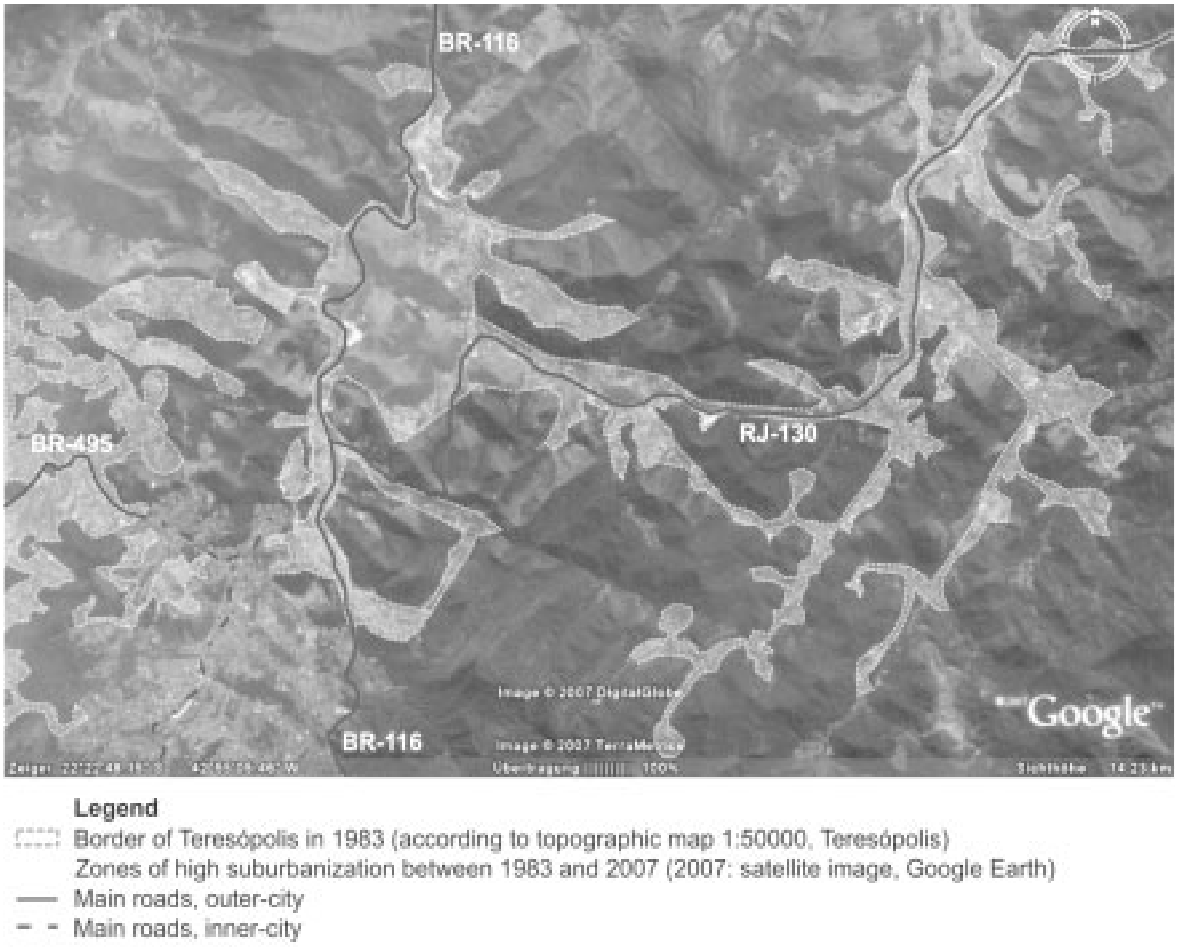
But not only the *favelas*, also *condominios*, hotels and recreation facilities put high pressure on the remaining forest fragments. Between Teresópolis and Bom Sucesso, villages and houses along the road RJ-130 (direction Nova Friburgo) have merged into an almost closed settlement area. Considering the desires for panoramic views, security, protection against animals, and other aesthetic aspects (Nehren 2008), forests are often seen as barriers or places of insecurity and therefore cleared.

Apart from suburbanisation and tourism development, the RJ-130 is also important for the agricultural sector. With the bituminisation and enlargement of the road in 1974, the transport time to the market in Rio de Janeiro was significantly reduced and larger trucks could be used. Mainly for this reason, the rural region emerged as a main producer of vegetables and the formerly heterogeneous land use structure changed to a pattern which can still be observed in most valleys: Vegetable gardening in the floodplains and intramontane basins, animal husbandry or citrus plantations on the hills and forest fragments particularly on steep slopes and on the Atlantic (south) side, in many cases protecting springs and source areas (picture 14).

Regarding forest fragmentation and landscape degradation processes, studies in the Corrego Sujo catchment area showed that in spite of the late agricultural intensification, already considerable erosion processes had occurred. Although there are less deep gullies compared to the coastal ranges, initial stages of linear erosion as well as some deeper gullies have formed mainly on steep slopes under pastures (picture 15). Nehren (2008) observed that the occurrence of gullies varies significantly under comparable environmental conditions and concluded under consideration of historical data that land use type, intensity, and period are of uppermost relevance for their formation. This explains the relatively low number of gullies in the more recently developed, remote Corrego Sujo valley as compared to others, such as this of the Rio Paquequer along the BR-116, with good road connections, earlier development and high stocking rates. The high number of gullies in the coastal ranges can be explained by a long land use history with expanded coffee plantations and livestock farming and, of course, the natural conditions with erosive rainfall, steep slopes and highly erodible soils.

Currently further land use intensification takes place in the Corrego Sujo and neighbouring valleys. The high demand for vegetables at the market of Rio de Janeiro causes an expansion of cultivated areas. Due to the limited land resources, floodplains are drained, former pastures or *capoeiras* are converted into vegetable fields and sometimes edges of forest fragments are cut down or burned off. In some cases, hilly areas have completely turned into vegetable landscapes (picture 16) and soils in the floodplains have been transformed to highly productive *Anthrosols*. With the expansion of vegetable cultivation from the floodplains to hills with steep slopes, the problem of soil erosion increases dramatically (picture 17). In contrast to pastures, where linear structures such as gullies predominate, inter-rill and rill erosion are the characteristic types on steep slopes with vegetable cultivation. However, in addition gullies can develop along the drainage channels.

The burning of *capoeiras* is still common practice, keeping the land free for later agricultural use, but in recent times also for land speculation. Sometimes the fires encroach on neighbouring forest fragments. According to Article 1 of Decree 750 (*Decreto da Mata Atlântica [750/93]*), the use of primary forests as well as secondary forests of intermediate-advanced and advanced succession stages is prohibited. Therefore the burning or cutting of forests has the risk of getting in judicial trouble, which can indeed be avoided by burning the vegetation in early succession stages. Moreover, the risk can be minimised by cutting or burning - little by little - a few trees on the edges of the fragments, which is very difficult to observe on satellite images.



Picture 11: Suburbanisation in Teresópolis between 1983 and 2007 (Nehren 2008)

Soil samples of four forest fragments in intermediate to advanced succession stages in the hinterland of Teresópolis clearly show that these stands were already burned and partially used as agricultural land in earlier times (Nehren 2008). For the hinterland of Teresópolis, the author comes to the conclusion that most fragments were burned in historical times and are therefore not remains of a formerly large forest, but relatively young secondary forest patches. In some cases these fragments contain older core segments typically on steeper slopes or around springs.

Picture 12: Settlement on a steep slope in Teresópolis

Picture 13: Flood damages, Rio das Bengalas (2004)

Picture 14: Landscape with irrigated vegetable production systems in the hinterland of Teresópolis

Picture 15: Initial gully erosion in the Corrego Sujo catchment area

Picture 16: Completely transformed agricultural landscape in the Rio das Bengalas valley

Picture 17: Erosion risk and forest fragmentation due to vegetable gardening on steep slopes

Synthesis and Outlook

Following Nehren & Heinrich (2007), the Serra dos Órgãos region can be divided into three landscape units with respect to the historical land use and degradation patterns:

(a) The heavily degraded coastal zone including the coastal ranges which were already influenced by shifting cultivation in prehistoric times and from the 16th century on by colonial exploitation cycles. While the pre-historic degradation can be seen as moderate, the historical land use practices caused high deforestation rates accompanied by other degradation types, such as soil erosion in the coastal ranges and on the hills (typically so-called “half oranges”), landslides along roads as well as negative impacts on water resources and local climate. Today, wide parts of the lower ranges and some of the half oranges are reforested. All forest fragments found here have a maximum age of 140 years (Dantas & Coelho Netto 1995).

(b) The steep slopes of the Serra dos Órgãos facing the Atlantic Ocean are predominantly forested and under protection. Soil analyses and historical data show that the lower, accessible parts have been used for centuries. Relatively untouched rainforests with undisturbed soil profiles are limited to very steep slopes and the upper ranges over 1,000 m a.s.l. (“*alto montana”*).

(c) The mountainous hinterland of Teresópolis (800 – 1,200 m a.s.l.) is a cultural landscape, dominated by pastures on the hills and vegetable fields in the valleys. Small forest fragments are scattered throughout the region, predominately on the Atlantic side. In the Corrego Sujo catchment area, they cover approximately 26.4% of the total land area (on basis of remote sensing data for the year 2005; Nehren 2008). First European settlements in the region date back to the late 18th century. Although anthropogenic influence is relatively young, forests are highly fragmented. However, soil degradation and erosion processes are considerably lower compared to the lowlands.

The current land use intensification process in the mountain region is accompanied by forest fragmentation. In contrast to other regions such as the Amazon, where large forest areas are still being cleared, the fragmentation process in the Serra dos Órgãos is characterised by smaller losses, often on fragment edges. In the municipality of Teresópolis suburbanisation processes, agricultural intensification and tourism development have been identified as the main causes.

With the stepwise deforestation, buffer zones and stepping stones are reduced. In the past years, eucalyptus plantations are of growing importance as well. However, in the well-investigated Corrego Sujo catchment area, they presently cover less than 0.5% of the total land area.

As a consequence of land use intensification, overgrazing, deforestation and slash-and-burn-practices, erosion problems occur on slopes and along the streams. While gullies typically develop in pastures, vegetable gardening on steep slopes leads to inter-rill and rill erosion. Thereby large soil masses are eroded, so that in many cases the thin soil cover is removed within a short time period and saprolite or bedrock appear at the surface. This will certainly lead to a considerable reduction of land use options. However, from the perspective of short time profit maximisation, vegetable production on steep slopes – in contrast to livestock farming – might be promising, even under consideration of higher costs for irrigation. This promise of a fast profit imposes a growing threat to the remaining forest fragments and hampers the sustainable development of the region. Therefore management strategies need to be developed and implemented, taking into consideration the connectivity of forest fragments as well as suitable land use types and practices. For erosion prevention, Nehren (2008) suggests restricting vegetable fields to maximum slope angles of 6 degrees or, with appropriate measures such as terraces, up to 12 degrees, respectively. In the future, more detailed studies need to be carried out, comparing land use systems at different slope angles and lengths as well as soil conditions, allowing the development of optimised management strategies for the respective conditions.

Erosion problems also occur along rivers, where lateral erosion causes high losses of agricultural land and moreover poses a threat to buildings and bridges. With the loss of vegetable land in the floodplains, the pressure to cultivate hillsides becomes even higher, causing erosion problems mentioned above as well as further forest losses. But apart from the visible erosion damages, the consequences for the whole soil-water-system are alarming and have not been realised and investigated yet. Deforestation, soil sealing and compaction are responsible for lower infiltration rates and an increased runoff, leading to excessive vertical erosion of the rivers and a lowering of the groundwater table. Consequently, the floodplains, as former accumulation zones, will change to erosion areas in the near future. With the lower sustained flow, irrigation water will become scarce in the intensively used agricultural landscape, at least during dry seasons. This will probably cause conflicts of water allocation and finally result in a decrease of the vegetable production in the rural areas as well as supply bottlenecks in Rio de Janeiro City. It is worth discussing which effects a partial or total collapse of the production will have on landscape development, natural forest succession and possible reforestation strategies.

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PART II

Interdisciplinary analysis for land use and biodiversity conservation

CHAPTER 3

DEMANDS ON INTERDISCIPLINARY RESEARCH IN HUMAN-ECOLOGICAL SYSTEMS

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Implementation of sustainability in dynamic systems

Both, the quantitative analysis and the explanation of systems in general, imply an interdisciplinary approach due to the complexity of systems in general. A prerequisite for an in-depth analysis of a system is the assessment of all factors that affect the system as well as their interactions. The identification of all factors together with their interactions poses a great scientific challenge, all the more for complex human-ecological systems. In order to analyse such systems, simplifying models have to be developed that mirror the interrelation between mankind, technology, the biosphere and the abiotic factors of the system. Even these simplified models show a high level of complexity and only can successfully emulate systems, if they integrate expert knowledge of all disciplines relevant to the functioning of the system. Such an interdisciplinary approach necessitates expert knowledge of not only various fields, but of various experts, who have to work together effectively to channel their expertise into one model. The secret of a successful interdisciplinary project relies on the implementation of the expertise of each team member, provided that each team member possesses sufficient insights into the possibilities that arise due to the interrelation of his field of expertise to the other fields.

Human-ecological systems comprise nature, mankind and technology. The realisation of sustainability in human-ecological systems is interlinked to the system's state of equilibrium, which ideally should be a dynamic equilibrium, *'panta rhei'* ('everything flows', Heraklit, around 500 BC). A scientific basis for the research on sustainability in land use systems for the different eco systems is still not available. Research is only at the beginning of a long road to put together experts with the aim to research sustainability.

Human-ecological system 'land use'

In an ecosystem in equilibrium, there is circular flow between 'free' inputs such as radiation and precipitation, and output that exceeds the actual requirements of the system (biomass, dry matter). Farmers interfere with the natural ecosystem and replace it with agrosystems (Ruthenberg 1976) that need to yield products. Accordingly, they have to bring in production factors (work, energies etc.), to first create and then keep an agrosystem productive. Such land use systems occur in different states:

a. Systems in 'equilibrium', in which the productivity is maintained by the farmer's actions.
b. Systems in 'degradation', in which the farmer's actions are insufficient to maintain the productivity of the system.
c. Systems stabilised at an equilibrium with low productivity level (e.g. extensive pasture management).
d. Systems in growth, in which productivity is developed by the farmer.

In general, land use systems compete with ecosystems. This becomes increasingly apparent in warm and humid ecosystems, where the demand for inputs, in particular in the phase of intensification, grows disproportionately. The population development and associated dynamic factors contribute to the intensification of land use systems and related follow-up costs to maintain the system's productivity or to implement sustainability.

A comprehensive analysis of the dynamics of land use systems stabilised at an equilibrium with low productivity level (c.) toward systems in equilibrium with a high level of productivity (a.) along a gradient from low to high efficiency use of supporting inputs is almost impossible. In particular when considering that the costs for insulation in the tropics are two to three times higher as in temperate zones, that the vegetation period is all year round and that the 'hydrological' period varies greatly in accordance with the ecosystem, from the humid tropics to arid locations.

With increasing prices for supporting inputs, the importance of the efficiency of the use of inputs increases, too. Consequently, sustainability in combination with a high productivity becomes more expensive. However, in consideration of the long-term benefits of conserving the availability of the resources, and of maintaining an ecological equilibrium in a region, the distribution of the required costs on the farmers appears to be economically reasonable. The calculation of such reconciliation concepts is an integral part of research projects concerned with questions of equilibrium states of ecosystems and can only be carried out by an interdisciplinary approach.

Such calculations are important for:

a. the identification of attributes and long-term environmental and socio-economic effects of various land use systems
b. the identification of biological and agricultural characteristics of landscapes and watersheds in the tropics and subtropics
c. the identification of useful land classification systems
d. the determination of appropriate land use planning and development efforts, involving people and institutions at the farm, community, regional and national, levels.

The calculation of reconciliation concepts requires the development of simplified models, because the reality is too complex for modelling. Again, the development of models following a holistic approach poses a challenge to scientists, who have to combine their respective expert knowledge to one model reflecting reality and therefore building the basis for further decisions.

Paradigm shift in science: Interdisciplinary and transdisciplinary research for sustainable systems

Nowadays, new developments occur at the interfaces of the specialized disciplines, which already have reached a high level. This understanding has already spread, it can even be said that a change of paradigm has taken place: 'Up to now the focus of sciences has been to decompose the world into its basic components and to classify those parts and pieces. Now we start to deal with the mechanisms of their interaction' (Gaese & Höynck 2002).

This can only be achieved by the integration of 'interdiciplinarity' and 'transdiciplinarity' into research. Exceeding interdisciplinary in its meaning, transdiciplinarity is understood as an integrative form of research, aimed at obtaining knowledge between and beyond disciplines via practice in problem-solving, which requires the integration of practical knowledge and experience.

In the seventies and eighties of the last century, the necessity of holistic approaches in environmental and resources research, as opposed to mono-causal 'ceteris-paribus' assumptions, was known. The first complex cybernetic models originated by Frederic Vester in these times. Although already 200 years before, Alexander von Humboldt found that the explanation of natural phenomena necessitates the unification of the various branches of scientific knowledge, he as well as Hegel knew that only the whole resembles the truth, this wisdom suddenly appeared in a fresh light, when the environmental scientists were in need to develop new methodologies. The article by Ruthenberg (1976) about 'Agricultural production in the tropics as a system' identified him as avant-gardist of the agricultural sciences. In 2005, almost 30 years later, the German Research Foundation DFG published the memorandum on 'Future perspectives of Agriculture Science and Research', demanding a turnaround toward interdisciplinary research. The memorandum asserts that agricultural research deals with agricultural ecosystems, with socio-technical and socio-economic circumstances and with supersystems influencing them – statements which I remember heaving heard in the lectures from Prof. Ruthenberg (Prof. for Economics of Agricultural Production in the Tropics, University of Hohenheim) in the seventies. A further conclusion of the memorandum is that there are interactions between agricultural science and related scientific disciplines, e.g. Economic and

Social Sciences, Biological and Environmental Sciences, Planning and Engineering Sciences (DFG 2005, p. 102). Especially since the memorandum was written under the impact of a growing world population, increasing degradation of entire regions, in particular of tropical and subtropical regions, and alarmingly negative climate change scenarios, it is worth reading especially for scientists focusing on interdisciplinary land use and ecosystem research.

Furthermore, the memorandum denotes that agricultural science is concerned with the basic essentials for mankind and of global importance. ‘These include the efficient use of water resources and of scarce nutrients as well as worldwide food security’ (DFG 2005, p. 137). From these requirements, the most relevant recommendations are cited in the following:

1. Agricultural science must focus on new research fields because both its content and methodological advances (e.g. “molecularisation” in life sciences) have changed in the last few decades. These include the areas of environmental impacts, sustainability, quality assurance, agricultural landscape research and global food security.

2. Agricultural science is by its nature a system science, under whose umbrella scientists from different disciplines jointly develop approaches to solving problems. The new research fields require a system oriented approach on all accounts, and this must therefore consistently be developed in agricultural research and teaching.

3. Under changing conditions, sciences draw their innovative strength and their validity above all from theory and methodology.

4. Future organisational structures must lead to the promotion of interdisciplinarity and systems thinking. To this end, all research areas within the soil science, crop science and livestock science and, as cross-sectional disciplines, the environmental sciences, engineering and economics and social sciences, must each carry at least one professorship.

5. Cooperation across regional and institutional boundaries must be strengthened in the future. Cooperative projects between universities and non-university institutions must be promoted more intensively.

Systems science requires a paradigm shift, leading the way from research carried out by the single-scientist toward team research and from causality toward systems thinking. Such a fundamental turnaround demands learning. Thus, the proposal on the research programme ‘Land Management’ by the Federal Ministry of

Education and Research reads as follows: 'We need innovative concepts and strategies for land management and the relevant basic knowledge, technologies, instruments and system solutions in order to be able to face the challenges of regional and global change…. Research on land management consistently aims at integration following different strategic approaches: Previously separate research branches of the natural sciences and technology are combined with the economic and social sciences with the aim of studying the different aspects of global and regional change – environment/climate, business/technology, society/culture – in a broader context. This integrates different but related topics in a cross-disciplinary approach'.

An essential element of an integrated approach in environmental research is the assessment of dynamics of and interactions between the elements of the system. The demand for systems thinking in resources use, as cited from the BMBF proposal, originates from the hypothesis that sustainability in research use is only achievable, if all relevant factors of the system and their interactions are considered. Or, if there is a turning away from the simple causal chains established in science. This leads back to the central question: How can the sustainability of a system, such as a landscape unit or a watershed, be reached and further, be maintained? In this context, Wolff (2004) suggests an alternative approach, questioning the threats to sustainability of a system. In view of that, systems become endangered if

a. they lack economic productivity
b. they come into conflict with external interests, even when the system itself functions well internally
c. the stakeholders stop caring for the relevant aspects of the system. Typical reasons for this type of threat are the "prisoner's dilemma", and the lack of productivity (a)
d. a system comes under pressure (e.g. lack of productivity (a.).

Threats to sustainability in a landscape unit are physical (e.g. nature disasters), ecological (e.g. degradation processes), socio-economic (inefficient institutions, corruption, wrong signals induced by a disequilibrium of the market), financial (e.g. insufficient mechanisms of collection of charges, operating costs) or political (e.g. incompatible targets, negative impacts of regional or national politics).

When sustainability in systems becomes visibly threatened, damage already has taken place. This often causes adverse long-term effects and hampers fast and targeted counter measures. Therefore, systems have to be better explored internally (interactions between subsystems, relevant factors) and externally (manipulation between systems, effects on the whole system). This fundamental insight that found a late consideration in the DFG memorandum quoted has brought about a first step in the right direction. For decades, science was dedicated to the analytic arrangement of the world into its elements - now we start to investigate the mechanisms of their concurrence (Gaese and Höynck 2002). In conclusion, this means a rethinking and revision of our scientific system that is based on the expertise of our scientists, who are requested to think outside of the box and establish interdisciplinary and transdisciplinary networks.

The difficulties in finding adequate methods for interdisciplinary research

The researchers working in interdisciplinary projects centred on land use systems, resources and landscapes come from different scientific backgrounds: economics, natural sciences, agricultural sciences, engineering and sociology. If the researchers integrate into an interdisciplinary project, they want to approach the research question from different perspectives, to engage in finding the answer to the problem and to become familiar with the perspectives of their colleagues' scientific backgrounds. This represents only the first step of team working in multidisciplinary and transdisciplinary cooperation. Interdisciplinary cooperation requires a basic insight of the participating scientists in the scientific background of the colleagues to gain a mutual understanding of all relevant elements of the system. In the next step, the influencing factors and coefficient between the disciplines are determined, in order to quantify the interactions between the system's elements. At this point, the methodological interconnection between the disciplines starts. The different backgrounds of the disciplines also use different scientific equipments. Even if the *'explanandum'* is common to all disciplines represented in the project, the *'explanantes'* differ.

The way out of this dilemma is the application of integrated modelling. The basic principle of integrated modelling is the partitioning of the different disciplines into subsystems. The respective subsystem behaviour depends on its own structure and on external influences (e.g. surronding subsystems). The system behaviour requires the integration of the submodels and allows understanding of the whole model and forecasting. Some integrative methods and integrated modelling approaches are discussed in Gaiser et al. (2003). In this BMBF-financed research project about water availability and vulnerability of ecosystems and society in the semiarid Northeast of Brazil, an interdisciplinary approach was realised. The simulation models developed pursue the goal of integrating and quantifying the interaction of various biophysical processes in order to achieve a better understanding of the observed yield variations of crops. More recent areas of application of integrated modelling lie in land use planning, climate impact research, decision support systems, and GIS- and GPS-assisted precision agriculture: 'They increasingly serve as heuristic tools in scientific research and training, land use planning and the studies of the ecological and environmental effects of land use' (DFG 2005, S. 95).

The BLUMEN project and the follow-up project are 'integrated research projects'. The aim of such projects is the development of scenarios on the basis of land use dynamics and current mitigation processes at different sites, to predict and evaluate control measures under varying conditions. These scenarios are based on regionally integrated ecological-economic modelling. Different land use systems will be analysed for their direct and external effects and their relevance for the natural resources and for the economical development. The comparison of different sites allows for the introduction of variables such as social-economic structure, indices of ecosystems, control programmes of national institutes, cultural factors, developmental state and technical changes. A long-term aim that will be difficult to realise within the financial frame of research projects will be the integration of the capacity dynamics by the connection of primary production and manufacturing, therefore an integration of the different sectors.

For the development of a comprehensive strategy, promising land use systems have to be found, which comply with the conditions of sustainability yet to be defined. Accordingly, potential and viability of local production systems have to be assessed. Here, the integration of primary production, manufacturing and markets play key roles. In an exemplary manner, land use systems, which hold a potential for ecologically sustainable systems will be analysed, in particular silvicultural, agro-silvicultural and silvopastoral land use systems. For Brazil, it can be assumed that in mountainous regions with increasing proximity to urban areas, the intensity of land use increases, whereas in industrialized countries, the intensity of land use in mountainous areas rather decreases with increasing proximity to cities, to the point of pure scenic importance. Furthermore, it can be assumed that the demand for environmental goods implies high income elasticity. Therefore, there is a positive correlation between the protection of resources and economic development. Relevant parameters to describe sustainability of land use systems can be classified as follows:

- technological parameters
- ecological parameters
- economical parameters
- social parameters
- cultural parameters

In the end, only site-specific, sustainable and environmentally suitable use of natural resources leads to efficient land use and to stable rural communities (German Advisory Council 1993) based on:

- the sustainable production of high-quality agricultural products
- the coverage of an adequate income of the rural population
- conservation and creation of rural cultivated landscapes
- preservation of the cultural heritage

The ongoing growth of world population and the increasing utilization of natural resources urgently require more and more international efforts towards the conservation of ecosystems and landscapes – especially in the highly vulnerable tropical and subtropical regions – where in the near future more than 90% of global population will be concentrated. Scientists of all relevant disciplines and all countries in South and North are asked to contribute to that cardinal problem of survival of mankind. Alexander von Humboldt was one of the first to realise (Saltzwedel et. al 2004) that science has to mediate itself to society, not only in matters of education policy, but in its own interest.

To share knowledge is to give away power, since knowledge means power. Where status and prestige play major roles, it is of utmost importance to understand that the higher benefit from interdisciplinary research relies on shared knowledge. In a short-term view, the individual benefit might be reduced, which is overcompensated in the long-term view by obtaining new dimensions of understanding. In international cooperation projects, the problem of sharing knowledge is multiplied: Objectives, measures, methods, and ethics of interdisciplinary research must be turned into a compulsory component of academic formation at partner universities.

Modern research for sustainable land use in the tropics and subtropics has therefore to force the association of individual disciplines into a network for modelling research. The freedom of scientific reason is the freedom of critical conscience; the prerequisite for critics is always a pluralism of independent partners who are jointly able to attain a higher level of conscience. Since collective awareness is a reflection of the institutions, in which it is generated, this conscience has to be institutionalized in higher education.

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CHAPTER 4

ECONOMIC ASPECTS OF LAND USE IN THE ATLANTIC FOREST OF RIO DE JANEIRO

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Introduction

The environmental conditions of the mountain region of Rio de Janeiro are not only favourable for the development of a fantastic forest landscape, but also for agricultural crop growth and human wellbeing.

The municipality of Teresópolis has thus evolved as a fast-growing city, famous for its leisure value to weekend tourism from the Rio de Janeiro City. The municipality has also developed fame as a major production region of horticulture products, for which production conditions as well as marketing conditions are exceptionally favourable in the relative cool and humid climate of the mountain region of Rio de Janeiro state.

From economic point of view, the following questions should be addressed:

1. Do production systems in agricultural offer a sound basis of living to the farming families?
2. What competition exists between the agricultural sector and the preservation concerns for the remnants of the Mata Atlântica?

3. What externalities occur in land-use systems?
4. What are the threats to the livelihoods of farmers?
5. Are there potentials to create a win-win situation between economic and environmental concerns?

Finally all these considerations can offer indications to decision-makers, identifying instruments for environmental policies as well as priorities for action.

Economic analysis of land use systems

Three main differences can be identified, being very much related to the production potentials depending mainly on slope and accessibility to irrigation water.

Horticulture systems have evolved where profound well drained soils can be found, mainly in the alluvial valley bottoms and mountain bases, where eroded soils are accumulated. These systems are continuously creeping up also into steeper slopes, up to where irrigation water can be pumped.

Animal husbandry systems, mainly beef cattle pasture systems, were established on slopes, covering rather large conjunctive areas, sometimes extending over several hills. Depending on the accessibility by roads, pasture systems compete with economic forestry activities, dominated by Eucalyptus. Forage production, like elephant grass and sugar cane can be found at the valley bottoms, partly competing with the horticulture production systems, although rather occupying the water logged vicinities of rivers.

All land use systems compete with the natural forest vegetation. Recent slash-and-burn activities, though, do principally occur on the slopes to give space for pasture or economic forestry land.

Horticulture farming is clearly is the most important production sector in terms of providing the livelihoods of households. Specialized horticulture farms is practiced in about 95 % of the farms, occupying about 11% of the agricultural land, while about 1 % of the farms are animal husbandry, mainly cattle farms, another 4 % are categorized as mixed systems. The share of land cover of pasture land is higher than 80 %, thus being the most significant competitor for forest land. This data was generated for the agricultural census 1995/1996, the general situation of small-scale farming in horticulture and rather large-scale farming in the animal husbandry sector is certainly unchanged (Torrico et al. 2004).

Income situation of horticulture farmers

To assess the income situation from agricultural production systems, a random sample household questionnaire (N=111) was executed in the focus area of analysis, in the Corrego Sujo watershed. The average cropping area for horticulture farms in our sample was estimated to be 0.85 ha, sustaining households of 3.8 persons in average (Friederich 2005).

In Brazil, minimum wages are a sound indicator for a minimum income required to sustain maximum 2 persons. The minimum wage is supposed to be a benchmark for wages. In the rural area, more importantly, it is paid to retired agricultural labourers, who are entitled to a monthly pension of the minimum salary, if they have reached the age of 60 and if they can prove to have worked as agricultural labourers or farmers for minimum 180 months (Brazil-MPS 2009).

In Rio de Janeiro State, the minimum salary of rural labourers was increased from 2003 to 2004 from 265 R$/Month to 290 R$/month, which is closely corresponding to the usual daily wage of 15 R$/day, if the rural labourers were employed full time (232 working days per year).

In Teresópolis, employment of rural labourers in horticulture farms is rather the exemptions, more commonly farming families are taken in as share croppers. Thus, landlords still maintain a high dependency of sharecroppers, the variation of crop shares to be delivered, marketing dependencies but also provision of inputs are manifold.

Still, looking at the average labour income generated even in the lowest income fraction, the first quartile, the available cash income is in the range of 7,000 R$ for a crop sharing family, contributing income of two minimum salaries per household. The operation area of the lowest quartile farmers was estimated to be below 0.5 ha. Labour demand per horticulture crop vary between 0.53 Manyears per ha for lettuce and 2.79 Manyears per ha for Rocket. So the average earned cash income of 7,000 R$ corresponds to a maximum labour input of 1.5 Manyears. The earned income from agricultural activities even in the relatively unfavourable dependency situation of sharecroppers is suitable to sustain a family adequately according to Brazilian standards, a situation not often found in rural areas. Tenants and land owners even have to be considered as comparatively well off.

Table 1: Income distribution in the study area, ratio of income group depending to land ownership status in 2004.

Annual Labour Income	**1. Quartile**	**2. Quartile**	**3. Quartile**	**4. Quartile**
Revenue (Brazilian Real)	23,385 R$	55,873 R$	81,810 R$	133,233 R$
Revenue minus average production costs (~60%)*	14,031 R$	33,524 R$	49,086 R$	79,940 R$
Land owners	4%	12%	10%	10%
Tenant	13%	20%	28%	38%
Crop sharers	63%	56%	41%	31%
Relative (left for free)	17%	8%	17%	21%
Not specified	4%	4%	3%	0%
*Minimum salary in Rio de Janeiro***	3,480 R$			

** Database BLUMEN; Estimation of variable production costs exempt labour costs vary between 40 – 75 % depending on the respective crop (MINHO 2005; Rent or interest on capital goods are not considered. The income of crop sharer can be reduced up to 50 %, depending on the contract.*

*** http://www.portalbrasil.net/salariominimo_riodejaneiro.htm 14/07/2009*

Income situation of animal husbandry

It was found to be very difficult to characterize animal husbandry systems, since they were discovered to often not be managed according to economic standards. The variance in stocking rates of 0.2 Tropical Gross Animal Units (TGAU) per ha up to 6.7 TGAU/ha in cattle farming suggests also a large variance in the economic performance of farms.

The productivity of land in the main economic activity of animal husbandry, in beef meat production is very low, potentially generating revenues of about 100 – 150 R$/ha per year (Barreiro 2005), not even considering production costs.

It can be concluded, that cattle farming is maintained rather for status then for income generation, often practiced by absentee farmers.

Table 2: Revenues from cattle production systems in Teresópolis, based on farm survey in 2004 (Barreiro 2005).

Cattle production system	**Revenues (R$/ha/year)**
Complete Cycle 3 years	127.8
Complete Cycle 4 years	109.4
Complete Cycle 5 years	95.2
Breeding 50%	112.9
Breeding 66%	130.2
Breeding 75%	141.4
Breeding 85%	157.6
Fattening 2 years	195.4
Fattening 3 years	120.8
Fattening 4 years	69.1

Income situation of economic forestry

In the mountainous region of Teresópolis, economic forestry has not achieved a considerable extent yet, since the accessibility of potential plantation areas is rather difficult. In comparison to other regions of Brazil, where economic forestry is linked to large scale paper industry, there are no large connected areas of Eucalyptus or Pinus plantation. Still, the economic attractiveness of economic forest has increased to comply predominantly with the demand for local markets in construction wood. Also for fuel wood there is a small local market.

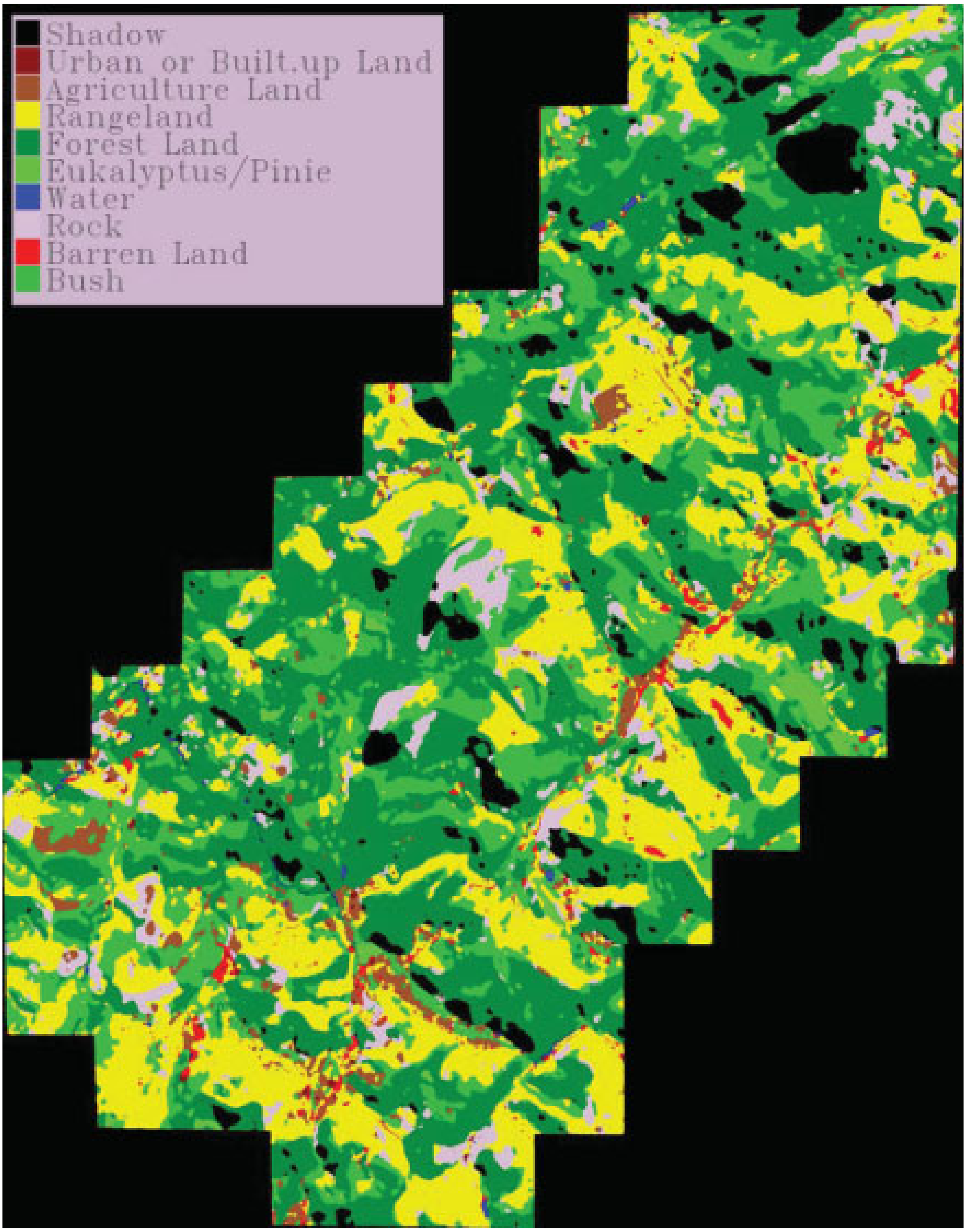

Figure 1: Land cover Côrrejo Sujo Basin.

Source: Ikonos Scene 2000-06-22 12 44 GMT (Wüstner 2005)

Since economic forestry is rather a new activity, farmers are not too familiar with the appropriate management practices, and the variance of economic performance is accordingly. Forestry activities are investment activities, the major efforts of cultivation lie in the planting year, followed by minimum four years of further input for maintaining the plantation, while revenues only are achieved in the later follow-up years. As an appropriate indicator for such an investment activity, the annuities allow to compare to gross margin calculations of short-cycle agricultural activities. In contrast to the calculations of labour income for horticulture farms above, annuity calculations do fully consider labour costs and certainly capital costs.

Annuity calculations for Eucalyptus plantations have resulted in about 1,000-2,500 R$/ha (Xiromeriti, 2009), depending on the wood quality produced. This is certainly much more profitable than animal husbandry, while horticulture systems undoubtedly have the highest potential for income generation.

Competition among land use systems and forest conservation

The topography of the mountainous land is a very important constraint on land use potentials. Horticulture farming is restricted to the flat, alluvial, well drained valley bottoms. It can be observed that attempts are made to conquer the slopes. This process is quickly succeeded by severe erosion in the steeper parts (Nehren 2006). At the valley bottoms, horticulture farming competes with auxiliary forests, which would be important for the protection of the water bodies. By law, an auxiliary vegetation belt of 30 m is foreseen, which in the reality of the study area is reduced to a few meters, if at all in existence. In Côrrego Sujo study area, the share of horticulture land is estimated to be about 3 % of the total land cover, which is a rather small share (Figure 1, Wüstner 2005).

As can be seen on the land cover classification of Corrego Sujo, base on an Ikonos Scene, the direct vicinity of forest land is mostly classified as bush and pasture land, both related to cattle production systems. Pasture land is artificial grassland, created through plantation of African gramineae, predominantly *Brachiaria decumbens*, introduced about 60 years ago (Barreiro, 2009). In the absence of grazing cattle and without care, woody species re-conquer the land, which in the bushy stage is referred to as "Capoeira" – bushland. To maintain the option of pasture use on the considerable Capoeira surface (about 20 % of the total land conver) the vegetation cover is regularly removed by the application of fire, allowing *Brachiaria decumbens* seeds to come up again. This practice is applied, before considerable trees appear, which would make the process of clearing the land much more difficult. Another very important aspect, though, is the forest protection law for the Rainforest Areas in general and the Mata Atlântica in specific. According to law (Código Florestal Lei 4.771/65, Art. 2), existing forests may not be cut down on slopes steeper than 45 %, which is the reality of most of the Capoeria land, and according to specific law for the Mata Atlântica forest [Decretos Federais Nr. 99.542 (1990) and Nr. 750 (1993)] , land owners are limited in their decisions on using their land, since the use of secondary forests of medium and advanced succession status requires permission. This means, that allowing Capoeira turning into forest is to loose decision rights for land owners, being a good reason to not allow the recuperation of forest land (Gaese et al. 2007).

Capoeira land can thus be seen rather as unused pasture land then a succession step in the process of recuperation of forest area. Combined with the pasture land actually in use, the total area preserved for cattle breeding amounts to about 47 % of the land cover, thus surpassing the share of forest land (~ 40 %) considerably (Figure 1, Wüstner 2005).

The encroachment of pasture land on existing forest land still occurs, the main competition of land use and forest conservation, though, lies in the potential recuperation area of the Capoeiria.

Externalities

Horticulture farming is intensive farming, involving intensive use of manure, mineral fertilizer and pesticides. Locally, water bodies may show considerable charges of pollutants, threatening the health of the local population. Also the practices observed in dealing with pesticides are not always suitable, lacking suitable protection clothes, cleaning of sprayers close to water bodies, etc. On a wider scale, the contribution of horticulture to water pollution is very limited through the small share of horticulture land cover and the self-cleaning capacity of water bodies, even if lacking auxiliary vegetation in the horticulture valleys. An important favourable factor is the abundance of rainfall in the area.

Erosion of horticulture in the slopes is serious. This poses mainly a threat to the eroding areas themselves.

Erosion is a constant process in the slopes, only occurring with significant differences in speed. Under forest cover, erosion processes are very slow, and thus considerable depth of soil cover can be found, although of very diverse depth. Under pasture use, the erosion process is accelerated, especially where cattle movements are concentrated, e.g. along fences and on accesses to water fountains.

The practice of applying fire for maintaining pasture land results in a total loss of woody vegetation, also along ravines of water fountains. As a result of the loss protective auxiliary vegetation around fountains and small water courses on steep slopes, water runoff and erosion is increased, leading to the temporary or even permanent drying-up of water sources for the cattle as well as for the downstream farmers. Further cattle is deprived of shadow trees, which certainly is a factor reducing the performance of cattle production, even if difficult to be expressed in specific growth rates.

Accelerated run-off in general is considered as a reason for temporary flood events in the valleys, as commented by affected farmers. Supporting measurement results need to be supplied still.

The practice of applying fire to the intended clearing of pasture land imposes a substantial risk to neighbouring forest fragments. Unintended uncontrolled burning of forests occurs rather frequently, a good reason why this practice is actually illegal.

In terms of contamination, cattle ranging threatens water courses supposed to be used as drinking water for downstream farmers. Where possible, cattle accesses water bodies to satisfy there drinking needs. During this process, water fountains are being contaminated by the animal faeces.

Threats to livelihoods

In the situation of farming systems in Teresópolis, production systems are market oriented, not subsistency systems. So the main threat to livelihood is insufficient income generation within a specific period of time. Apart of this, also the health situation has to be considered.

Livelihoods of farmers are threatened, when the household income highly depend on the farm income, and when production risks occur, meaning that revenue generation falls significantly short from expectations. This is the more severe, the longer the cropping cycle and thus the period without cash income is going on. The main threat to livelihoods deriving from short-term market fluctuations and environmental threats, such as rainfall patterns crop diseases and plagues (accounting for 10-40 % of losses, more frequent in the rainy summer season from November to February), are liquidity problems (Torrico et al. 2004).

Trends in price structures do also affect the livelihoods of farmers. As almost everywhere in the world, input prices tend to increase faster than output prices for agricultural products. Especially energy costs have been increasing in the observation period (2003-2005) and will continue to increase as a worldwide trend. This strongly affects intensive production system, in terms of increased energy-related input prices, such as mineral fertilizers and agrochemicals, and as an important factor in the region, the pumping costs for irrigation.

Erosion, increased water run-off triggering seasonal drying up of water sources and water contamination (health) are processes threatening the potential productivity of farm resources. These threats are of long-term character, erosion and changes in the hydrological situation due to wider changes in the land use cover, in the future potentially accelerated through climate change must be considered as irreversible.

The social status of farming households is an important factor for the vulnerability of farming systems. Most of the farmers are sharecroppers. Their land use rights are only securely regulated in the short term; there is certainly a high dependency on the goodwill of the landlord. On the other hand, most of the sharecroppers-landlord relationships involve the transference of part of the production risk to the landlord. Since sharecroppers are rather operating on small farm units and since they have no access to the official credit markets, sharecropping farmers must be considered as the most vulnerable group of farmers in terms of response options to liquidity problems.

Beside the landlord-sharecropper dependency, small-scale farmers tend to also depend on intermediate traders who buy the crop from the field. Further marketing requires to prepare marketable quantities of cleaned and packed produce, usually done at packing stations. Considering the large number of traders active in the region, this dependency is not severe. On the contrary, this system reduces marketing risks of the small-scale farmers substantially, even if they receive reduced producer prizes in comparison to more direct marketing channels. The margin between producer prizes and market prices varies between 20 % (lettuce) and almost 75 % (Parsley), depending on the processing requirements (Torrico et al. 2004).

For most of the farmers, the overall economic risk of production is rather low, compensation potential very high because of short production cycles of most crops. The choice of crops to be produced is very large (20 vegetable crops were considered as main crops), diversification takes place in associate or parallel plantations, on small scale rather in diversified cropping cycles. Crops with considerable marketing or production risks are mainly produced in larger farm units, accounting also for a higher average profitability of production in relation to land resources.

The above described externalities certainly have negative effects on the situation of farmers in a downstream situation. The availability of clean water from upstream fountains is at risk, which means that households might be deprived from clean drinking water and clean irrigation water for high quality production. In how far the loss of forest cover in the landscape has a positive or negative impact on farming systems is rather difficult to predict, since effects may vary a lot locally. While certainly being important for local climate and hydraulic regulations, forest fragments also might provide threats for neighbouring horticulture and husbandry farms. Pest and plague cycles may be related to the proximity of forest fragments, and risks to husbandry systems by disease vectors may occur. These factors have not yet been quantifiable, and can thus not be counterbalanced against the acknowledged ecoservices of forest in stabilizing production conditions in the wider region.

The vulnerability of horticulture farming systems on slopes is more severe than in the valley bottoms. The main potential to respond to the irreversible threat of erosion would be adequate soil management and an adaptation of the cropping systems. For the threatened areas appropriate strategies are not developed yet. Research and technology transfer strategies are necessary.

Potential win-win situation between economic and ecological concerns

The discussion above related that forest conservation is an important factor for stabilizing the ecological environment of all agricultural production systems. The stability of forest fragments is endangered principally by advancing pasture land. Considering the low profitability of extensive cattle ranging occupying the largest share of the land-use cover, this is the most promising starting point for regaining forest land, at very low opportunity costs. Ways need to be found to convince landowners to transform at least substantial parts of their land into forest land. Economic forestry might support such a process, although a complete replacement of pasture land with Eucalyptus plantations would rather be a horrible scenario.

The above discussion of present pasture management shows that a dialogue needs to be sought with large-scale landowners. Allowing the bush vegetation (Capoeira) to re-grow into forest vegetation would be a great step towards increasing forest cover and connectivity of fragments. Protection legislation seems to be rather disincentivating than to support change.

Considered as an incentive to create private areas of forest protection, IBAMA supports the establishment of private protection areas, RPPN (Reservas Particulares do Patrimônio Natural). Private investors can dedicate biodiverse forest land to become conservation units, for which the research, touristic and education use is allowed (Ambiente Brasil 2004). Creators of RPPN will receive tax preferences as an economic incentive, and IBAMA support in protection area management. Considering the fact, that potential protection land already needs to be ecologically valuable, this tool is not suitable to increase forest area. Further such a private engagement means to allow IBAMA to control environmental protection activities, while landowners have to widely give up their decision rights for their own land. Considering the status of fragmentation, it is doubtful that this tool only appropriate for comparatively large forest areas can contribute to a significant change.

However, individual reforestation initiatives in the study region prove that large landholders of pasture land might be convinced to change their land-use, appropriate conditions must be discussed.

Water quality protection is another issue to be considered, which could be easily achieved by enforcing environmental law on auxiliary vegetation belts. Considering the fact that this would withdraw the basis of livelihoods for the majority of small-scale horticulture farmers, this does not appear to be an appropriate option to achieve water protection. Instead, farmers can easily be convinced to substantially reduce the application of mineral fertilizer and agrochemicals, since these input costs are rather considerable. For the specific regional/local conditions a strategy for Integrated Pest Management needs to be developed. Being only exposed to the application information of the producers of agrochemicals and fertilizers, farmers would very much welcome to receive information on how to reduce agrochemicals from scientists or extension services. Local farmers' organisations have invited researchers from BLUMEN project to jointly establish improved strategies in phyto-sanity and fertilization.

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Chapter 5

THE CONTRIBUTION OF SERRA DOS ÓRGÃOS NATIONAL PARK TO BIODIVERSITY CONSERVATION

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Introduction

Protected areas are considered the most effective strategy to maintain natural environments in minimal conditions of human perturbation and intervention (Shaffer 1999, Bruner et al. 2001). Especially the stricter protected of these areas play an important role in the conservation of natural populations and threatened habitats (Terborgh & van Schaik 2002).

The establishment of Yellowstone National Park in 1872 was a cornerstone in the history of protected areas. Six decades later, Brazil joined this initiative, with the creation of Itatiaia National Park in 1937 and the creation of Iguaçu National Park and Serra dos Órgãos National Park in 1939. Thereafter, twenty years went by before the Brazilian government established new protected areas. In the late XX and early XXI century, the number of protected areas in Brazil increased and today, 300 national protected areas exist. Thus, on one hand, large areas have been placed under legal protection, but on the other hand, new protected areas have not been given the same structure as the first ones, and often lack minimal infrastructure and personnel to guarantee their protection. Nevertheless, even these areas, the so called "paper parks", present smaller deforestation indexes than areas without legal protection (Ribeiro & Veríssimo 2007).

Protected areas contribute to a country's social and economic objectives through supporting ecosystem services, promoting sustainable use of renewable resources, and underpinning much tourism and recreation, but they can only deliver their environmental, social and economic benefits if they are effectively managed (Hockings 2000).

This chapter presents management actions undertaken by Serra dos Órgãos National Park in order to contribute to biodiversity conservation.

Serra dos Órgãos' biodiversity

Serra dos Órgãos National Park, created in 1939, is the third oldest national park in Brazil. It is located in Rio de Janeiro state and about 90 km away from Rio de Janeiro city. The name of the national park (meaning organ mountains) is attributable to the shape of its mountains, which, seen from Guanabara Bay, reminded the first European settlers of the pipes of a church organ. Figure 1 shows the location of the park.

As of 2008, the park's area was increased by 88% (Viveiros de Castro et al., 2008; Brasil 2008), and today protects 20,030 hectares of the Atlantic Forest, one of the five most threatened biodiversity hotspots of the planet (Myers et al. 2000; Mittermeier et al. 2005). The importance of the Atlantic Forest has been internationally recognized by the establishment of a UNESCO Biosphere Reserve.

In an evaluation by the Brazilian Ministry of Environment, Serra dos Órgãos has been identified as an area of extreme biological importance for all the theme groups evaluated (flora, invertebrates, fish, reptiles and amphibians, birds, mammals and abiotic factors) (MMA 2002). The area was identified as exposed to high human pressure and pointed out as a priority area for the establishment of ecological corridors and for the management of non-protected areas.

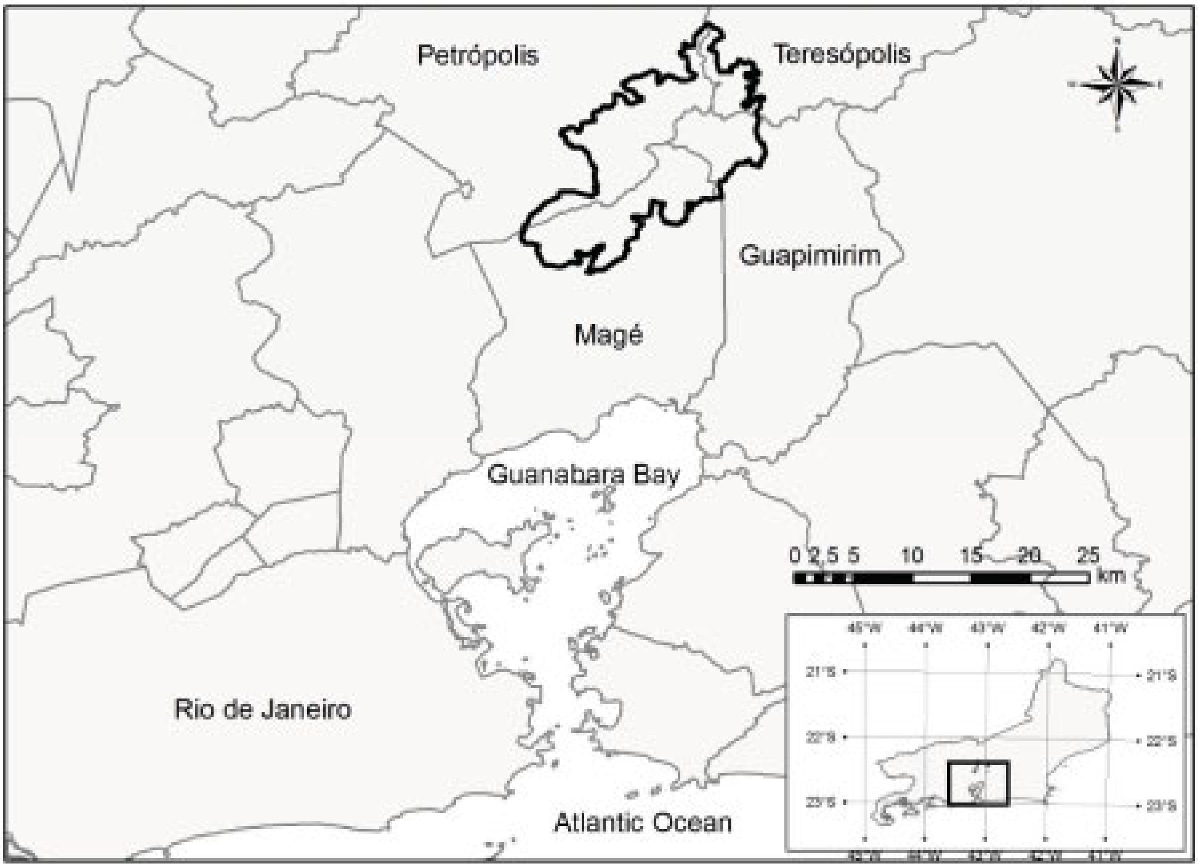

Figure 1: Location of Serra dos Órgãos National Park in relation to the municipalities of Teresópolis, Petrópolis, Magé, Guapimirim and Rio de Janeiro.

Defined as one of the strategic areas of the Project Parks and Reserves of the Pilot Program for the Protection of Tropical Forests of Brazil – PPG7, the park occupies a central position in the Serra do Mar Ecological Corridor. The park is inserted in one the largest Atlantic Forest remnants and is connected to other protected areas.

As the name suggests, the Serra dos Órgãos National park has a unique mountain relief. It is located in the higher section of Serra do Mar mountain chain. The altitude in the park varies from 80 to 2,263 meters above sea level, at a distance of approximately 13 km of the coast, with more than ten mountain peaks and 7,56% of the park's area higher than 2,000 meters.

This considerable altitudinal gradient has contributed high habitat and species richness. The park protects well conserved Atlantic Forest vegetation, which can be divided into four phytophysiognomies, according to altitude (Rizzini 1959). The national park contains more than 2,000 species of plants, amongst which some threatened species stand out, such as the imperial bromeliad *Alcantarea imperialis* and the giant fern *Dicksonia sellowiana* (Viveiros de Castro 2008).

The great habitat diversity, generated by different climate, soil types, geological and vegetation formations, can also contribute to explain the high animal diversity in Serra dos Órgãos National Park. Although gaps of knowledge exist for some taxa and most studies are concentrated in few areas, there are records of 462 species of birds, 83 of mammals, 102 of amphibians, 82 of reptiles and 6 of fish, totaling 727 species of vertebrates at Serra dos Órgãos National Park, which corresponds to 20% of the vertebrate species in Brazil (Cronemberger and Viveiros de Castro 2007) in an area of 0.00235% of the Brazilian territory, as shown in table 1.

Table 1: Number of vertebrate species in Serra dos Órgãos National Park (PARNASO), in relation to the total number of species in Brazil.

Group	PARNASO*	Brazil**	PARNASO/Total	Endangered*
Mammals	83	541	15.34%	28
Birds	462	1696	27.24%	72
Reptiles	82	633	12.95%	1
Amphibians	102	775	13.16%	16
Fish	6	2106	0.28%	2

Source: * PARNASO Management Plan; **Lewinsohn (2006).

Comparing the park's species list and the official lists of threatened animals (Bergallo et al. 2000, IBAMA 2003, IUCN 2006), there are 120 endangered animal species in the park: one invertebrate, two fishes, 16 amphibians, one reptile, 72 birds and 28 mammals, including the woolly spider monkey *Brachyteles arachnoides*, the largest primate of the Americas and one of the most threatened in the world, and *Brachycephalus didactylus*, the smallest amphibian on Earth. This numbers are undoubtly underestimated, since the available species lists are preliminary and many taxa as well as areas haven't been surveyed yet.

Serra dos Órgãos avifauna is the richest in all Atlantic Forest, with 462 bird species (Mallet-Rodrigues et al. 2007, Viveiros de Castro 2008), including 142, or 65,4% of the 217 species endemic to the Atlantic Forest (Bencke *et al*. 2006). This makes the Serra dos Órgãos the areas which is richest endemic bird species in the entire Atlantic Forest. Therefore, it is considered an IBA – Important Birding Area (Bencke et al. 2006). This area has also been identified as a KBA – Key Biodiversity Area for all the taxonomic groups analyzed (Eken et al. 2004).

Besides the importance of its biodiversity, Serra dos Órgãos National Park protects the mountain Dedo de Deus (God's Finger). The Dedo de Deus is a geologic monument that attracts many tourists and is considered a natural heritage of Brazil, as defined by the National Institute of Historic and Artistic Heritage. This mountain is the symbol of Rio de Janeiro state and is represented in the state's coat of arms.

The exceptional landscape value of the Serra dos Órgãos fascinates great numbers of tourists and represents an important factor of local development. The park receives about 100,000 visitors each year, and the mountainous landscape is an important landmark to one of the most important tourism areas in Rio de Janeiro state. The park also protects significant historic heritage such as the Chapel of Our Lady of the Conception of Soberbo, built in 1713, a remnant of the first establishments of the region.

The park plays a fundamental role in the protection of water supplies which are used by the local population and which are important for climate stabilization, benefitting the 700,000 inhabitants of the surroundings.

The main threat to the park and other forest remnants poses the pressure by the large human population in its surroundings. Urban sprawl results in forest clearing, water and air pollution and less circulation area for animals with large area requirements. Illegal hunting still takes place in the park and is another source of menace to wild animals.

National Park Management

Serra dos Órgãos National Park is located in complex scenery, not far from the large metropolitan area of Rio de Janeiro and surrounded by rapidly growing cities, such as Petrópolis and Teresópolis. Conserving this amazing biodiversity poses a challenge that requires the use of multidisciplinary tools and the extension of park activities to the outside of its boundaries. Law enforcement and repression of environmental crimes, conflict management, environmental education, research and wildlife management are some of the actions needed to achieve the goal of biodiversity conservation.

The park's management plan integrates these and other activities. The management plan is the document that establishes park's zoning, rules and the activities needed to achieve the protected area's objective (Brasil 2000). Serra dos Órgãos Park had its first management plan published in 1980. Recently, park staff elaborated a new management plan (Viveiros de Castro 2008).

Activities in the management plan are divided in thematic programs, such as protection, management, visitation and environmental education. Each program has its own goals, activities and deadlines to achieve. The park has been monitoring the achievement of planned goals ever since the management plan was published in 2008.

The park's protection program includes actions both within and outside its boundaries. Park rangers combat illegal hunting and the capture of wild animal for the pet market, deforestation, and illegal construction near the park's borders. They also analyze the environmental viability of nearby industrial and commercial projects and their possible impacts on the park.

Law enforcement rangers have issued about 1.4 million dollars in tickets for environmental felonies in 2008. The number of tickets grew by 220% since 2001. Although the number of law enforcement rangers is still not enough to take care of the entire park area and its surroundings, in recent years the park has increased its number of agents from four in 2001, to seven in 2009. The most common felony is the capture and possession of wild animals.

Animals captured inside the park and in other natural areas, mostly birds, are kept as pets in the surrounding regions. Therefore, the park's actions concerning the repression of illegal possession and traffic of wild animals contribute to the maintenance of stable natural populations. In 2008, 530 animals were received in the park, 437 of which were birds, thereof 131 of the threatened bird species *Sporophila frontalis*.

Another threat to the National Park's biodiversity is criminal fires. The park has a firefighting brigade of 42 men who work under a six-month contract each year in the dry season. Fires are common in the park surroundings, mostly related to the practice of slash-and-burn agriculture. The brigade acts to avoid these fires from hitting the park. A seconda fire source is hot-air balloons, a very dangerous but still practiced cultural habit in Brazil.

One of the greatest problems faced by restricted protected areas is the conflict of interests with human communities established in the area and its surroundings. Due to its mountainous relief, Serra dos Órgãos National Park had only about 5% of its area with prior human occupation before the park was created. Nevertheless, the park has to deal with conflicts of interests with many groups. The mediation of these conflicts is an important action to minimize the impact upon the park's biodiversity.

During the process of enlargement of the park's area, which lasted from 2006 to 2008, the park promoted ample dialogue with inhabitants of the surroundings, to negotiate the park's borders and conservation compromises with the human population. Because the human population in the surroundings of the park was sensible to conservation issues, the outcome of the dialogues was the proposition of new areas to be incorporated to the park by the residents of the surroundings, adding almost two thousands hectares to the original proposal (Viveiros de Castro et al. 2008).

The most important forum for conflict mediation and local involvement for Serra dos Órgãos National Park is its consultative council. The park's council is formed of 55 institutions such as local communities associations, environmental non-governmental organizations, governmental agencies, companies and universities. The objective of the council is to involve the local community in the park's management, to promote participative environmental management and to provide a voice to all parties interested in the management of local natural resources. The council meets every two months to discuss subjects of interest to the park and the surroundings, priorities and conflicts, acting as a space for dialogue, divulgation and environmental education.

As part of the relationship with the residents of the surroundings, the park develops an environmental education program for local schools, which includes the reception of about 8000 students a year and training programs to provide teachers with information and tools to discuss the importance of conservation in the classroom. The park staff also participates in educative events in the communities to straighten the relationship with society, and promotes environmental friendly practices in agriculture.

One strategy to sensitize nearby communities to the importance of national park conservation is to facilitate access to the park. The park offers a 50% discount for park fees for local residents. During the visit, rangers and guides as well as signs attempt to sensitize the tourists and disseminate minimum impact practices in natural habitats.

All these actions reduce negative impacts on the park, but are not sufficient to guarantee biodiversity conservation. Besides preventing and mitigating external impacts on park's biodiversity, it is important to inventory species and learn about the biology and ecology of natural populations through scientific research, to be able to propose efficient management actions.

Scientific research is one of the objectives of national parks, as established by the federal Law 9985/2000, which creates the Brazilian National System of protected Areas (Brasil 2000). Scientific research in protected areas is conducted by universities and research centers, which must require a permit to work inside protected areas. Since 2005, Serra dos Órgãos National park has been the protected area with the highest number of scientific research projects in the development in Brazil.

Serra dos Órgãos National Park stimulates management-oriented research by providing support to projects of interest. Logistic and financial support for expeditions to remote areas of the park is offered by means of partnerships, such as the partnership between the park and the concessionaire of the highway that crosses the park. This company gives financial support to five research projects selected by the park each year. Although the support is of little amount, this financial support is fundamental for the research groups to be able to afford the costs of expeditions.

Research management involves communication with scientists and institutions, discussion and dissemination of research results and planning of new research projects. The main forum of interaction between the park and the academic community is the symposium hosted yearly by the park. In these symposia, scientists and park managers discuss how to apply the results of scientific research to park's management. Research results are presented to park staff before they are published, which raises the speed to implement the scientific findings in the park's management.

Thus, the findings prompted by research on the threatened and endemic primate *Brachyteles arachnoides*, the largest primate of the Americas, were used to establish the park's zonation. Areas of occurrence of *B. arachnoides* were considered intangible zones by the park's management plan, prohibiting visitor access and guaranteeing better conditions for the persistence of this population.

Research projects that aim to evaluate impacts of visitation are of utmost value to national parks, because they have the potential to efficiently guide the parks' regulations. At Serra dos Órgãos National Park, the results of research projects about water quality (Terra and Araujo 2007), environmental impacts of camping (Schutte et al. 2008) and endemic species of Asteraceae (Heiden et al. 2007) were used to guide management actions such as closure of some camping areas, construction of restrooms, and visitor orientation on water safety.

Likewise, studies about exotic species are guiding control actions applied by parks (Ribeiro et al. 2008). The occurrence of the jackfruit tree (*Artocarpus heterophyllus*), detected in the frame of a research project, led to its quick removal by park agents. *Artocarpus heterophyllus* is an exotic tree with high dispersal ability originating from India,, which can dominate extensive areas and cause serious conservation problems, as seen in Tijuca National Park. Another research project identified the occurrence of an exotic primate species, *Callithrix penicillata*, and studied its hybridization with the native, endemic and threatened species *C. aurita*. In cooperation with the park, the scientists are not only conducting their studies, but are actually managing the population, by removing exotic and hybrid individuals.

Evaluating the effectiveness of protected areas for biodiversity conservation is a challenge faced by protected areas around the globe (Gaston et al. 2008; Ewers & Rodrigues 2008, McDonald-Madden et al. 2009). Serra dos Órgãos National Park is now addressing this challenge by implementing monitoring actions. A pilot study has already proved the feasibility of monitoring large mammals, which are good indicators of environmental quality and of the effectiveness of the connection between Serra dos Orgãos National Park and the neighboring protected areas of Três Picos State Park and Tinguá Biological Reserve. Based on this pilot study, a long term project for monitoring large mammals is being established. Starting in 2008, impacts of the BR-116 highway, which crosses the park with a length of 10 kilometers, are being monitored by the highway concessionaire, with studies on air, water and sound pollution as well as animal road-kills. These studies will be used to guide mitigation actions, such as construction of fauna tunnels and prohibition of transport of chemicals.

The next challenge will be to combine the experience of the various research groups that work at the park with the emerging results of the monitoring actions and incorporate these into an integrated biodiversity monitoring system. This will be carried out in valuable collaboration with the academic community. Serra dos Órgãos National Park has been chosen as a pilot location for the implementation of a comprehensive monitoring project by the Brazilian Ministry of Science and Technology.

The establishment of protected areas is an important conservation strategy. The challenge to protected areas is to be more than a "paper park" and to broaden their role beyond the merely legal protection of areas. Efficient management and monitoring of protected areas represent a step upward in the conservation scale, and are the more important in regions subjected to great human pressure.

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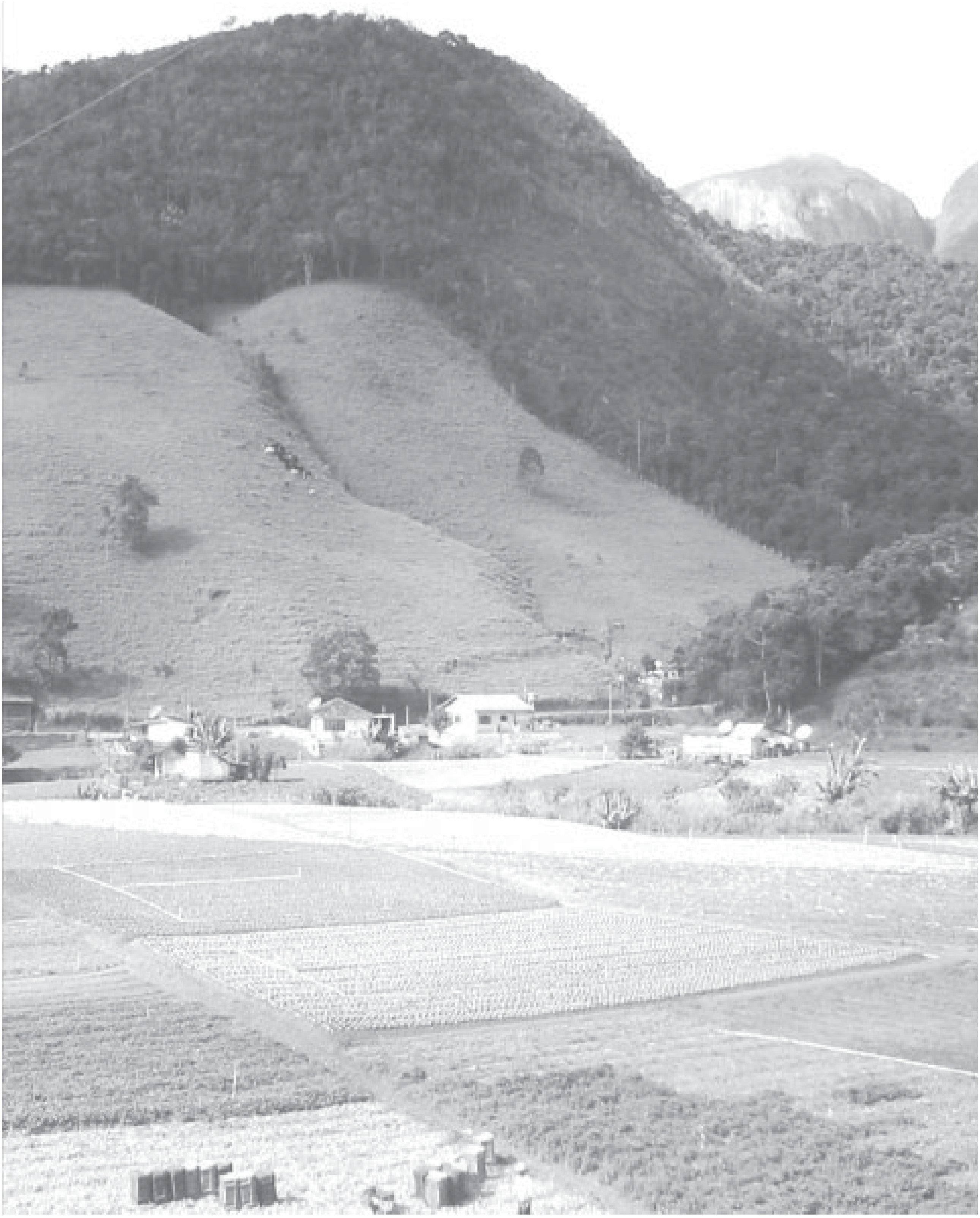
PART III

Land use systems



CHAPTER 6

ASSESSING AGRO-ECOLOGICAL SYSTEMS IN THE MATA ATLÂNTICA

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Keywords: Agro-climax, eco-climax, eco-volume, resilience, eco-capacity

Introduction

Assessing various agro-ecological systems requires combining measurement methods which are used in farming systems, ecological studies and forestry. Ideally one would have common methods applicable to all possible cases. Foresters work mainly with DBH[1] (diameter at breast height) and stem basal area at breast height (BA) as they are mostly interested in extractable bole (stem) volume. In ecological studies, all plant species and all plant parts are of interest, including weeds and root systems. In farming systems, growth studies normally consider aboveground biomass of a single crop and its harvest index *(HI)*. If root and tuber crops are to be compared with cereals, then total biomass including roots will be considered and the *HI* calculated as a fraction of the total biomass which precludes any decent

[1] See glossary at the end for definitions

comparison with the usual cereal *HI*. Finally, growth studies rely heavily on leaf area index *(LAI)* and on biomass-related parameters, because plants actually develop spatially as units of fresh mass. Both *LAI* and fresh mass change steadily according to age and to environmental conditions. Hence, assessing mixed agro-ecological stands requires adapted methods and variables.

Assessing agro-climax and eco-climax equilibria through litter study

Eco-climax is defined by Odum as the culmination state after a succession "in a stabilized ecosystem in which maximum biomass (or high information content) and symbiotic function between organisms are maintained per unit of available energy flow" (Odum 1969, p 262). When the system approaches its climax, the increase in net productivity rate of the plants is consumed by its own heterotrophs. The system comes into equilibrium and reaches peak efficiency at channelling the energy of the sun into the food web of the community (Whittaker 1970, Odum 1969). Janssens *et al*. (2005) compare the biomass production of orchards with natural systems in climax state, and propose the notion agro-climax as an alternative to that of eco-climax. Each agro-climax is characterised by a certain level of agro-diversity, contributing in its manmade way to biodiversity.

Net primary production

Net primary production ***(NPP)*** can be measured as:

$$NPP = \Delta B + L_t$$ Zhong Li et al. (2002). (Eq. 1)

Biomass (B) measured on different annual crops can be considered as a good measure of the yearly litter fall (L_t) and hence of the corresponding *NPP*. For different perennial crops the whole biomass capital is measured whereas yearly litter fall is taken as a measure of *NPP* at equilibrium of the system. This equilibrium is approached when net biomass increase (ΔB) of the system is 0.

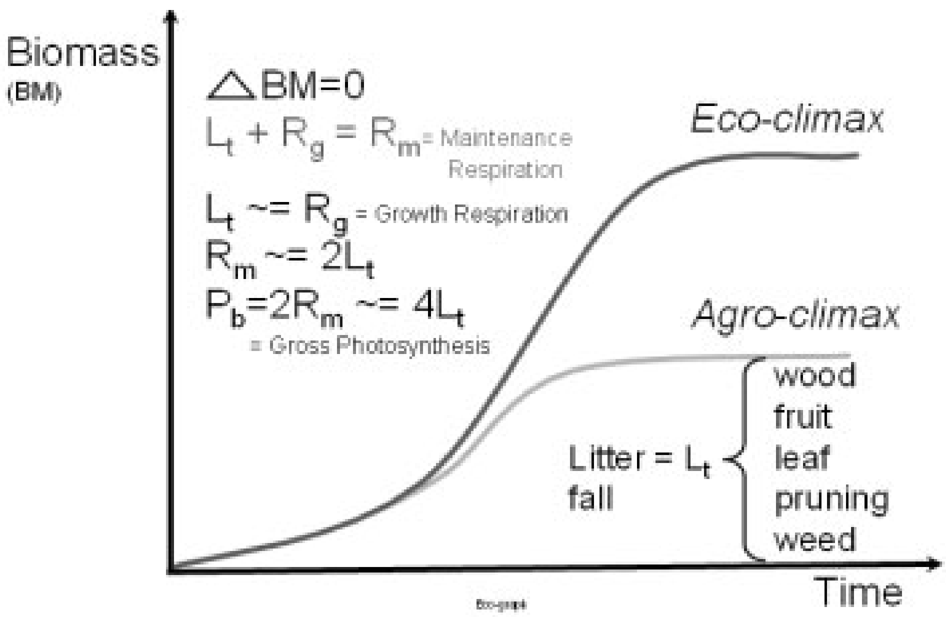
Litter

Soil litter *(L_s)* and yearly litter fall are important indicators of an agro-ecological system. At equilibrium of the system, i.e. when the net increase of the total biomass equals zero, the yearly vegetation increase is actually offset by yearly litter fall. In the latter case, yearly litter fall $L_t \sim \frac{1}{4} P_b$ or yearly gross photosynthesis $P_b \sim 4L_t$ (Janssens *et al*. 2004).

This P_b is closely related to the site index used by foresters. For annual crops, P_b will normally be smaller than that of the nearby forest. Through intensification it may be possible to approximate and even to surpass the productivity of the neighboring forest. At equilibrium of the system, the *Olson coefficient* = L_t/L_s permits easy interpretation of litter dynamics based solely on soil litter, which is much easier to collect. Ideally, one should take soil litter at maximum and at minimum level over the year.

Note that for annual crops the annual biomass production can be considered as litter fall, i.e:

$$K\text{-}_{Olson\ AC} = BM_{AC}/L_{s\text{-}AC} \qquad \text{(Eq. 2)}$$



Source: Janssens *et al.* (2006)

Figure 1: Evolution of agro-climax and eco-climax equilibria

Joining soil, vegetation and rain at agro-climax equilibrium

If $hL_t = mC$ (Nye & Greenland 1959)

when $\Delta B=0$ and where h = humification, m = mineralisation and

if $P_b =\sim 4\ L_t$ (Eq. 3)

then gross photosynthesis $P_b =\sim 4C(m/h) =\sim 4L_t$.

But if rain water efficiency $(R_{ue}) = P_T/(1+U/T)$, i.e. biomass produced/mm rain/year

where P_T = productivity of transpiration = P/T

P = biomass yield

U = unproductive water loss

T = productive water loss (transpiration),

again, there is a connexion to photosynthesis P_b and litter fall L_t through P_T at agro-climax equilibrium

$P = R_{ue}\ (T+U) = R_{ue}\ .\ Rain = NPP$ (net primary production)

$= L_t + \Delta B = L_t$ when $\Delta B=0$.

Hence,

$$P_b = 4C(m/h) = 4\ R_{ue}.Rain = 4L_t = 4L_s \times K_{Olson}. \quad \text{(Eq. 4)}$$

Issues

A problem arises when defining aboveground *NPP* and harvest index for tuber crops. All observations with tuber crops indicate very large harvest indices (*HI*) when compared with cereals, even when tuber yield is expressed w.r.t. the total above- and belowground biomass. There is a need to clarify this concept.

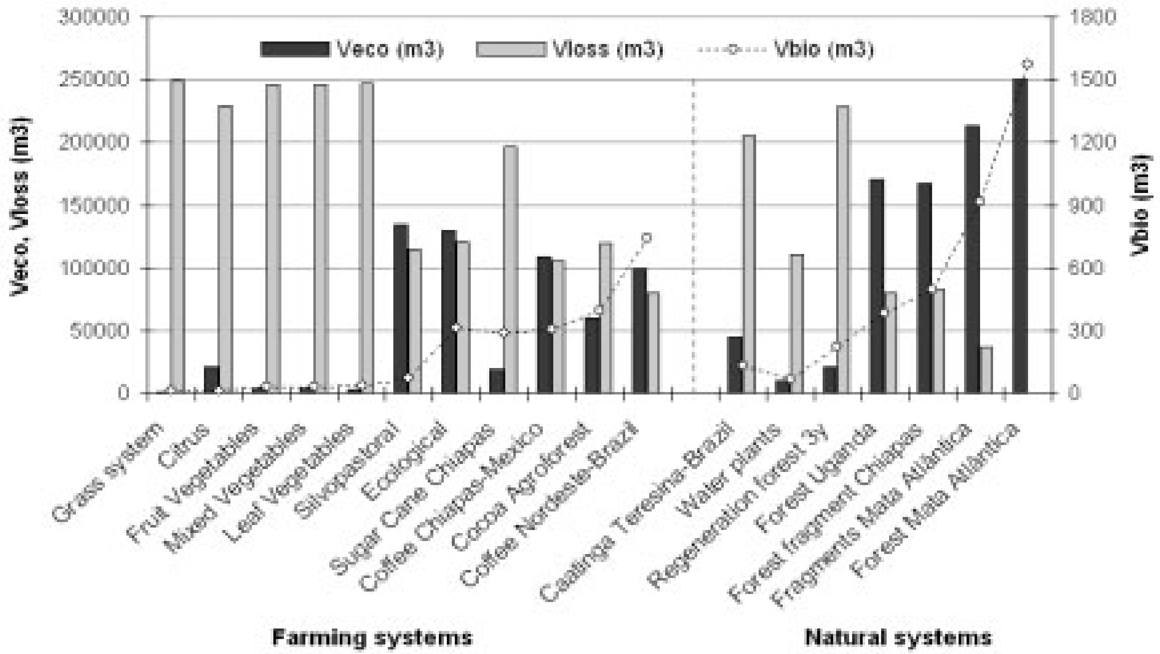
Characterising agro-ecological systems through spatial parameters

Vegetation space

Basic input data are eco-height (H_{eco}) and basal area *(BA)* for each of the land and farm use categories. Eco-height for one of the latter categories is the average vegetation heighted in time and within category community area variations. The basic output data are easy to calculate, as bio-volume *(V_{bio})* is $BA \times H_{eco}$ and eco-volume *(V_{eco})* = area x H_{eco}. In this case *BA* is taken at soil level and not at breast height. However, it is best to record *BA* both at soil level and at breast height whenever possible.

The functionality of eco-volume tends to be overlooked. Janssens *et al*. (2004) indicate that eco-volume has an effect on precipitation (additional precipitation also termed eco-precipitation[2] is generated), as well as on the regulation of the microclimate and water cycle. Eco-volume has a direct influence on such areas as water cycling, gross primary productivity *(GPP),* net primary productivity *(NPP),* and energy flow. Eco-volume is as well related to the landscape ecology concept proposed by Troll (1939) concerning interactions between environment and vegetation.The eco-climax state is considered as the stage at which eco-volume potential is highest. Hence, potential eco-volume *(V_{pot})* reflects the state of full maturity of a forest, sometimes called "climax". This stage shows a structured functional unit in equilibrium with regard to the energy and matter flows between its constituent elements, attaining maximal interactions between organisms (plant, animal and other living organisms—also referred to as a biotic community or biocoenosis) living together within their environment (biotope) andfunctioning as a limit concept (Torrico 2006; *cfr. ultra*) . Therefore, we calculate $V_{pot}=V_{loss}+V_{eco}$.

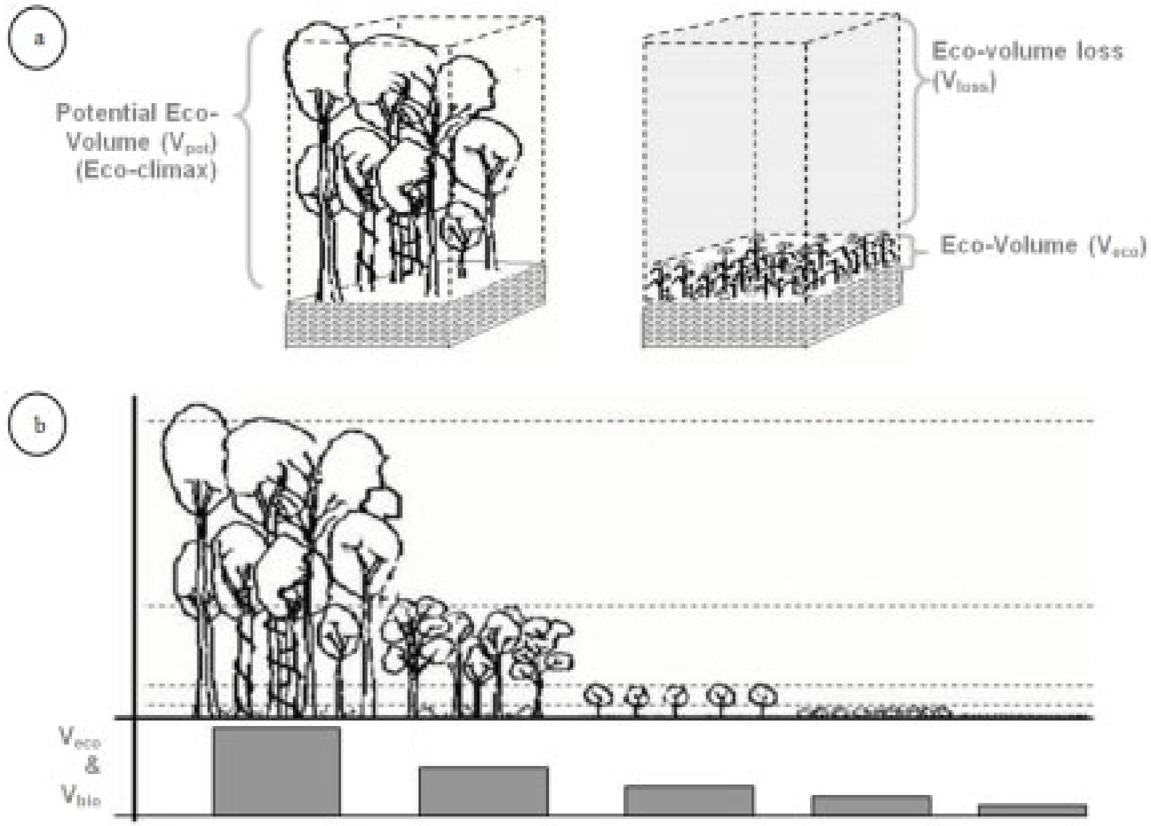
[2] *Eco-precipitation refers to complementary rains generated by ecologically sound management of a watershed basin.*



Source: Torrico (2006)

Figure 2: Eco-volume (V_{eco}), bio-volume (V_{bio}) and volume-loss (V_{loss}) of agricultural and natural systems.

The V_{pot} for the region of Teresópolis is given by the mature forest of the National Park "Serra dos Orgâos" (250,000 m^3 ha^{-1}). For the waterlogged areas where only aquatic plants may thrive, V_{eco} amounts to 120000 m^3 ha^{-1}, whereas for the coffee producing region in the northeast of Brazil, we took an average of 180,000 m^3 ha^{-1}. The Volume-loss (V_{loss}), equals $V_{po\ t}$ - V_{eco}, and represents the regression of an ecosystem in terms of V_{eco}. The bigger the V_{loss}, the bigger will be the ecosystem losses in quality, function, and services (Figure 3).



Source: Torrico (2006)

Figure 3: a) Potential Eco-volume and losst of V_{eco}. b) Different vegetation communities and their general relation in terms of $V_{eco,}$ V_{bio} and V_{loss}.

Specific weight

If we know the real volume of a mass it is easy to calculate its specific weight *(Spwt)*. In our case we are dealing with an approximate volume V_{bio} which relates differently to dry biomass as

$$S_{pwt} = B/V_{bio} \text{ in t/m}^3$$

Specific weight estimates for annual crops are far beyond reality not only because of biased estimates of bio-volumes but also because of an important *B* contribution coming from below-ground root tubers.

The eco-volume efficiency *(V_e)* expressed in dry matter yield (ton), energy *(MJ)* or money (€) per lost eco-volume appears to be a powerful discriminating tool. For example, to generate a ton of dry matter in grass and citrus systems means sacrificing 166,067 m^3 and 145,397 m^3 of V_{eco}, respectively. These represent roughly the volume of a medium-sized football stadium. This high attrition rate is due to the very low productivity of these systems. The same V_e applied to monetary units highlights the most efficient system in Teresópolis as the fruit-vegetables system with an average value of 3451 m^3 * ton DM^{-1} * ha^{-1}. If we divide V_{loss} by yield expressed in Euros, it follows that to generate one hundred Euros it is necessary to sacrifice an eco-volume as large as a football stadium. From this point of view the cattle, sylvo-pastoral and citrus systems are the least efficient systems and the most destructive of the ecosystem.

Issues

There is still further research needed to correctly define bio-volume with tuber crops. In this model only aboveground parts were taken into account. A similar problem arises when defining aboveground *NPP* and the harvest index.

The energetic content of eco-volume and ecological adaptation

In Mexico, sugar cane farmers developed an agro-climax (Janssens *et al*. 2006) where harvestable energy is concentrated by reducing eco-volume and increasing the cane–to-leaf ratio by double-burning. In Benin, forest vegetation as compared to that of annual crops deploys an impressive eco-volume per unit of energy (Figure 4).

Efficiency of spatial colonisation determines growth efficiency

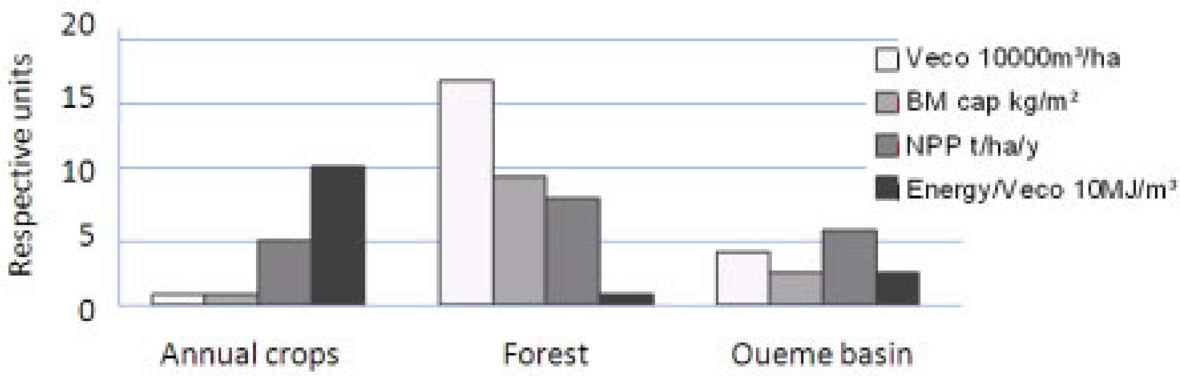
Different ways chosen by plants under different agro-ecological conditions ensure species survival and perpetuation. *Eco-volume efficiency (V_e)* relates the yield expressed either in $US or energy units to the lost V_{eco} calculated at the maximal eco-volume at eco-climax in the same locality. V_e measures efficiency against potential $V_{eco\ (V\_pot)}$.,expressed in MJ m^{-3} or $US m^{-3}. Under difficult situations plants will try to develop highly specialized reserve organs with highly concentrated energy storage. When considering eco-volume as a major characteristic of each crop morphotype or each vegetation type rather than biomass, it follows that energy and input flows should be divided by eco-volume. How large an eco-volume can be developed per unit of water or per unit of solar input, each season per year?

The principle of maximum power holds per unit of 2-D area

Natural systems are believed to evolve towards entities that become most efficient at capturing energy:

"…in the struggle for existence, the advantage must go to those organisms whose energy-capturing devices are most efficient in directing available energy into channels favorable to the preservation of the species" (A.J. Lotka 1922, p. 147);

"The maximum power principle can be stated: During self organization, system designs develop and prevail that maximize power intake, energy transformation, and those uses that reinforce production and efficiency" (H.T. Odum 1995, p.311). This theory could be verified in Benin by comparing biomass capital and yearly net primary production *(NPP)* of annual crops vs. forest stands in the Oueme Basin (Figure 3). The weight-related parameters all pointing to forests as the best accumulators and producers of energy on a surface basis, i.e. on a two-dimensional basis. However, agro-ecological systems are not a construct of weight projected on a two-dimensional plane. They actually represent a bio-volume, itself occupying a three-dimensional box.



Source: Janssens *et al*. (2009)

Figure 4: Energy allocation in agro-ecological systems is in fact spatially bound

The principle of minimum energy holds per unit of 3-D space

When expressing energy captured by agro-ecological systems in the Oueme Basin, Benin, one is struck by the fact that forest vegetation contains less energy per unit of eco-volume (Figure 4). In other words, the natural vegetation tends to evolve towards maximizing its eco-volume at the least expenditure of energy per unit. Plant growth in fact consists of developing maximum eco-volume with the minimum of energy. Furthermore, forest stands are not only more efficient than annual crops at producing *NPP*, their eco-volume/rain rate is over ten-fold that of annual crops. The principle of minimum energy is essentially a restatement of the second law of thermodynamics, which states that for a closed system, with constant external parameters and entropy, the internal energy will decrease and approach a minimum value at equilibrium (Janssens *et al*. 2009).

Calculating the transformity of agro-ecological systems (Odum 1994, 1995) will shed more light on their balance.

The agro-biodiversity signature of eco-volume unveils the eco-capacity of a system

It is believed that eco-volume is one of the important determinants of the eco-capacity of a system. This eco-volume would be compounded by intrinsic biological vitality (I_{vit}) into eco-capacity (C_{eco}) as follows: $C_{eco} = V_{eco} \,.\, I_{vit}$

What are the most important contributors to the vitality of a given eco-volume? It is surmised that the resilience of a system is a major indicator of its vitality and hence of its eco-capacity.

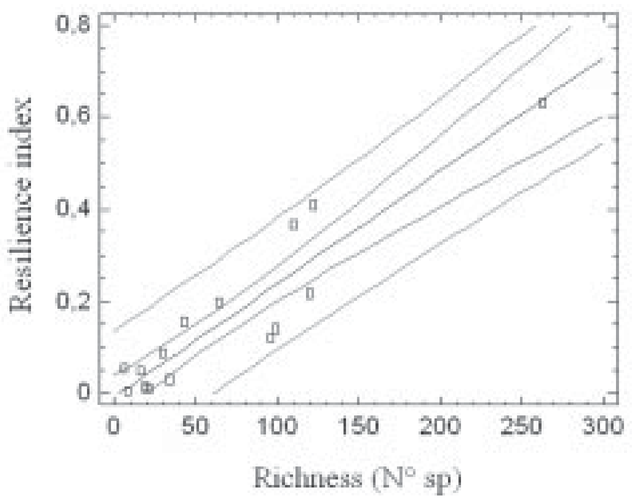
Resilience

Resilience is considered to be the capacity of a system to endure stress and bounce back. Resilience relates to the continuity of an ecosystem and its ability to endure changes, disturbances andstresses as well as to its capacity to rebuild itself to an equilibrium level, at which it is capable of achieving its ecosystem functions, and providing goods and services. The more resilient the ecosystem, the faster its capability to return to its original long-lasting equilibrium state; the bigger its ability to tolerate changes, disturbances and stresses, the higher the probability of the ecosystem being able to maintain efficient functioning (Torrico 2006).

The resilience index or R_i measures the resilience of a system by rating the actual bio-volume (V_{bio}) to the potential eco-volume (V_{pot}), or $R_i=V_{bio}/V_{pot}$. Bio-volume represents the current state of the system and V_{pot} represents the state in equilibrium of the ecosystem.

Systems with indices between 0.3 and 0.5 possess high resilience capacity. Above 0.5 systems are approaching climax (Fig. 5). Indices between 0.1 and 0.2 represent systems with average resilience capability; those smaller than 0.1 are indicative of low resilience. It is interesting to note that R_i is in fact a measure of crowding intensity $C_i = V_{bio}/V_{eco}$ (Janssens *et al.* 2004) where eco-volume is considered at its maximum climax level. It also points to the fact that high levels of bio-volume cannot be attained without a corresponding eco-volume (Torrico 2006).

Agricultural systems	Resilience (%)	Richness
Grass system	0,005	8
Citrus	0,006	8
Fruit Vegetables	0,012	19
Mixed Vegetables	0,013	21
Leaf Vegetables	0,014	19
Sylvopastoral	0,029	34
Ecological	0,124	96
Coffee Chiapas-Mexico	0,142	99
Cocoa Agro-forest	0,220	120
Coffee Nordeste-Brazil	0,411	122
Caatinga Teresina-Brazil	0,052	16
Water plants	0,054	6
Regeneration forest (3 y)	0,088	30
Forest Uganda	0,154	43
Forest fragment Chiapas	0,198	64
Fragments Mata Atlântica	0,365	110
Forest Mata Atlântica	0,630	263



Source: Torrico (2006)

Figure 5: Simple Regression - Resilience index vs. Richness. The output shows the results of fitting a linear model to describe the relationship between resilience index and richness. The equation of the fitted model is resilience index = -0.0075 + 0.0024*richness. Correlation coefficient = 0.934. R-squared = 87.3 percent

The agricultural systems with high resilience indices *(R_i)* were Coffee Nordeste in Brazil (0.41), Cocoa Agro-forest in Cameroon (0.22), Coffee in Chiapas Mexico (0.14) and Ecological horticulture in the Mata Atlântica (0.12), all four agroforestry systems. The lowest indices correspond to the grass (0.005), citrus (0.006), vegetables (0.013 on average) and sylvopastoral (0.029) systems (Fig. 5, 6a and 6b).

(a)

(b)

(c)

(d)

Figure 6a. Farming systems in Côrrego Sujo: (a) Ecological farm; (b) Fruit Vegetables; (c) Leaf Vegetables; (d) Mixed leaf and fruit vegetables.

(e)

(f)

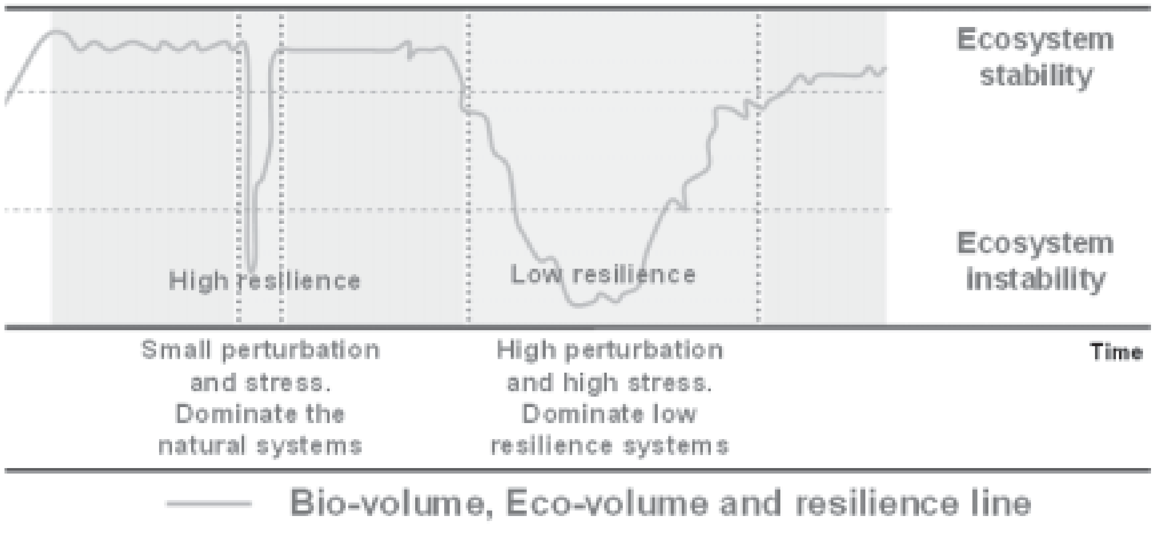
(g)

(h)

Figure 6b. Farming systems in Côrrego Sujo: (e) Cattle; (f) Sislvopastoral; (g) Citrus; (h) erosion produced by leaf vegetables systems.

When agricultural systems like cattle and vegetable systems are predominant in the landscape, the natural system can not guarantee the provision of the same goods and benefits as in the previous equilibrium state, and thus has very low resilience. The lower the natural capacity to adapt to changes, the higher is the risk to decline. Forest systems present middle to high resilience. The Atlantic rain forest is near the climax level. The aquatic plant systems and the forest in regeneration (3 years old) present a low resilience index (0.054 and 0.088 respectively). The lowest value for the index corresponds to a young Caatinga with only 0.052 (Fig. 5).

Figure 6 shows situations in relation to the stability and resilience of ecosystems. High resilience generally prevails when a system approaches stability (or climax). At climax stage an ecosystem can suffer minor perturbations or stresses, the impact of which can be quickly and easily reversed to the stable equilibrium state, e.g. small deforested areas in the rain forest. Low resilience occurs when stress and perturbations are bigger. Consequently, the ecosystem presents difficulties returning to the stable stage or needs more time and resources, e.g. current agricultural systems and cattle systems that dominate the landscapes in the Atlantic rain forest region (Fig. 7).



Source: Torrico (2006)

Figure 7. Bio-volume, eco-volume and resilience line, ecosystem stability in small perturbed and low stressed natural systems and in highly perturbed and highly stressed low resilience systems. Ecosystem stability as a function of recovery time.

Biodiversity and Resilience

Biological diversity appears to enhance the resilience of desirable ecosystem states, which is required to secure the production of essential ecosystem services (Elmqvist *et al*. 2003). Species that directly or indirectly influence the ability of the ecosystem to function will enhance resilience, in contrast to sets of species that do not have a significant role in altering the state of the ecosystem (Walker 1992). We found a statistically significant correlation of 0.93 (+/- 0.06) between resilience index and richness at 99% of confidence level (Fig. 5). The model based on the resilience index explained 87.3% of the variability. The Atlantic rain forest has the most number of species (263 species with DBH bigger than 5 cm on 0.8 hectare (Thier 2006, Seele 2005, Wesenberg 2004), while surprisingly the cocoa agro-forestry system in Cameroon and the coffee agro-forestry system in North-East Brazil have a larger number of species (120 and 122 respectively) than all other farming systems including the ecological one (Fig. 5). It is incorrect to say that we can lose many species with impunity. A cut-off stage would (eventually) arrive when there would be simply too few species to maintain basic ecosystem functions (Myers 1996). The same author finds that biodiversity contributes as an environmental service tool of semi-absolute value in the sense of reducing severe risk, but that it plays only a relatively minor role in supplying many other services. Paine (1969) and Holling *et al.* (1995) affirm that resilience may be linked to the prevalence of a rather limited number of organisms and groups of organisms (*keystone species).*

The proposed resilience index R_i could stand for the initially proposed vitality index I_{vit} and hence, eco-capacity could be re-written as

$$C_{eco} = V_{eco} \,.\, I_{vit} =\sim V_{eco} \,.\, R_i = V_{bio} \,(V_{eco}/V_{pot}).$$

This equation says that the actual measured bio-volume will have less eco-capacity if its actual eco-volume is far from the potential eco-volume. In other words, if the eco-volume loss is reduced, the bio-volume will be closest to maximum eco-capacity. Furthermore, other parameters should be integrated in the ideal vitality index, as for example the role of epiphytes.

Agro-climax amplifies the alternating concentration and dilution of natural resources

Odum (1969) describes the basic conflict between the strategies of man and the organisation of nature. The goal of agriculture as now generally practiced is to achieve high rates of production *(P)* of readily harvestable products with little standing crop *(B)* left to accumulate on the landscape, in other words, a high *P/B* efficiency. Nature's strategy/organisaton, on the other hand, as seen in the outcome of the successional process, is directed towards the reverse efficiency, a high *B/P* ratio. Economic activities want to obtain as much production from the landscape as possible, by developing and maintaining early successional types of ecosystems, usually monocultures.

From an energetic point of view, agriculture is an alternative concentration/dilution process. Yet, farmers concentrate natural resources (water, manure, plastic tunnels, etc.) in a very efficient way and subsequently dilute them over the field as efficiently as possible. South of the Sahara the efficiency of the agricultural concentration-dilution dialectic process (binome) is poor, resulting in a mining type of agriculture with frequent bush fires and poor interaction between animal and crop husbandry. The dilution of natural resources like water andfertilisers is the most critical step in agriculture (Janssens & Mulindabigwi 2009).

Domestication of natural systems into agricultural systems encompasses concentration of energy within space, i.e. reducing the eco-volume for a similar bio-volume or increasing both the bio-volume and the Wesenberg coefficient. This rationale has been followed by most sugar cane growers throughout the world by burning sugar cane twice for each harvest, enabling them to reach a higher Wesenberg coefficient and a greater energy content per harvestable bio-volume than that of green cane. By doing so 248.4 $GJ*ha^{-1}*y^{-1}$ are lost simply in the interest of concentrating harvestable energy more easily (Janssens *et al.* 2009). Eventually, the crop morphotypes/vegetation types with the largest R_{UE} (rain use efficiency) or W_{UE} (water use efficiency) or N_{UE} (nutrient use efficiency) on an eco-volume basis will take the lead in a particular environment. Hence, plants are not weight-watchers but space invaders.

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Glossary

Abundance

Percentual importance of given vegetation structure. All components add to 100% for a given vegetation type along the thinking of Braun-Blanquet

Agrobiodiversity

The many ways in the farmers use the natural diversity for production, including their choice of crops and also their management of land, water, and biota.

The dynamic variation in cropping systems, output und management practice that occurs within and between agro-ecosystems. It arises from bio-physical differences, and from the many and changing ways in which farmers manage diverse genetic resources and natural variability, and organize their management in dynamic social and economic context.(BL,1996)

Agroclimax

Janssens et al. (2004a, 2005), defines agroclimax like the relative stabile biomass production from an orchard or farming system and determines the allometric relation to estimate the gross photosynthesis. He contends that aboveground gross photosynthesis is close to four-fold the litter fall. $Bf \approx 4 * L_t$ Where: Bf = Gross photosynthesis; L_f = Litter fall

Basal area (BA)

Is the surface of the stem at breast height for usual forest inventory measurements. For estimating bio-volume one normally uses the stem surface at soil level.

Biomass capital (BM CAP)

Biomass of annual crops was estimated by weighing sample plots of different crops. For the different perennial crops the whole biomass capital is measured by using standard allometric methods.

Bio-Volume (V_{bio})

Bio-volume, is the total volume of the plants (trees, bushes, herbaceous, etc) that occupy a certain space. Hence, bio-volume of a plant is its fresh biomass divided by its corresponding *specific fresh weight*. When only dry biomass is known, the total fresh mass can be estimated by dividing total (dry) biomass through dry matter content. The concept is based on the hypothesis that plants mainly compete for space. It is expressed in m^3ha^{-1}. Based on the tube theory by West et al. (1999) a very quick approach is proposed by Janssens *et al.* (2006). If a plant is an assembly of tubes and, if all parts could be squeezed within a cylinder equivalent to the total bio-volume then V_{bio} = *Basal stem area x* H_{eco}.

Crowding intensity (C)

The crowding intensity is the inverse of the Wesenberg coefficient expressed as a percentage, or

$$C = 1/W = (V_{bio}/V_{eco})100$$

Eco-height (H_{eco})

Eco-height renders a weighted average over time and across the different vegetation community fractions. In this case, a vegetation reaches community status as from canopy closure onwards and its height will be given by the domineering (upper layer) plants.

Eco-precipitations

Are complementary rains generated by ecological sound management of a watershed basin.

Eco Volume (V_{eco})

Surface of given phytocenose or agricultural system multiplied by the eco-height. Eco-Volume normally to be expressed on ha basis. It is expressed in m^3ha^{-1}. Eco-volume is the product of the area occupied by a uniform type of vegetation and its eco-height.

Eco-Volume efficiency (Ve)

Relates the yield expressed either in \$US or energy units to the lost V_{eco} w.r.t. the maximal eco-volume at eco-climax in the same locality. It measures the efficiency in relation to the potential V_{eco} (V_{pot}). It is expressed in MJ m^{-3} or \$US m^{-3}:

$$V_e = Yield / V_{loss} = Yield/(V_{pot} - V_{eco})$$

The (Eco)-Volume-loss (V_{loss}), equals V_{pot} - V_{eco}, and represents the regression of an ecosystem in terms of V_{eco}.

Landscape homogeneity

The eco-height has been weighed for eco-volume. When weighing height of a vegetation with regard to the weight of the basal area of the different vegetation components the outcome can be considered the *dominant height (H_{dom})* of a vegetation stand, or

$$H_{dom} = \Sigma V_{bio}/\Sigma BA \qquad \text{(Sophia Bäumert 2008)}$$

And the landscape homogeneity is

$$Landscape\ homog.\% = 100 * H_{eco} / H_{dom}$$

Olson coefficient is the rate between total yearly litter fall *(Lt)* and soil litter *(Ls) = Lt/Ls*

The potential eco-volume_(V_{pot}) reflects the state of full maturity of a forest, sometimes called "climax".

Resilience Index (Ri)

Measures the resilience of the systems by comparing bio-volume (V_{bio}) with the potential eco-volume (V_{pot}). Bio-volume represents the current state of the systems and V_{pot} represents the state in equilibrium of the ecosystems.

Transformity

The ratio obtained by dividing the total emergy that was used in a process by the energy yielded by the process. Transformities have the dimensions of emergy/energy (sej/J). A transformity for a product is calculated by summing all of the emergy inflows to the process and dividing by the energy of the product. Transformities are used to convert energies of different forms to emergy of the same form. Work May be defined as organized motion and is measured in Joules (J). Work can be mechanical, electrical, magnetic, or of other origin.

Wesenberg coefficient (W)

This coefficient is the rate of eco-volume to bio-volume in m^3/m^3

$$\text{Or} \qquad W = V_{eco}/V_{bi}$$

CHAPTER 7

ENVIRONMENTAL IMPACT OF LAND USE SYSTEMS IN THE CÔRREGO SUJO BASIN TERESÓPOLIS, BRAZIL

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Abstract: This paper provides a set of indices based on emergy analysis for the Côrrego Sujo basin, Teresópolis-Brazil. Encompassing natural and agricultural systems, the Côrrego Sujo basin has been affected by destruction and fragmentation of natural habitats and unsustainable land use practices. The main objective is to evaluate the environmental impact of the land use systems, the load capacity and the use of natural and economic resources. This study was carried out in the Côrrego Sujo basin and the studied land use systems were: i) agriculture, ii) grassland and cattle, iii) rainforest, iv) forest in regeneration stages (fallow: 1, 2 and 3 years old). For this study, an emergy analysis was required. Emergy analyses integrate all flows within a system of coupled economic and environmental work in common biophysical units (solar emjoules – sej). The main conclusions are: the basin is not dependent on purchased resources and the environmental impact is moderate; the efficiency of the basin as a system is highly positive and it represents a positive contribution to the economy; the emergy exchange ratio is at a moderate level and; the biggest contributions to the system come from natural sources showing that the ecological sustainability is moderate to good.

Introduction

After the Convention of Rio de Janeiro in 1992, there was an increasing concern and interest for internalising environmental costs (Kumar 2004 and Mota 2000). The intrinsic value of natural resources such as soil as a contribution to national, regional and local economic productivity is not adequately recorded in financial planning and decision making. As a consequence, long-term sustainability is challenged by degrading natural resources (Cohen 2006) and by improper functionality of ecosystems. There is also a need to develop quantitative tools that can be used to support policy makers (Bouman 1999) in order to understand the functions of natural systems and to identify equilibrium stages within agricultural systems.

The Atlantic Forest, or Mata Atlântica, is one of the worlds most outstanding and most threatened ecosystems (Myers 1990, Myers *et al*. 2000 and Mittermeier *et al*. 2005). On the one hand, it hosts an enormous structural, floristic and faunal diversity comprising a high degree of endemism at all levels of organism organization (Fonseca 1985, Fonseca *et al.* 1999, Kinzey 1981, Morawetz & Krügel 1997, Mori *et al*. 1981 and Prance 1987). On the other hand, its destruction since the beginning of the colonization of South America has led to a dramatic reduction and fragmentation of the ecosystem (Bertoni *et al.* 1988, Dean 1996 and Leitão Filho 1987). Of the five South American biodiversity hotspots, the Atlantic Forest is the most densely populated one and comprises the smallest portion of protected areas (Mittermeier *et al*. 2005). Today some of the biggest Brazilian urban agglomerations and agricultural landscapes with different land use types are embedded in the area once almost continuously covered by the Mata Atlântica.

The reduction and fragmentation of natural ecosystems by anthropogenic impacts have elevated the rate of species extinction by thousand times the natural background rate (Pimm *et al.* 1995). However, physical and chemical qualities of landscapes are also affected by the destruction and fragmentation of natural habitats and unsustainable land use practices. Soil erosion and landslides are certainly natural processes, but they are intensified by man-made degradations (Augustin 1999, Coelho Netto 2003). Other parameters affected by anthropogenic landscape transformations are soil and air quality as well as surface and groundwater availability and quality. In turn, the negative effects of man-made habitat destruction are impairing the productivity of land use systems. In spite of this, the importance of ecosystem services has not been sufficiently recognized and appreciated by society (Tonhasca Jr. 2005).

Accelerating anthropogenic climate change will undoubtedly magnify the effects of habitat destruction and fragmentation (Thomas *et al.* 2004). Its specific effects on biodiversity have yet to be assessed for most of the biodiversity hotspots (Midgley *et al.* 2002). In general, the ongoing climate change is affecting the vulnerability of ecosystems and land use systems at economic, social and environmental levels (Parmesan & Yohe 2003 and Rahmstorf & Schellnhuber 2007). Therefore, the evaluation of related risk and resilience potentials considering climate change scenarios is indispensable for developing concepts, strategies and instruments for sustainable natural and agricultural resources management and conservation. Trade-offs and synergy analyses will help in finding an equilibrium point, as a multidisciplinary organizing principle and conceptual model for the design and organization of research and development projects in order to quantify and assess the sustainability of agricultural production systems (Crissman 1998).

In this sense, the objective this paper is to evaluate the environmental impact of the land use systems, the load capacity and the use of natural and economic resources using emergy methodology in Teresópolis, Rio de Janeiro.

Material and Methods

This study was carried out in the Côrrego Sujo basin, Rio de Janeiro, during April 2003 to December 2005. Emergy analysis was carried out to compare the main land use systems and natural systems in the municipality of Teresópolis, mountain region of the Atlantic Forest. The studied systems were: i) agriculture, ii) grassland and cattle, iii) rainforest, iv) forest in regeneration stages (fallow: 1, 2 and 3 years old). The results of these systems in the Côrrego Sujo Basin were extrapolated to the whole municipality of Teresópolis.

For this purpose, the emergy method was required. Emergy methodology (Odum 1996 and Odum 1998) is a quantitative evaluation method which valorizes the nature input to the economical systems. Emergy is a measure of direct and indirect supporting energy needed in different work processes supporting a product or a service (money, mass, energy, information), using a common unit. The procedure for the emergy evaluation is described and summarized by Haden (2003) in three steps: the first one consists of drawing the energy system diagram (Figure 1), the second one elaborates the emergy evaluation table and the third one calculates the emergy indicators as well as the summary diagrams. The summary diagrams shows all aggregated emergy inputs that come from the economy system as service or materials and from the natural system as renewable or non-renewable resources.

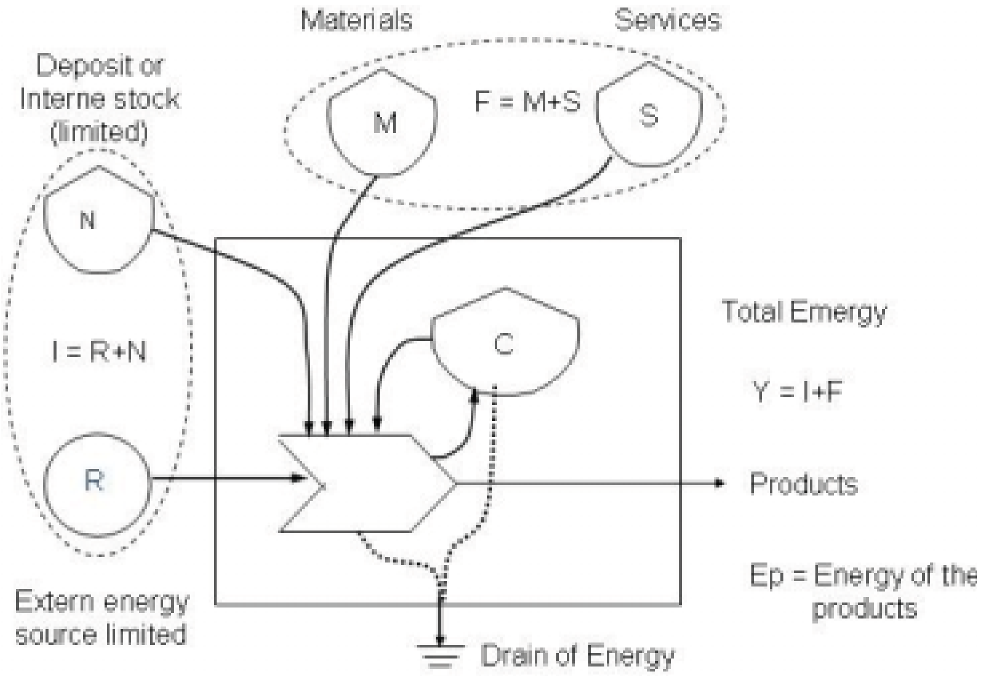

Figure 1**:** Aggregated emergy input and outputs from the economy system (service and materials) as well as renewable and non-renewable resources from the natural system.

In Figure 1, R is the sum of the renewable emergy flows supporting the economy (i.e. rain, waves, tide); N is the sum of non-renewable resources from within the system (national) boundary; M is the sum of all materials used or paid in the system; S is the sum of all services used or paid in the system; Y is the total consumed emergy; Ep is the total energy produced from the system and C is the capital of the system (biomass, biodiversity, water, soil fertility, etc). After tabulating the material and energy flow data for the system in question and correcting for their emergy contributions using transformities, a number of emergy ratios and indices can be calculated. The indices used to determine the sustainability of the “Côrrego sujo” are described in Table 1.

Table 1: Summary of the emergy indices used.

Indices	Formula	Observation
Emergy Yield Ratio	EYR = Y/F	Evaluates the efficiency of a production unit or process. If the relationship is smaller than 1 the system consumes more than what it produces;
Environmental Load Ratio	ELR = (N+F)/R.	Measures the environmental impact. When the relation has a high value it suggests that the system uses high technological levels in terms of emergy;
Emergetic Investiment Ratio	EIR = F/I.	Measures the dependence of the system from bought products, and indirectly measures the environmental loads;
Emergy Exchange Ratio	EER= Y/income*3,18E12	Measures the capital loss of the system. If the values are smaller than 1, it means that the system transfers positively to the economic urban system;
Transformity	Tr = Y/Ep (Sej/J)	Is the amount of energy expressed in (sej/J) or (sej/g), which has been used to create a flow or resource;
Renewability	%R = R/Y*100 (%)	Indicates the percentage of renewable emergy in relation to the total emergy used from the system.

Source: Adapted from Odum (1996)

Results and discussions

Description of the land cover and land use of the Côrrego Sujo basin

Land cover: Forests occupy the biggest area with 36.2%, followed by grasses (31.1 %), bushes (18.8 %), the areas corresponding to rocks, open areas, settlements (11.4%), and with 2.6 % in the last position is the crop area. In general, the wavy relief of the mountainous area is dominated by three components, the first are the fragments of the Atlantic forest that extend into the higher parts or on steep slopes; the second component is composed of hillside pastures where Brachiaria dominates, and in some cases covers complete hills; and the third component encompasses agriculture in the river-beds. Many grass swards are actively regenerating and eventually end up in bush vegetation (Capoeiras).

Land use description: The water-basin of concern in this study, "Côrrego Sujo" has a surface of 5,323 ha, which was divided into 8 basins to facilitate data collection. The digitalization of the images "Iconos" gave the following land use division: Forests occupy the biggest area with 36%, followed by grasses (31 %), bushes (19 %), areas corresponding to rocks, open areas and settlements (12 %), and last with 2.6 % is the crop area.

The most important land covers in the municipally of Teresópolis are: developed forest, forest of intermediate development, forest in initial development condition, Grasses and bushes, agricultural and vegetation of waterlogged areas (described in Chapter 1: Torrico et al. 2009).

The agriculture in the region is characterized by intensive, small (less than one ha) but often irrigated horticultural production systems. This horticultural system has little or no interaction with the cattle and forest subsystem. Inputs such as organic and inorganic fertilizers are introduced to the system. The plants are produced in the region using good quality seed. Most of the young plantlets are produced locally in specialized nurseries. The products of the system are marketed by different channels, mostly dominated by middlemen who take the production to the surrounding markets. The productive units generally opt for diversification market strategies, since the prices fluctuate quite a bit during the whole year.

From 1,793 ha under agricultural production, 74% (1,327 ha) correspond to cattle production and 2% to sylvopastoral systems. The average animal load is 11 animals pro 10 ha. Extreme values of 2 up to 67 animals pro 10 ha were found. In the humid season the average milk production is 7.5 l*day^{-1}, and in the dry season of 4.5 l*day^{-1}. After 40 months of fattening, the meat livestock produces approximately 165 kg of clean meat/head that are marketed through middlemen and sold in bordering markets. The remaining 24% is used mainly by horticultural systems. The intensive horticultural systems are the most important economic activity in the area and take up ca. 403 ha. There are mainly five types of horticultural systems in the region and they are summarized in Table 2.

Table 2: Summary of the most important farming systems.

	Eco-farm	Fruit Vegetables	Leaf Vegetables	Mixed Vegetables	Citrus
Production units (%)	2	20	58	15	5
Seeds quality	good	good	very good	very good	good
Fertilizers	any	high	high	high	low
Pesticides	any	high	high	high	any
Herbicides	any	middle	middle	middle	any
Irrigation	low	high	high	high	any
Principal product	diversified	chayote, tomato	salad, cabbage	chayote, salad	mandarin

Of the 2,954 existent establishments in Teresópolis, a little more than 2,500 have positive conditions for agricultural production. Manpower is enough to increase cultivation area or to intensify production. On the average, there are three people per farm unit who are totally dedicated to production. The population growth in the region has remained constant in the past years, i.e. less than 1% of annual growth. Forests occupy the biggest area with 36.2%, followed by the grasses (31.1 %), bushes (18.8 %), the areas corresponding to rocks, open areas, settlements (11.4%), and with 2.6 % in the last position is the crop area.

Emergy evaluation

The aggregated data for the Côrrego Sujo basin show in general that the consumption of materials and services expressed in emergy terms are very low in comparison to the total emergy used in the basin. Figure 3 shows the pathways of emergy flows in the Côrrego Sujo basin - Teresópolis. This is justified given the minimum area, approx. 1.8%, which is occupied by crops under intensive use of inputs from human economy. The biggest quantity of emergy is from natural renewable and non-renewable sources, mainly in form of water, minerals and organic matter (Table 3). The basin has a high capacity to store biomass and in emergy terms, its value is 2.1E18 sej. The loss of organic matter (3.5% average soil content) through soil erosion for the whole basin is 2.38E19 sej, in economic terms, this would represent between 1.7 and 4.9 million dollars per year.

Table 3: Summary of the yearly emergy flows for agriculture in Côrrego Sujo basin, 2005.

Name of flow	**Quantity (E+17 sej)**
Local renewable sources (R)	318
Local non-renewable sources (N)	238
Purchased resources (M)	0.41
Services and labour (S)	0.04
Emergy Yield (Y)	556
Feedback from economy (F = M S)	0.45
Biomass saved in system	21.7

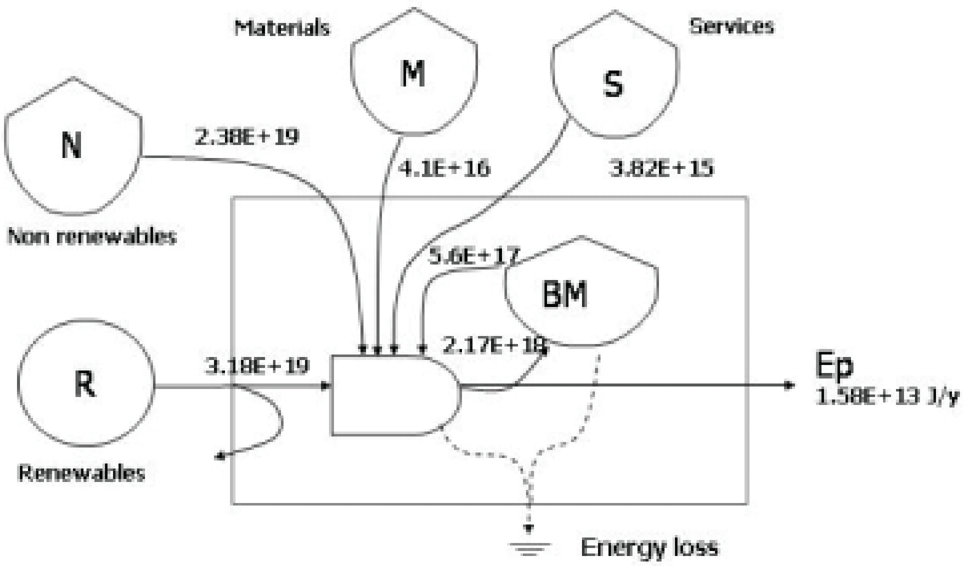

Figure 4: Overview diagram showing the main pathways of emergy flows in Côrrego Sujo agriculture, 2005. (Ep: total energy produced and BM: accumulated Biomass)

The principal renewable flows are sunlight, rainfall and minerals. Purchased goods, fertilizers, fuels, and services are also shown. Internal production systems include forests and forest in regeneration (1 to 3 years old), citrus orchards, intensive and ecological farming; livestock are shown in Figure 4.

Table 4: Computed transformity and emergy indices for the Côrrego Sujo Basin.

Description	**Value**
Transformity (Tr, sej J^{-1})	1.8E5
Net emergy yield ratio (EYR)	1234
Emergy investment ratio (EIR)	0.001
Environmental loading rate (ELR)	0.75
Renewability (% R)	57
Emergy exchange ratio (EER)	3.05

From Table 4 it can be deduced that in general, the basin is not dependent on purchased resources (EIR 0.001). The sources from the economy (material and services) increase the environmental load indirectly because it used a great quantity of non renewable sources to manufacture them. The environmental impact is moderate (ELR 0.75) as the system makes high use of renewable resources. The efficiency of the basin as a system is highly positive (EYR 1,234), which indicates that it takes more emergy from the environment than that it takes from the economic system in form of materials and services. It represents a positive contribution to the economy. The EER of 3.05 indicates that there is a certain decapitalization of the system, because it exports emergy to the urban systems at moderate to average levels. In general, the basin, considered as a system, is characterized by a half rate renewability (% R = 57) indicating again that the biggest contributions come from natural sources, which shows that the ecological sustainability is moderate to good.

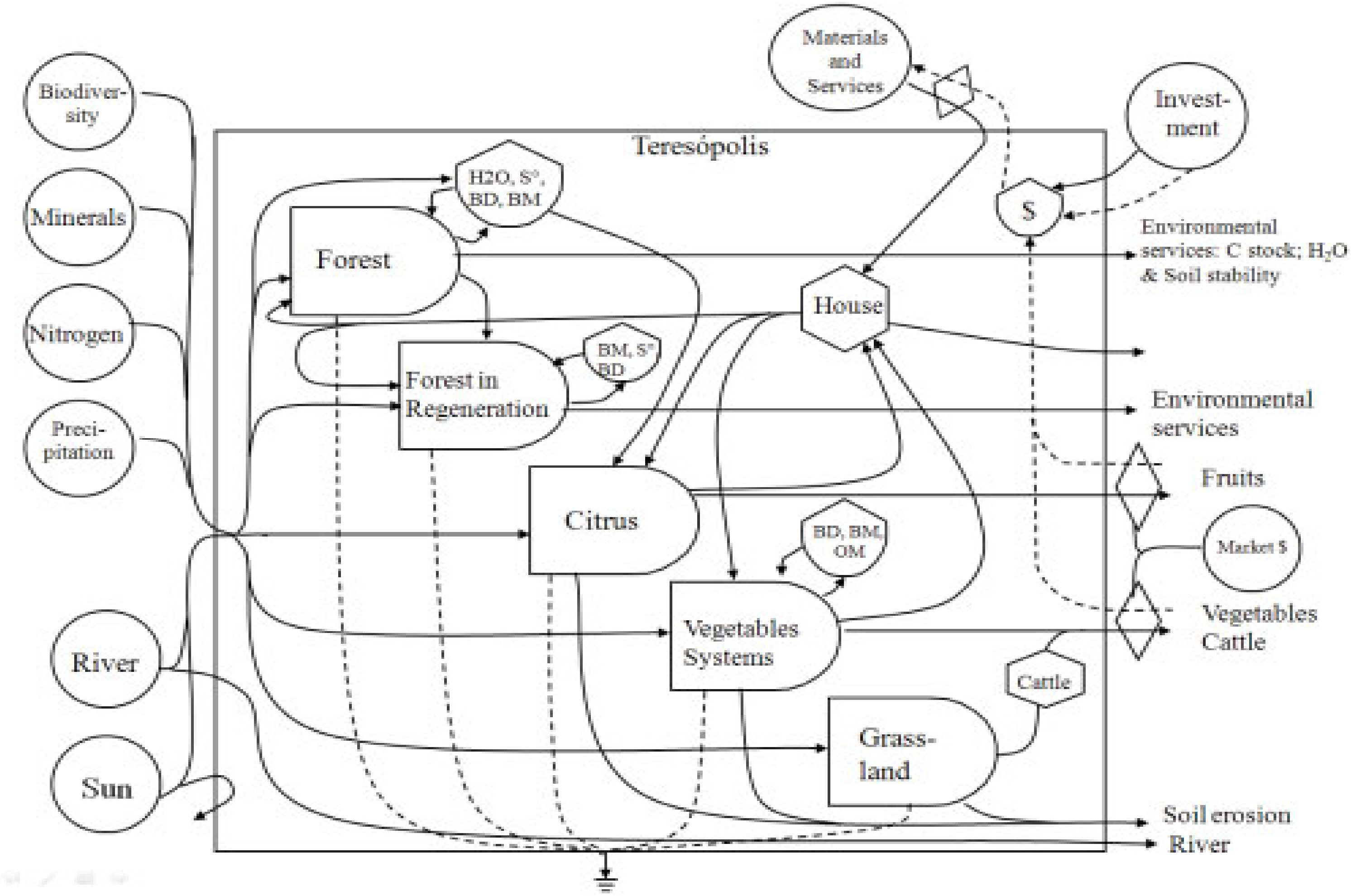

Figure 3**:** Overview diagram showing the pathways of emergy flows in the Côrrego Sujo basin - Teresópolis. Environmental/economic system depicts resource flows entering the system and the organization of major internal components that utilize those resources. BD: Biodiversity, BM: Biomass, OM: Organic Mater.

Table 5: Sensitivity analysis for the water-basin Côrrego Sujo: alternative systems to actual cattle production.

Alternative systems to actual cattle production	Variable Change			
	%R	EER	Economic	ELR
Ecological or organic systems	+++	+	+	+++
Intensive Vegetable systems	+	--	+++	o
Citrus	+	o	+	+
Forestry	++	++	++	+++
Follow	++	+	-	++

(+) low positive impact; (++) middle positive impact; (+++) high positive impact; (-) low negative impact; (--) middle negative impact; (o) neutral

From Table 5 it is possible to appreciate that the biggest positive impact in terms of emergy indices was achieved through substituting cattle production with ecological systems. In this case, the use of non-renewable energies decreased considerably down to a value of 1.17E15 sej $ha^{-1}yr^{-1}$. This value was obtained from the soil erosion at 3.5% of organic matter. In economic terms, this means that 0.3 to 0.8 million dollars are spent annually for non-renewable energy in the whole basin, which is a quite considerable quantity for such a small area, representing about 50% of the annual investment in the basin. Substituting these cattle systems with ecological or organic systems will convey clear advantages in all aspects, e.g. economically, the revenues are multiplied 4 to 12 times; ecologically the negative impact decreases and the stock of carbon and biomass increases considerably.

The ecological and organic systems considerably increase the renewability (%R) of the whole system. Then the forestry and fallow systems follow with mid-sized positive impacts. The decapitalization of the system (EER) increases when we change cattle production system into intensive vegetable systems and still remains neutral with citrus systems. The systems increase the use of natural resources (ELR) by ecological and organic systems and forestry.

In Teresópolis, annual agricultural crops and short rotation perennials (mixed systems) tend to give the greatest economic productivity per hectare per annum but have marginal or even negative returns on emergy due to inputs for soil preparation, fertilizing and harvesting in accordance with Holgrem (2003), who studied crop rotation and its effect on the emergy ratios. Long rotations and low input plantation and natural forestry (eco-farm) have lower economic productivity per hectare per annum, but can more easily be managed in a sustainable way. In addition, they can be grown on marginal land that is too poor for food production. These advantages show up as high emergy yield ratios. Farmers that organize their operations by drawing on high yield emergy sources (vegetable systems) are able to displace their fellow farmers who continue to organize their farming systems around local renewable emergy flows - a process observed in Teresópolis as a fairly rapid shift from annual farming systems to intensive chemical use farming and inefficient livestock.

The results from the vegetable systems demonstrated the increased yield per area that result from the investments in high energy resources (e.g. fertilizers, services). However, the dependence on these inputs reduces the fraction of renewable energy and increases environmental degradation, making these systems less sustainable relative to systems more dependent on renewable energies.

Dependence on non-renewable energies for larger yields may be a good strategy when non-renewable energies are readily available. However, when non-renewable energy sources are no longer available, or environmental degradation prohibits their use, agriculture will need to be reorganized to rely on the limited flow of renewable resources.

Conclusions

The landscape is dominated by three components: forests (fragments, 36.2%), grasses (31.1%) and forest regeneration (18.8%). This landscape tends to change little by little, replacing pastures either by horticulture or in places with steeper slopes, by forest regeneration. The cropped area is only 2.6% of the total available land.

The basin is not dependent on purchased resources and the environmental impact is moderate. The efficiency of the basin as a system is highly positive; it represents a positive contribution to the economy. The emergy exchange ratio is moderate . The biggest contributions to the system come from natural sources, and show that the ecological sustainability is moderate to good. The largest value of sustainability corresponds to the ecological systems in ecological terms and also it is the only one that has the capacity to save capital in form of biomass in the system. These systems use fewer resources from economy and more natural renewable resources, which guarantee its sustainability. They ensure the survival of the producer throughout time and preservation of the biodiversity. The substitution of the cattle systems with any other agricultural or forest system represents economic and environmental clear gains. The best options are the ecological, agro-forestry and forest systems.

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CHAPTER 8

SUSTAINABILITY ANALYSIS OF THE ANIMAL HUSBANDRY AGRIBUSINESS IN THE MUNICIPALITY OF TERESÔPOLIS, RIO DE JANEIRO, BRAZIL

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Abstract: As a result of deforestation, great areas in the Brazilian Atlantic Rainforest (Mata Atlântica) are covered by pastures. That gave rise to a cattle husbandry of net extractive characteristics, that does not consider the local environmental conditions, nor does it replace the extracted nutrients. At the present time, the effects of the continued degradation of pastures throughout several decades of extractive grazing can be confirmed. The main purpose of this work is the study of the sustainability of the agribusiness related to the animal production, and particularly to cattle husbandry, in the Municipality of Teresópolis, Rio de Janeiro. By means of primary data (surveys to farmers and local experts) and secondary data (literature review) the technology applied and the current socio-economic situation of the animal husbandry systems are described. Moreover, considering criteria of sustainability and the Good Agricultural Practices and the EISA Common Codex for Integrated Farming norms as reference patterns, the cattle farmers are segmented in two differentiated groups. On one side, the small cattle

farmers, whose main activity is the family agriculture, running cattle farming partially for self consumption and on the other side, the large, specialized and market-oriented cattle breeders. Although in both cases, it is not possible to consider the farming systems as sustainable in the long term, higher tendencies towards sustainability among large cattle breeders can be recognized (i.e. by obtaining greater added value to the end product than small cattle farmers). In addition, a series of guidelines for overcoming the problems and disadvantages detected are recommended. These include aspects of land use regulation, farmers´ qualification, grazing management, technical support, monitoring of pastures, sanitary management and commercialization.

Introduction

The central subject of this work is the sustainability of cattle systems in the Atlantic rainforest region (Mata Atlântica). Due to the local climatic conditions of high rainfalls and temperature, the original natural vegetation was rainforest. However, with the arrival of the first settlers to the Brazilian Atlantic coast, the surface occupied by the forest receded slowly throughout the centuries, due to the necessity of new land to cultivate cash crops like coffee and sugar cane, or to the extraction of vegetal coal and tropical woods, and finally to cattle ranching.

In the State of Rio de Janeiro, the initial nucleus of settlements, it can be noticed that the Atlantic rainforest was eliminated of all low and of easy access zones (baixada). There, only vestiges and fragments can be found, particularly in the mountain region (Serra do Mar). Mainly protected in national parks, it can be also found in small fragments located in private farms of local producers.

In 2003, of a total surface of 43,778 km^2 occupied by the State of Rio de Janeiro, nearly 30% of the state territory corresponded to Atlantic rainforest (gathering primary and secondary formations), and nearly 60% was occupied by pastures and cattle activity (Embrapa 2003). On the other hand, an independent study indicates that 100% of the State of Rio de Janeiro corresponded once to Atlantic rainforest, and that only 19.2% remained in 2000 (SOS Mata Atlântica 2002). This leads us to suggest that the present area dedicated to cattle husbandry surpasses the 60% of the state surface. The object of our study, sustainability of cattle husbandry, thus covers most of the State of Rio de Janeiro territory, which could also be extended to the situation in the neighbouring states.

Several studies support the thesis that the pastures of this region do not enjoy good health, but that they undergo a continuous process of deterioration. Currently, many initiatives are being implemented by the local government in order to revert the process of land degradation (Embrapa Solos 1999). There are several factors that in a way or another result in this progressive deterioration and threaten the long term sustainability of pastures. These factors include: continuous nutrient extraction without fertilization, overgrazing, low diversity of forage species, poaching, transit and trampling of heavy animals, and steep slopes.

Evidently, the cattle aptitude of this region, particularly the hilly Municipality of Teresôpolis, is questionable due to the prevailing pedologic, topographic and climatic conditions. The initial ecological conditions were changed and altered drastically by human intervention, transforming richly adapted native vegetation, in harmony with the surrounding environment, into a monoculture of marked different characteristics, with smaller production of biomass by surface unit and biological diversity. It is well-known the importance of pastures and cattle production for the local economy and the social communities. Thus, cattle production has to be turned into a sustainable system for the long term, as well as improved the related agribusiness in the region. To do so the present process of pasture deterioration has to be reverted and a more efficient system for the allocation of the existing resources has to be implemented. This constitutes a challenge of vital importance for the area of study.

The main objectives of this study are the followings:

i. Description of the animal husbandry systems in the Municipality of Teresôpolis, Rio de Janeiro, Brazil.

ii. Analyse the sustainability of the present cattle husbandry systems in that region.

iii. Propose some guidelines to improve animal production sustainability and minimize production risks.

Materials and Methods

In the course of the 3-months field work 24 animal husbandry farmers, including cattle, goat, sheep and horse breeders, were surveyed by means of a questionnaire.

In addition, the author was assisted by qualified local experts and technicians and rural development agencies. For input prices (veterinarian medicines, fertilizers, feeds, and mineral salts) the author turned to the stores mentioned by the farmers.

All above mentioned surveys and interviews were carried out during the months of June, July and August of 2004, in the Municipality of Teresôpolis, Rio de Janeiro. The municipal site of Teresôpolis is located at an altitude of 902 m, latitude S22°26’12’’, longitude W42°58’42’’.

Considering the surveyed production costs and incomes, the author developed an economic analysis that eased the comparison between cattle husbandry systems was carried out.

For the sustainability analysis of the animal husbandry systems, the guidelines and requirements of the Good Agricultural Practices (FAO 2003), the EISA Common Codex for Integrated Farming (EISA 2004) and the criteria exposed by Glatzle (1999) were taken into consideration. These norms and criteria are used as reference patterns in the analysis, stressing this important point.

Findings and Discussion

Description of the cattle husbandry systems

Natural- physical location: The location of the different production systems in Teresópolis agrees completely with the von Thünen Land Use Theory (Schätzl 1992), because:

Cattle are mostly located in marginal areas like steep slopes and floodable plains covered with pastures. It is usually far away from routes.

Horses, sheep and goats are bred in stables. Pastures are used for walking and exposing them to the sun, but grazing plays a secondary role. Access is usually very easy (near routes).

Agriculture is carried out mostly in plains and near routes. This fact facilitates the daily transport of inputs and products.

Farm types and structure: According to INCRA (1998) the farm types in Teresôpolis showed the following pattern: 1,264 farms occupying a total area of 40,469 ha and exploring a surface of 24,429 ha. About 51.3% of the farms in Teresôpolis were less than 10 ha in size (smallholdings), occupying only 6.7% of the explored area, whilst farms larger than 150 ha (3.4%) cover the largest portion (36.6%) of the explored area. Nonetheless, smallholdings explore 72.3% of their total area, while large farms explore only the 50.6%.

The same source indicated also that the vast majority of cattle heads (70.6% of 8,988) is distributed in medium (40-150 ha) and large farms. On the other hand, smallholdings breeding cattle keep only nearly 5 % of the total cattle herd of Teresôpolis. According to qualified local experts[3], in 2003, just 5 years later declined the number of cattle heads up to 7,912 turning the cattle herd younger and more breeders, but maintaining high stocking rates, due to the reduction of pastures area in the Municipality (Table 1). The experts stated that the vast majority (> 70%) of cattle heads is the crossbred called Mestizo or Comun race.

In accordance with IBGE (2002), horses and donkeys represented 1,236, goats 320 and sheep 202 heads.

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[3] Dra. Regina Lopes and Dr. Marcus Gouvea of the "Nucleo de Defesa Sanitaria de Nova Friburgo" - RJ, that took place on 17.08.2004.

Table 1: Cattle herd composition in 2003 in Teresópolis.

Categories	Age	Number	%
Bulls		188	2.4
Bred cows		2,354	29.8
Calves mal	< 4 months	288	3.6
Calves fem	< 4 months	309	3.9
Calves mal	4 - 12 months	578	7.3
Calves fem	4 - 12 months	594	7.5
Steers	12 – 24 months	658	8.3
Heifers	12 – 24 months	948	12.0
Steers	24 – 36 months	474	6.0
Heifers	24 – 36 months	422	5.3
Steers	> 36 months	207	2.6
Old cows	> 36 months	892	11.3
Total		7,912	100.0

Source: Núcleo de Defesa Sanitaria de Nova Friburgo-RJ (2003).

Socio demographic-features: The following conclusions about the different farmers' activities surveyed, as well as their most important features, can be drawn:

a. Animal husbandry ranks mostly as a secondary activity (75%), and it is usually associated with a status image (100%).

b. For many farmers tradition is a reason to run this business (58%).

c. Most farmers run other businesses like agriculture (42%) or trade (25%). It is also an option for pensioners (8%).

d. Other important reasons for animal husbandry are self consumption (29%) and pleasure (21%).

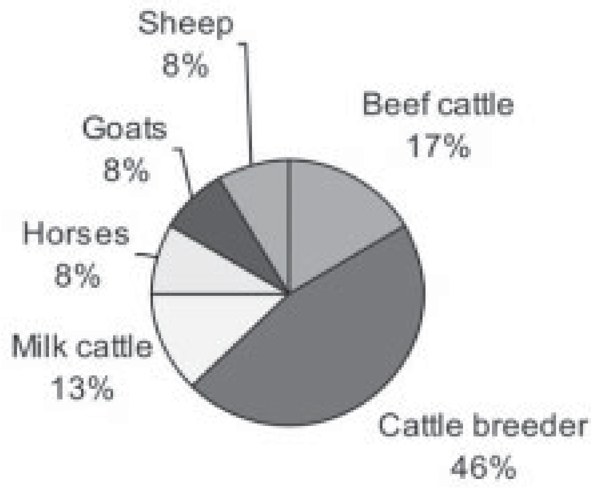
e. Among small breeders self consumption plays an important role, mixed with agriculture (70%).

f. Agriculture seems to "subsidy" cattle production among small breeders.

g. Among large breeders cattle production has status and pleasure as important reasons, but it is also market oriented.

h. The family plays a very important role in the production system. It is always present.

i. Most ranchers own their own farm (83%).



Source: Author, based on farmers' surveys.

Figure 1: Productive orientation of the surveyed farmers.

Animal nutrition: The general pastures' features in the surveyed cattle husbandry systems can be summarized as follows:

a. Cattle production is based on pastures of braquiaria (*Brachiaria decumbens*), mostly managed by alternating paddocks or continuously, but they are neither sown nor fertilized or limed and they have no leguminous.

b. Only a few ranchers rotate paddocks, have sown the pastures or feed animals with chopped elephant grass (*capim*) or sugar cane.

c. Chopped capim and animal feed are usually related to more intensive cattle production systems like dairy cattle.

d. Use of common and mineral salt constitutes is a standard management among cattle producers.

Cattle sanitary care: The cattle sanitary management among surveyed farmers looks as follows:

a. The standard sanitary handling carried out by the ranchers includes vaccination against foot-and-mouth disease (*aphthous fever*), manqueira (*carbuncle*), rabies and worms.

b. Some farmers apply an improved health handling that considers treatments against, for example, brucelosis, ticks, calf diarrhoea or more applications of vermicides.

Technology and productivity levels: the surveyed characteristics of the animal husbandry systems of Teresôpolis can be summarized as follows:

a. There is no dominant pure cattle race. Mestizo is the race most frequently found, as stated by the technicians of the Nucleo de Defesa Sanitaria do Nova Friburgo. The Mestizo cattle is not a definable race but rather a crossbred of different races, including Bos taurus and Bos indicus genetic. This indefinable race mixture is widespread in Teresôpolis and in other Municipalities of Rio de Janeiro. It has the advantages of being the cheapest alternative and its good adaptation to the local climate.

b. Only the best producers (and big ones) breed pure cattle races (e.g. Nelore) or cross them reasonably.

c. The milking procedure is mostly manual, particularly in dairy cattle. The only mechanical procedure found was the milking of goats.

d. Technical support is not widespread. The majority of farmers do not receive qualified agronomic advice. The presence of the veterinarian assessor in the animal farms is more frequent than the one of the agronomic engineer; they are usually called for sanitary management, particularly by the large cattle breeders.

e. The weight increase rates seem very low compared with productive standards. They are even among the lowest productive levels in Brazil, with a mean of 350 g/head/day (Bitencourt 2001). This means absence of technology, with degraded pastures or in process of degradation. The best weight increase was obtained in improved pastures in the Municipality of Sumidouro, not in a hilly region, but in low land.

f. The milk production shows also low values and a large seasonal variation (based in pastures): in the rainy season the milk obtained doubles the one obtained in the dry season. Another factor for the low productivity is the races: those cows with better genetic (i.e. Holstein-Frisian) produce much more milk than the others (i.e. crossbred with Gir).

Commercialization: About livestock inputs and sales of the cattle husbandry can be drawn the following conclusions:

a. Most ranchers rear their own animal reposition. That includes cattle, goat, sheep and horse offsprings.

b. Only those ranchers dedicated to beef cattle purchase steers or calves. They may sometimes buy the animals outside the Municipality. These statements are connected with the low efficiency showed by the fattening process of cattle in Teresópolis.

c. On the other hand, most ranchers sell their own steer production very young (calves of 7 – 8 months with 150 – 180 kg) or at nearly the end of the fattening process (steers 4 – 5 years with 390 – 450 kg). Old cows (300 – 360 kg) are also often sold (Table 2). These are the main cattle products in Teresópolis with the disadvantage that these beef steers are relatively aged and present hard meat.

Table 2: Prices for each end cattle product.

Categories	Price (in R$/arroba[4])	Price (in R$[5]/kg)
Fat ox (for exportation)	50	1.67
Bull	48	1.60
Cow	46	1.53

Source: Author, based on farmers' interviews.

d. Due to their genetic pattern (Mestizo) and to the long walks along the hills, their body conformation is not optimal for meat consumption. The same criticisms also apply to the old cows. Calves show two different end products. On one side

[4] 1 arroba = 30 kg
[5] 1 € = R$ 3,699240 = U$S 1,202600 (August 2004)
Source: Official euro site http://ec.europa.eu/budget/inforeuro

those calves of Mestizo crossbred; on the other side, those of industrial crossbreed using beef cattle races (e.g. Nelore, Marchigiana, Fleckvieh, Limousin) with more value added. The difference between both products and their potential, particularly due to the genetic, is reflected in the prices (Table 3). The consumer is aware of this difference and is ready to pay more for the better calves.

e. For some breeders self consumption represents a very important objective (particularly the small ones).

Table 3: Prices of calves according to genetic features.

Races	Price (R$ / arroba)	Aprox. end price (R$ / calf)
Nelore, Industrial crossbred	> 65	350 - 420
Comun, Mestizos	60	300 - 360

Source: Author, based on farmers' interviews.

Economic analysis: Basically salt consumption and the sanitary handling were considered as variable costs, while fixed cost included the worker wage and the field cost on a basis of a 100 ha pasture surface.

Based on the cost structure and the productive levels, the cattle system that reports the highest profit as well as the largest contribution margin is the two years long fattening one, reaching 420 kg of live weight at an animal age of three years (Table 4). Nevertheless, this production system is not found in Teresópolis, possibly due to the high necessary investment levels and to the prevalent natural conditions of the region (climate, soils, and topography).

Table 4: Revenues and contribution margins of cattle systems with standard and improved sanitary handling.

	Revenues (R$/ha/year)	CM improved san. handl. (R$/ha/year)	CM standard san. handl. (R$/ha/year)	Ranking
CC 3 ys[6]	127.8	95.2	103.4	5
CC 4 ys	109.4	77.0	85.1	8
CC 5 ys	95.2	63.5	71.4	9
Bred 50%	112.9	81.4	89.4	7
Bred 66%	130.2	97.6	105.9	4
Bred 75%	141.4	108.3	116.8	3
Bred 85%	157.6	124.1	132.7	2
Fat 2 ys	195.4	164.1	171.5	1
Fat 3 ys	120.8	89.0	96.5	6
Fat 4 ys	69.1	37.9	45.3	10

Source: Author, based on farmers' surveys.

The next option, based on contribution margin, is the cattle breeding system with 85% rate of wean, that is, with high levels of pregnancy, birth and wean. This productive scheme is found in Teresópolis among the large and specialized cattle producers. Thus, there is a crossing point between the models considered in this study and the field reality, confirming them.

Overall, the cattle breeding systems are clearly superior, even with 66% of wean, to the complete cycle systems and the other fattening systems (3 and 4 years long).

Similar observations can be drawn from the analysis of the profit obtain in the different cattle systems (Table 5).

[6] The abbreviations refers as follows: CC 3 ys – Complete cycle up to 3 years old, Bred 50% – Breeding cattle with 50% wean, Fat 2 ys – Beef cattle up to 3 years old.

Table 5: Profits of different cattle systems.

	Profit owner improved san. handling (R$/ha/year)	**Profit owner standard san. handling (R$/ha/year)**	**Profit renter improved san. handling (R$/ha/year)**	**Profit renter standard san. handling (R$/ha/year)**	**Ranking**
CC 3 ys	78.2	90.3	53.7	65.7	5
CC 4 ys	59.9	71.9	35.3	47.4	8
CC 5 ys	46.5	58.2	22.0	33.7	9
Bred 50%	64.9	76.6	40.2	51.9	7
Bred 66%	80.4	92.6	55.9	68.1	4
Bred 75%	91.7	103.9	67.1	79.3	3
Bred 85%	107.2	119.7	82.6	95.1	2
Fat 2 ys	146.9	158.2	122.4	133.7	1
Fat 3 ys	71.8	83.2	47.3	58.7	6
Fat 4 ys	20.9	32.1	-3.7	7.6	10

Source: Author, based on farmers' surveys.

The prevalent productive systems among the small cattle farmers in Teresópolis (i.e. long fattening periods and complete cycles) is shown to be less lucrative and of low productivity. This explains the tendency that large areas of pastures were left and dedicated to other purposes (i.e. agriculture). However, it is possible that these cattle systems fulfill the objectives considered by the small farmers, including self consumption, low productive risk and product diversification.

Sustainability analysis of cattle husbandry

Every farming production system must be sustainable in order to persist in the long term. Hence, it is worth exploring the aspects and conditions needed by a given system to be considered sustainable in the long term. According to Glatzle (1999), the following conditions must be fulfilled for a farming production system to be considered sustainable:

a. The export of products (fruits, meat, milk) must not surpass their renovation in the long term (the production must be balanced). The renovation speed depends on the potential of the natural resources (climate, soil, biotic environment) and on the applied external inputs.

b. The potential of the natural resources must not fall in the long term, due to the soil erosion, the degradation of the soil organic matter, the compaction, the creation of an ecologic imbalance (i.e. greater incidence of plagues, etc.) or other reasons.

c. Maintenance of the product exports throughout the years must not demand more external inputs every time.

d. The price of exported products must exceed the costs. Only by being economically profitable a production system can generate incomes.

Regarding the prevailing conditions in which a cattle farming is carried out in Teresópolis, it is possible to verify if the four requirements mentioned by Glatzle (1999) are fulfilled. This leads to the following comments:

a. The typical zootechnic parameters of the cattle production systems surveyed in Teresópolis show remarkable differences between the small and the large farmers (Table 6). In this point it should be remembered that the group of small farmers is very diverse and not specialized, whereas the large farmers are specialized in cattle breeding. Therefore, the better productive indexes are noticed in the latter group. It should be pointed out that other important zootechnic parameters like the extraction rate could not be calculated with the available data.

Table 6: Some zootechnic parameters of the cattle farmers surveyed in Teresópolis.

Criteria of herd productivity	Small farmers	Large farmers
Birth rate (%; base: cows and heifers allowed to service)	50 – 80	70 – 90
Yearly mortality of adult animals (%)	1 – 5	< 1
Heifer age at first service (months)	30 – 42	30
Steer age at sale (months)	42 – 48	---
Steer live weight at sale (kg)	390 – 450	---
Replacement age of bred cows (months)	72 – 180	72
Calf age at sale (months)	---	7 – 8
Calf weight at sale (kg)	---	150 – 180
Cows number per bull	4 – 22	60

Source: Author, based on farmers' surveys.

b. Significant surfaces of natural and sowed pastures in Teresópolis have been in permanent production for more than three decades after the deforestation. However, it is necessary to consider certain risk factors for the productive resources whose effects are already visible and verifiable: the soil compaction, generating bare surfaces without grass, due to cattle trampling and overgrazing. These uncovered surfaces can take the form of paths or not, and can be observed in wide zones of hills, either in pastures or within the grazed forests.

c. The dominance of only one forage specie (*Brachiaria decumbens*) evidences a low level of biological diversity, both in flora and fauna. The low biological diversity of pastures makes them more vulnerable to attacks of plagues and diseases, like the pastures "chicharrita" (*Deois flavopicta, Deois incompleta, Zulia entreriana*) that affect both brachiaria (*B. decumbens*) and elephant grass (*Pennisetum purpureum*) (Batista 2003). Nevertheless, as yet there have not been registered attacks of "chicharrita" in the pastures of Teresópolis.

d. The total deforestation, that is, the substitution of forest by pastures represents a significant lost of biodiversity too.

e. Field measurements have shown the low productivity of the pastures of *Brachiaria decumbens* in Teresópolis, consequence of the several decades under grazing without application of fertilizers.

f. In order to prove this productivity lost, it is necessary to determine biomass production by pastures and analysis of soil fertility during several years. This has to be done taking into account that the end of the mineralization of the soil organic matter after the deforestation reduces the availability of nitrogen and other vital nutrients for the pasture growth, thus limiting its production. Alternatives are suggested to replace the original soil fertility, and also improve animal nutrition, like by introduction of leguminous (e.g. *Leucena spp., Arachis pintoi*) and fertilization of pastures.

g. The economic aspect of cattle production is of singular importance. Cattle husbandry is an activity of low profit that needs a large scale to become attractive. Regarding the economical discussion it is concluded that from the economic point of view, and according to the natural resources of the region, the cattle breeding systems are the best and more suitable cattle-related productive options for Teresôpolis.

Considerations about the fulfilment of the EISA Common Codex in Cattle Husbandry and of the Good Agricultural Practices

Both norms EISA Common Codex (EISA 2004) and Good Agricultural Practices (FAO 2003) were analysed and discussed in a process that considered the following aspects: a) Organization, Management and Planning; b) Soil Management; c) Fodder Nutrition; d) Crop Protection; e) Animal Health and Welfare; f) Animal Husbandry and Environment; g) Waste Management and Pollution Control; h) Product Storage and Waste Disposal; i) Landscape, Wildlife and Biodiversity, j) Human and Social Capital.

These analysis leads also to the conclusion that the cattle husbandry systems in the Municipality of Teresôpolis are not sustainable, because of not fulfilling the requirements established by the studied norms. Particularly the small-scale cattle farmers show the biggest management problems, in comparison to the large cattle breeders with more advanced technology, which fulfil some of the norms requirements, but not completely.

Conclusions and outlook

Considering the negative results regarding the sustainability of the cattle husbandry systems in the Municipality of Teresôpolis including the ecological, economic and social points of view, some alternatives to improve the described situation in order to reach the desired sustainability are proposed.

Despite the current problems and difficulties, there are several opportunities ready to be exploited for the cattle husbandry agribusiness. The proposed recommendations involve a) land use regulation, b) farmers qualification, c) knowledge development by technical support and by introducing a monitoring system of rangeland sustainability, d) animal nutrition, e) genetic improvement, f) grazing management, g) cattle sanitary management and h) commercialization. These will surely raise the production levels of meat, milk and their sub-products in Teresópolis, as well as contribute to fulfil the requirements indicated by the studied norms and guidelines.

On one hand, both local authorities and the federal government should be active agents in leading the necessary processes of change, and in that way achieve the sustainable development needed by the region, particularly the cattle agribusiness. The efforts in this direction will complement those of the Ministry of Rural Development of the Brazilian government, that is, the effort to foster the sustainable development of the rural segment composed of family-operated farms.

On the other hand it is very important that the organised civil society get involved in the mentioned process, in order to gain politic representation by means of democratic participation of all groups of stakeholders. That way, unions of rural workers, communitarian associations of small-scale farmers and non governmental organisations should also be invited to contribute and to strengthen the whole process.

It is consider that the creation of a regional forum ("Forum Territorial") including not only the Municipality of Teresópolis but also other neighbouring Municipalities of the hilly region (Região Serrana) of the State of Rio de Janeiro that face the same challenges will contribute to solve in an organized manner the sustainability problems of cattle agribusiness. It is important to encourage a large participation of all stakeholders and groups of interest of the civil society as well as of public institutions and local authorities. The objective of this forum will be to elaborate a common strategic plan addressing the sustainability of cattle husbandry agribusiness by defining goals, activities, responsibilities and terms as well as to monitor and evaluate its implementation.

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Chapter 9

ECONOMIC ANALYSIS AND ASSESSMENT OF REFORESTATION WITH EUCALIPTUS IN THE REGION OF CORREGO SUJO TERESÓPOLIS, STATE OF RIO DE JANEIRO, BRAZIL

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Abstract: In Brazil's coastal region (Mata Atlântica), ecologically not adapted forms of land use have been practised for many decades. The question of how to manage these areas in terms of pasture use or agronomical use, especially in hillsides, is the central concern of this paper. It aims to examine if reforestations with imported species represent an ecological and economic alternative.

Introduction

Originally, the Brazilian coastal Rainforest (Mata Atlântica) covered the entire coast from Rio Grande do Sul in the south until Ceará in the north, characterized by rich biological diversity and a high endemism. The Mata Atlântica originally covered an area of 1.3 million km ^{2}; that is 15% of the Brazilian territory. Today, what remains is only about 4% of its expansion at the beginning of the colonization of Brazil (Zettel & Printz 2003). Today however it belongs to the most threatened ecological systems worldwide, since the region is the largest overcrowded area in Brazil. The rapid structural change, migration, the growth of urban agglomerations, the pressingly increasing population and agricultural land as well as the expansion of tourism have led to fragmentation and have thus endangered the Atlantic Rainforest.

The area under investigation is located in the Mata Atlântica (State of Rio de Janeiro) in the region in Côrrego Sujo (municipality of Teresópolis). Degradation is the main feature of the municipality. Ecologically unacceptable forms of land use have been practiced for many decades. Apart from the decrease of large forest areas due to their transformation into agricultural areas, this has caused the degradation and irreversible destruction of these areas. Reforestations are necessary for the redevelopment of the demoted locations and for countering the resulting timber deficit.

The question of how to manage these areas in terms of pasture use or agronomical use, especially on hillsides, is the central concern of this paper. It aims to examine whether reforestations with imported species represent an ecologically and economically viable alternative. For this purpose, we proceeded with an economic analysis and evaluation of the reforestation with eucalyptus on such demoted soils in the area under investigation.

The aim, we believe, should be to develop land use systems which are economically attractive for the farmers, but at the same time do not fail to pay regard to environmental and social aspects.

Methodology

The collection of data

For the collection of data and information interviews were carried out with people from the timber production and processing business, people from the regional authorities and administration offices , from research institutions (IEF.RJ - Instituto de Pesquisas e Estudos Florestais do Rio de Janeiro) as well as employees from the University of Rio Janeiro (UFRRJ - Universidade Federal Rural do Rio de Janeiro). Verbal and written communication methods were combined.

Primary sources (questionnaire to timber producers and processors) and secondary sources (bibliography) were used for the purpose of collecting and analyzing activities of reforestation in the region. Furthermore, the economic evaluation of eucalyptus reforestation in the region was carried out.

Survey

People from the local administration were interviewed in order to find out whether the timber producers cultivate eucalyptus or plan to cultivate eucalyptus, explore whether the existing reforestations in the region have taken place within the framework of a State development training program and whether major projects are being planned and encouraged in the future. For the interviews with the farmers, workers on sawmills and tree nurseries in the area, guidance questions were presented in the form of a questionnaire. Further information was gained during a series of more informal interviews.

Economic valuation of reforestation

Calculation of costs and revenues: For the analysis of economic expediency of eucalyptus reforestation in the region, two farms were selected as exemplary whose cultivations with eucalyptus were analyzed from the point of view of economic performance. Two family-owned farms were selected that are about [as large as] reforestation areas, but focus on different production. The first operation on an area of 12 hectares of land belongs to the medium-sized of production units in the region, while the second with an area of 6 hectares belongs to the smallholders. One farmer has a reforestation area of 3 hectares for the production of high-quality saw (Farm A); the other manufactures have 2 hectares to produce mainly firewood (Farm B). This is also a further statement about the economic attractiveness in terms of choice of the end result.

All costs for the implementation of reforestation and the sum of all revenues were calculated using the Excel spreadsheet program, resulting in a cash- flow analysis that uses the procedures of the capital value method to calculate the internal rate of return from the dynamic investment accounts, as well as in a cost-benefit analysis. These were used as tools to assess profitability.

Findings and Discussion

Changes in land use

The landscape in the examined area is dominated by crop land or horticulture farming, pasture farming and the fragmented forest. In recent years a change occurred in the use of land. The once dominant pasture land in the region has been slowly but steadily replaced by either horticulture farming or, on hillsides, by the preservation of the forest. Livestock farming decreased due to lack of profit in the region (Barreiro 2005).

In the state of Rio de Janeiro, an initiative to reforest with eucalyptus, called Pronaf Florestal, is being carried out. Eucalyptus should be planted only on hillsides and demoted soils. The project will made public in the region by the state organization EMATER. The agricultural advisory services are particularly well suited because they have direct contact with the rural population.

Timber production by reforestation with eucalyptus

In the first instance, the product of reforestation is charcoal, produced mostly in the saw mills. Long and straight trunks in particular can be sold as pole wood. Other possible products are saw log and firewood.

The farmers consider wood production in the region a safe long-term investment. Especially small family-owned farms and smallholders are trying to assure a second source of revenue with the creation of a tree nursery. Unprofitable pasture land is used for the cultivation of eucalyptus in the investigated area. Especially on slopes, degraded soils are preferred for reforestation (Ambiente Brasil 2005). According to the farmers' plantations with eucalyptus, it represents a good alternative to livestock husbandry due to its higher profitability.

After the 4th year the first thinning might occur. A thinning will be used to increase the timber yield in terms of quality and mass in the future (Niemtz et al. 2003). The 4-year-old trees deliver only very small quantities of suitable wood. The second thinning at age 6 to 8 years already provides greater financial returns.

Economic assessment of the reforestation

For investments such as a reforestation the question of economic profitability arises. This requires an economic analysis of reforestation which helps assessing whether implementation covers the criteria of the economy. Therefore, in this study different methods of the dynamic investment accounting are applied in order to gain insight on the economic convenience of reforestation with eucalyptus in the region. On the basis of two selected agricultural production units with different production focuses, the economic performance of eucalyptus reforestation in the region was examined. This was done by calculating production costs per hectare and year, a cash-flow analysis covering one period, as well as by calculating economic indicators (net present value and internal rate of return) and carrying out a cost-benefit analysis. The results of this analysis are shown in table 1. A summary of annual production cost, revenue and net revenue per ha can be appreciate in table 2 and 3.

Table 1: Shows the results of economic analysis together.

	Investment	**Net Return**	**Economic Indicators (12%)**			**Economic Indicators (16%)**		
	R $	***R $/ha***	***NPV***	***IIR***	***B/C***	***NPV***	***IIR***	***B/C***
Farm A	2,225	80,041	11,516	23.7	0.2	5,422	23.7	0.2
Farm B	3,105	44,099	8,667	25.7	2.8	4,667	25.7	2.0

R$ Brazilian real
NPV Net Present Value
IIR Internal Rate of Return (The internal rate of return may not be smaller than the adequate target rate (BRANDES & ODENING 1992).
B/C Benefits/Costs (B/C ≥1 is defined as Profit, B/C <1 as deficit and B/C = 1 as neither profit nor deficit (HANUSCH 1994).

Table 2: Summing up presentation of annually production costs, revenue and net revenue per ha as well as economic indicators, Farm A.

Year	*Costs*	*Revenue*	*Net revenue*
1	1,665	0	-1,665
2	600	0	-600
3	0	0	0
4	83	1,500	1,385
5	0	0	0
6	0	0	0
7	0	0	0
8	0	0	0
9	0	0	0
10	0	0	0
11	0	0	0
12	0	0	0
13	0	0	0
14	0	0	0
15	327	81,216	80,889
Σ	**2,675**	**82,716**	**80,041**

Table 3: Summing up presentation of annually production costs, revenue and net revenue per ha as well as economic indicators, Farm B

Year	*Costs*	*Revenue*	*Net revenue*
1	1,072	0	-1,072
2	495	0	-495
3	0	0	0
4	163	3,000	2,837
5	0	0	0
6	0	0	0
7	0	0	0
8	0	0	0
9	83	2,625	2,542
10	0	0	0
11	0	0	0
12	326	40,613	40,287
Σ	**2,232**	**46,238**	**44,099**

The results show that cultivation with eucalyptus in the investigation area of Corrego Sujo offers farmers a favourable investment possibility. The reforestation with eucalyptus can thus be classified as valid from an economic point of view.

Regarding the different production adjustments on the two selected farms, the following can be stated: the production of high-quality saw log (Farm A)is perhaps more attractive than firewood production (Farm B) in terms of profitability, yet it requires a higher amount of investment capital. The advantage of firewood production however is based on an even repayment of the capital employed.

Conclusions

Summing up, timber production through eucalyptus plantations is optimal for small to medium-sized businesses through a low-risk operation, creating medium-term profits and a secure market. The advanced timber production with eucalyptus plantations on degraded land for the study area is to be welcomed. The natural forest will be relieved as a wood supplier and at the same time financially uninteresting farmland will be exploited for the regeneration of the Mata Atlântica. Additionally, the surveyed companies will turn to ecologically sustainable forms of land use. Only the efforts of the government have been largely unsuccessful. The implementation of such alternatives was previously restricted related to sustainable forestry with fast-growing exotic species.

Ecological aspects of reforestation with eucalyptus

Apart from the economic analysis and valuation, the cultivation with eucalyptus was also analysed in terms of its ecological aspects, especially by consulting bibliographical references (data derived from related scientific literature). The reforestation with eucalyptus and its cultivation in suitable areas outside the natural forests is the only method which guarantees ample supply with forestal products in the medium term and is capable of reducing the pressure on natural forests at the same time (SBS 2001). Moreover, fast-growing species are considerably superior to the native forest species, especially if one takes into account the unfavourable conditions at such locations (Arias 2002). Therefore, sustainable forestry in demoted areas in the form of small-area reforestations with eucalyptus is to be supported not only from an economic viewpoint, but also from an ecological one.

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CHAPTER 10

THE AGRICULTURE EFFECT ON WATER QUALITY OF A WATERSHED IN MATA ATLÂNTICA RAIN FOREST, TERESÓPOLIS – RJ

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Abstract: Superficial water quality survey in one watershed of Paraíba do Sul River basin was held in order to assess the impact of the expansion of agricultural activity in the near boarder of the Brazilian Atlantic Rain Forest in Teresópolis, Rio de Janeiro State, Brazil. These catchments are important resources of water supply for some of the most populated cites of southeastern Brazil. Conventional and intensive vegetables and fruit crops are developed on high degree slopes and are usually found in association with forest areas where water resources can be tabbed for irrigation and human consumption. A great variety of pesticides are used for pest and disease control. Soil erosion, besides the lost of the riparian vegetation transports agrochemicals by runoff to creeks polluting aquatic systems. Monitoring of water quality parameters was conducted in order to classify them according to Brazilian standards and comparing to non polluted areas. The National Park of Serra dos Órgãos is one of the conservation unity of the Brazilian Agency Chico Mendes Institute for Biodiversity Conservation (ICMBio) of the Ministry of the Environment (MMA) was taken as control area of environmental quality and the priority site for monitoring springs threshold. This study evaluated the priority organochlorine pollutant, organophosphate pesticide and trace metal diffuse contamination of superficial water. Analysis of physical-chemical water quality parameters was conducted though 2004 and 2005 and shown the effect of rainfall erosion responses on the transport of sediment, pesticides and trace metals to the rivers. Organophosphate pesticides diazinon (0.88 µg L^{-1}), parathion-methyl (13.24 µg L^{-1}), malathion (13.2 µg L^{-1}) and chlorpyrifos (> 0.047 µg L^{-1}) were detected in superficial water after precipitation event. Water quality classification was in accordance to the National Council for the Environment directives CONAMA 357/05 and Healthy Ministry MS 518/04 for superficial and drinking-water quality. The methodology of water analysis was based in United State Environmental Protection Agency (US-EPA) recommended procedures. The use of screening models as criteria for identification of pesticides to be considered in a monitoring program to theses watershed were in agreement with the field data.

Keywords: Rain Forest, water, watershed risk assessment, pesticide.

Introduction

Recent documents on the fresh water availability for supplying of the world-wide economies warn to the high risk of collapse due to scarcity and to pollution (Alley et al. 2007). Although this, 70% of the drinking water resources are used in the agriculture which represents the main factor of pressure on this resource; not only due to the high consumption, but also as result of its expansion in direction to remaining natural vegetation and the risks associated to pollution raised from application of agrochemicals and erosion (FAO 2007).

The expansion of agricultural activity in the near boarder of the Brazilian Atlantic Rain Forest leads to the contamination of soil and water of the main streams of Paraíba do Sul River basin an important source of water for same of the most populated cites in the southwest (Brasil 2000). The intensive vegetables and fruit crops are developed on high degree slopes and are usually found in association with forest areas where water resources can be tabbed for irrigation and human consumption. The environmental services of rain forest in keeping the quality and quantity of fresh water are in great risk due to the type of farming systems developed and variety of pesticides used for pest and disease control. As a consequence of the lost of the riparian vegetation, soil erosion transports agrochemicals by runoff to the stream polluting aquatic systems.

The composition of natural water in small watershed is a result of the chemical composition of the rocks, vegetation and land uses. So a change in the land use impacts the composition of fresh water as it comes into contact during the runoff process.

Crop production in mountainous region of Rio de Janeiro is characterized to the high use of agricultural chemicals, occupation of the slopes and the suppression of the riparian vegetation. One of the most important characteristics of this type of handling is that from the moment they implant new areas of agriculture, erosion occurs and the transport of sediments for the channels contributing for alteration of the chemical, physical and biological properties of superficial and ground waters (Coelho Neto 2001).

Fertilizer and lime addiction is a frequent practice to compensate low fertility of oxisoils (Alvarez et al. 1996). As a consequence, nutrients and metals are transported to the channel causing a great ecological impact to the aquatic environment (Guadagnin et al. 2005). Most contaminants are easily transported when absorbed to soil clay particles released by erosion according to tillage system.

The fate of commonly used pesticides in tropical soil in area of intense corn and soybean cropping in Mato Grosso was studied by LAABS et al. (2000) and they showed that up to 70% of the samples had detectable levels of pesticides. The most frequent pesticide occurring in surface water were endosulfan compounds (-α, -β, -sulfate), ametryn, methalochlor, and metribuzin. Gomes et al. (2001) monitoring the ground water in a catchment of extensive sugar-cane crop in Ribeirão Preto, SP, detected tebuthiuron in groundwater. Mattos (2002) assessed the herbicide Glyphosate and its metabolite aminomethylphosphoric acid (AMPA) in water samples of a rice crop in south region.

The intensive use of pesticide is not only associated to the large agro-business systems. A pilot survey of organophosphorous and fungicides in water and sediment samples using immunoassay and gas chromatography techniques in farm systems in Rio de Janeiro, detected the occurrence of two pesticides, folpet and chlorothalonil, that exhibit a high persistence in the tropical environment (Oubiña et al. 1998). The same area was recently monitored and the results showed the contamination of 70% of water samples (Veiga et al. 2006). Marques et al (2002) determined the most commonly pesticides in use to vegetables in small cooperative system of production around a dam of Parnaíba River northwest, Brazil. The priority pesticides assessed in this study, carbendazin, fenvalerate, monocrotophos, piramicarb and trichlorfon are systematically applied to crop of diary vegetables consumed by the metropolitan population near theses production areas. Moreira (2002) assessed the health impact of pesticides on a community of Nova Friburgo, RJ. The concentration of organophosphorous and carbamate pesticides in water was higher than the limit of detection of the enzymatic method utilized (20 $\mu g\ L^{-1}$ of methyl-parathion). The values found in water samples in three monitoring points ($76.80 \pm 10.89\ \mu g\ L^{-1}$, $37.16 \pm 6.39\ \mu g\ L^{-1}$, $31.37 \pm 1.60\ \mu g\ L^{-1}$) demonstrates the risk exposure of the population to contamination of drinking and irrigation water. More than thirty different agrochemical formulations are routinely used in tomato, pepper, watercress, lettuce, cabbage, cauliflower and others leaf vegetables. Some of these pesticides are highly toxic like the herbicide paraquat and metamidophos an organophosphorous insecticide well known because of its high neurotoxicity. These results demonstrate the high vulnerability of water resources and the chemical risk for environment and human consumption.

The pathways by which pesticides reaches a water body are drift, runoff and leaching (schnoor 1992). Most contaminants are easily transported associated to clay particles due to erosion process (Hemond & Fechner-Levy 2000). A pesticide survey depends on a great effort and laboratorial structure because of the large number of agrochemical used, so a monitoring survey needs to establish a priority list of target molecule and sampling points (Einax et al. 1997). The standard settings determination of water quality classification was in accordance to CONAMA

357/05 (Brasil 2005) and MS 518-GM/04 (Brasil 2004) Brazilian directives for superficial and drinking-water quality. But besides de priority organic pollutants listed, a larger number of authorized and non-authorized classes of organic compounds are commonly found in conventional crop system. To access the risk of chemical contamination to agricultural chemicals via drinking water it was proposed the use of computer models as an auxiliary tool for predicting regional exposure from field-scale and to select the priority pollutants for monitoring survey.

The adoptions of pesticides indicators are the recommended strategy used by US-EPA (Wauchope 2006) and Europe directive (Tiktak 2004). A great number of models have been developed for assessing the potential for crop chemicals to move through or over soil and enter a water body (Gustafson 1995). In Brazil the use of computational models to assess the ecological risk to agricultural chemical was proposed by Spadotto (1996). The principal worry of this group is the risk of contamination of the Guarani aquifer in sugar-cane crop in Ribeirão Preto, São Paulo (Spadotto 2002).

The Córrego Sujo watershed (53.5 km²) was chosen for field investigation on the relationship between, pesticide loadings runoff and the water quality. In this preliminary work a survey was conducted in the period of 2004-2005 to describe the watershed characteristics and screening models were used to assess the potential of pesticide contamination.

Study Area

The geographic locations of the sampling points are listed in table 1. In this work we selected the three main springs in well preserved forest fragments and different agricultural activity are developed downstream of these creeks to the principal channel. Figure 1 illustrates the hydrological map of the watershed sampling points.

Materials and methods

Monitoring of water quality parameters was conducted in order to classify the resource according to Brazilian standards. pH, temperature, electrical conductivity, dissolved oxygen, total coliforms and E. coli, metals and anions were analyzed for evaluation of pollutants input.

Table 1: Sampling points identification by UTM[7] in the Córrego Sujo watershed, GPS (Global Position System - Datum WGS84).

LOCALIZATION	CODE
0729835 / 7542546	NJP
0729181 / 7542964	SJP
0727224 / 7542980	NFSL
0727153 / 7541599	CSFSL
0725665 / 7541813	NRS
0725770 / 7540610	NORS
0725770 / 7540610	Pt1RS
0725847 / 7540019	Pt2RS
0725993 / 7539792	CSRS
0720178 / 7535148	SCS

[7] UTM – The Universal Transversal de Mercator is a grid-based method of specifying locations on the surface of the Earth that is a practical application of a 2-dimensional Cartesian coordinate system

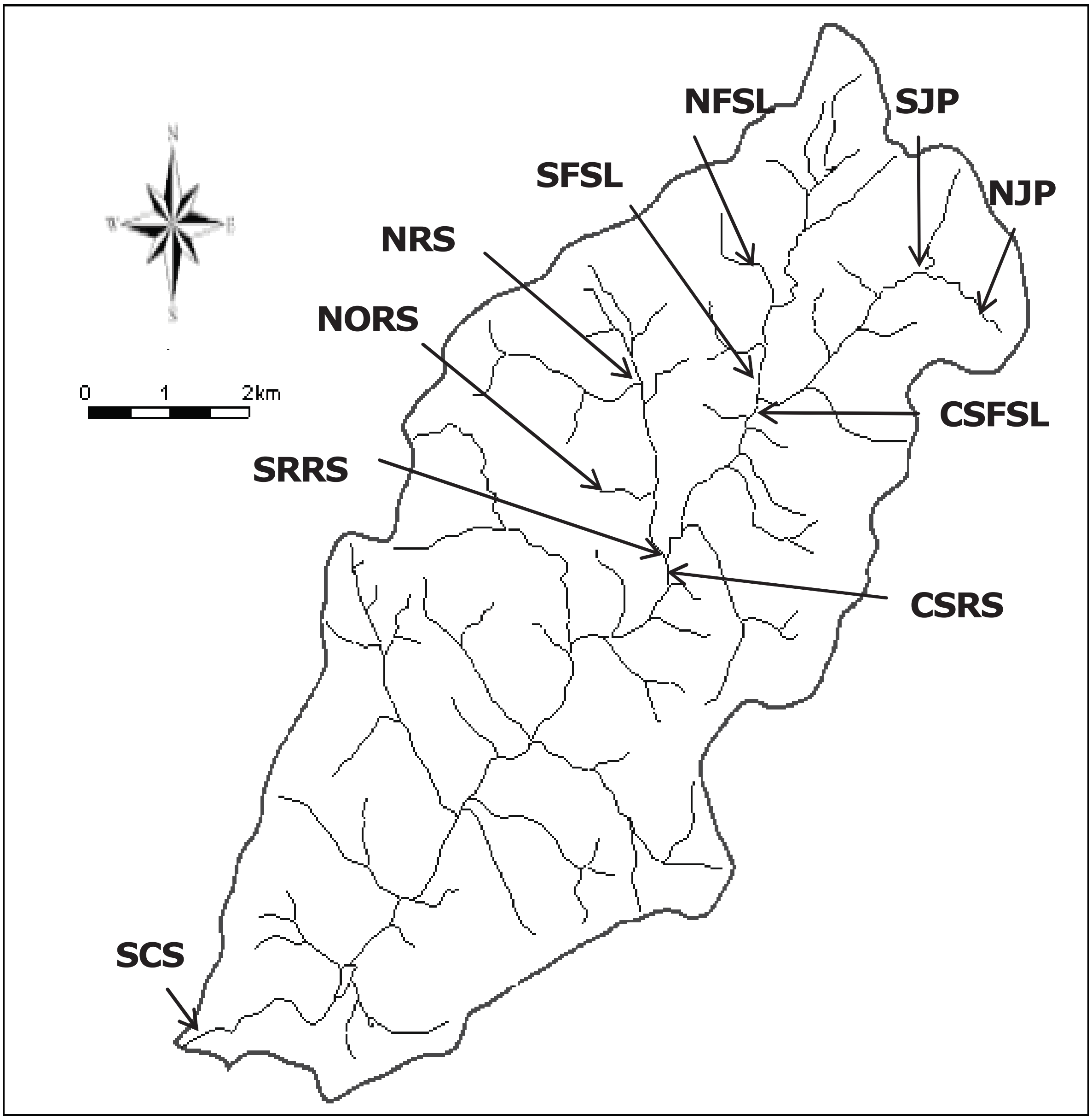


Figure 1: Hydrologic map of Córrego Sujo with sampling points´ localization.

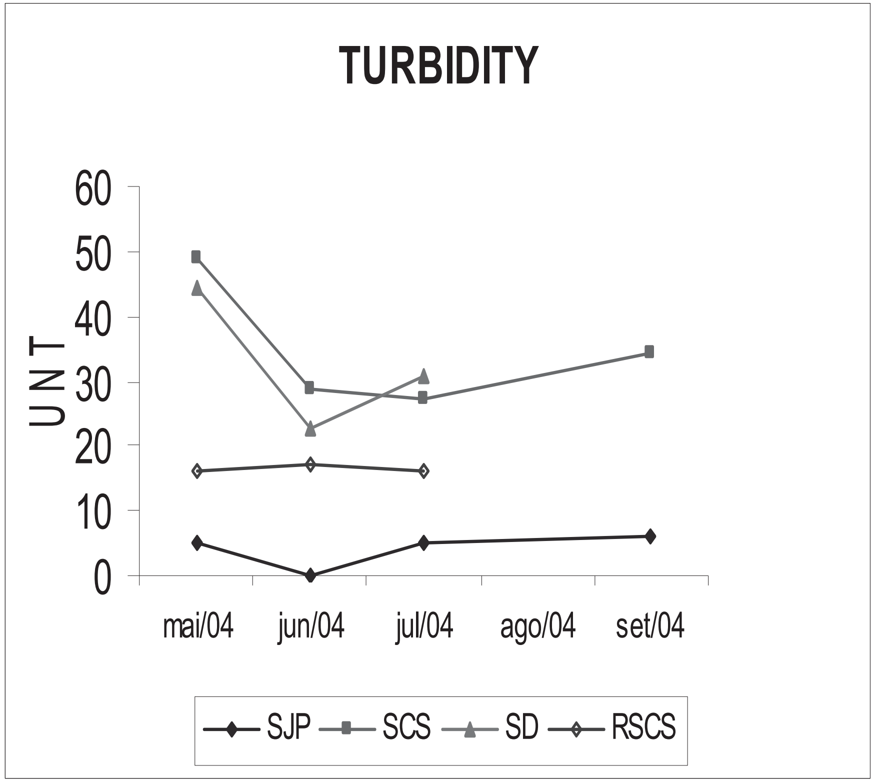
Most of parameter were analyzed using field instruments MEGA E, pH, Oximeter ALFAKIT Model AT110 and Foto-colorimeter La Motte, Model Smart. For cations and anions polypropylene bottles were conditioned with 10% nitric acid. The samples were filtrated with membrane (pore diameter 0,45 µm) and stabilized by adding nitric acid to pH 1. Determination of trace elements was performed by ICP OES, Inductively Coupled Plasma Optical Emission Spectrometry, JOBIN Yvon model Ultima 2. Ion-exchange chromatographic technique was used for anion determination using DIONEX Ion Analyzer Model DX-100, column AS-9 HC volum injection: 25µL, mobile phase: Na_2CO_3 9 mM, 1 mL min-1. Ultrapure water was obtained using Ultra Pure Water USF purifier from Elga. Water samples for POPs were collected in amber glass flasks (1 L), with alkaline detergent, EXTRAN® (Merck) and stored under refrigeration at 4 ± 2 ºC until solid phase extractions (US EPA 1998). Samples for organophosphorous pesticides were collected in polypropylene bags, NASCO®, 540mL. Organochlorine pesticides (certified standards with a purity better than 96 %) α-HCH, β-HCH, lindane, alachlor, heptachlor, metolachlor, aldrin, dieldrin, endrin, alpha and beta endosulfan, 4,4'-DDT, 4,4'-DDD, 4,4'-DDE, 2,4'-DDT, 2,4'-DDD and 2,4'-DDE were purchased from Dr. Ehrenstorfer-Schäfers Laboratory, Germany. Stock solutions of each organochlorine at 1 mg L-1 were prepared in acetone. A mixture of tetrachloro-m xylene and decachlorobiphenyl (200 µg mL^{-1} each in acetone) was used as surrogate to recovery control. Stocking and working solutions were prepared with ECD grade solvent, methanol, n-hexane, acetone and dichloromethane (Tedia) and stored at -18 °C. For POPs analysis it was used a Shimadzu gas chromatograph model 17A equipped with an auto sampler model AOC 20i, fitted with an electron capture detector and a DB-5 column (30 m x 0.32 mm inside diameter, 0.25 µm film thickness). A confirmatory chromatographic analysis of standards and samples in a column with a stationary phase of different polarity (DB-17) was the method of choice as an analytical alternative procedure to mass spectrometry as proposed by US EPA. The procedure used for the water analysis was based on method 3535A (US EPA, 1998) that describes the multiresidue extraction by C18 Solid Phase Extraction – SPE with octadecil disks, 500 mg, 0.45 µm, 47mm, supplied by J. T. Baker. Organophosphate (OP) pesticides were analyzed by the TRACE Serie 2000 from Thermo, gas chromatograph with Nitrogen-Phosphorous Detector (NPD); Chromatographic conditions: DB-1701 (14% cianopropyl-phenyl-86% dimethyl polisiloxane) 30m x 0,32mm x 0.25µm;

column flow: 1.1 mL/min, (H_2); injetor: 225 ºC; NPD: 300 ºC; heating program: 50ºC-130 (25ºC/min); 130-250ºC (5ºC/min), (10min); Splitless. OP certified standard from Dr.Ehrenstorfer-Schäfers, AG Dichlorvos, Diazinon, Methyl-parathion, Fenitrotion, Malathion, Chlorpirifos, Fentoate (>96 %).

Results

The World Health Organization (WHO 2006) establishes as sanitation criterion microbiological contamination. The screening survey indicated the presence of *E. coli* (or, alternatively, thermotolerant coliforms) in all samples, particular high counts were found in samples at the watershed outlet, in the confluence to Rio Preto. An exception was the spring NFSL.

Preliminary assessment was conducted to determine the environmental quality of sub-watershed with different agro system management. Water quality parameters, pH, Total Dissolved Solids, Turbidity, cations and anions at different points and scenarios were measured to support the environmental analysis following CONAMA 357/05 directive and elect the study areas. Figure 2 shows the result for 2004 monitoring of turbidity and conductivity parameters.



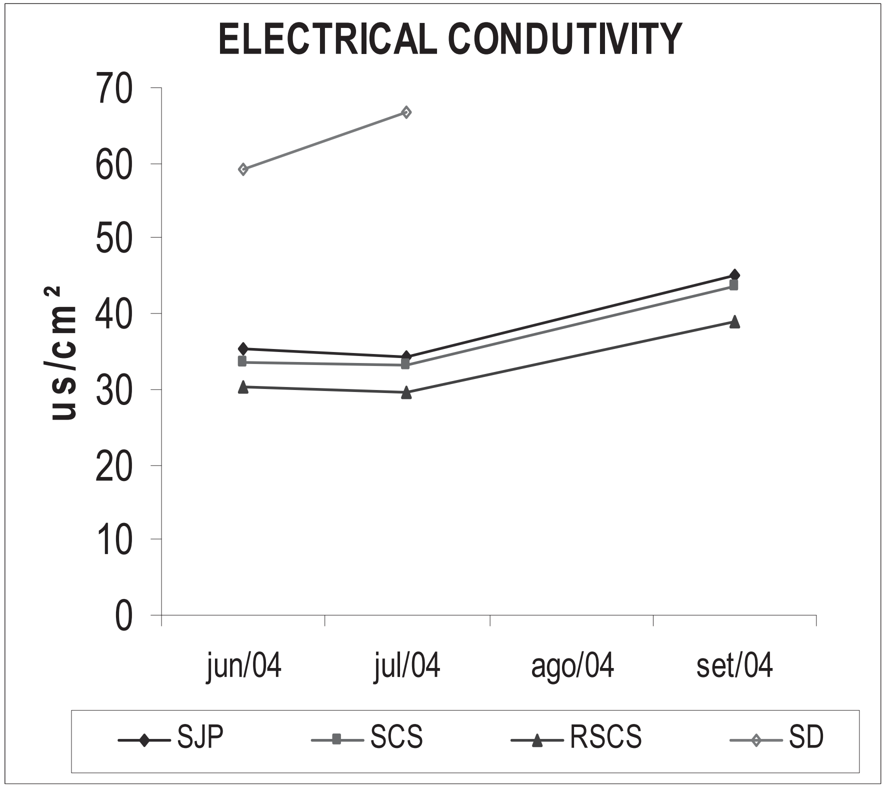


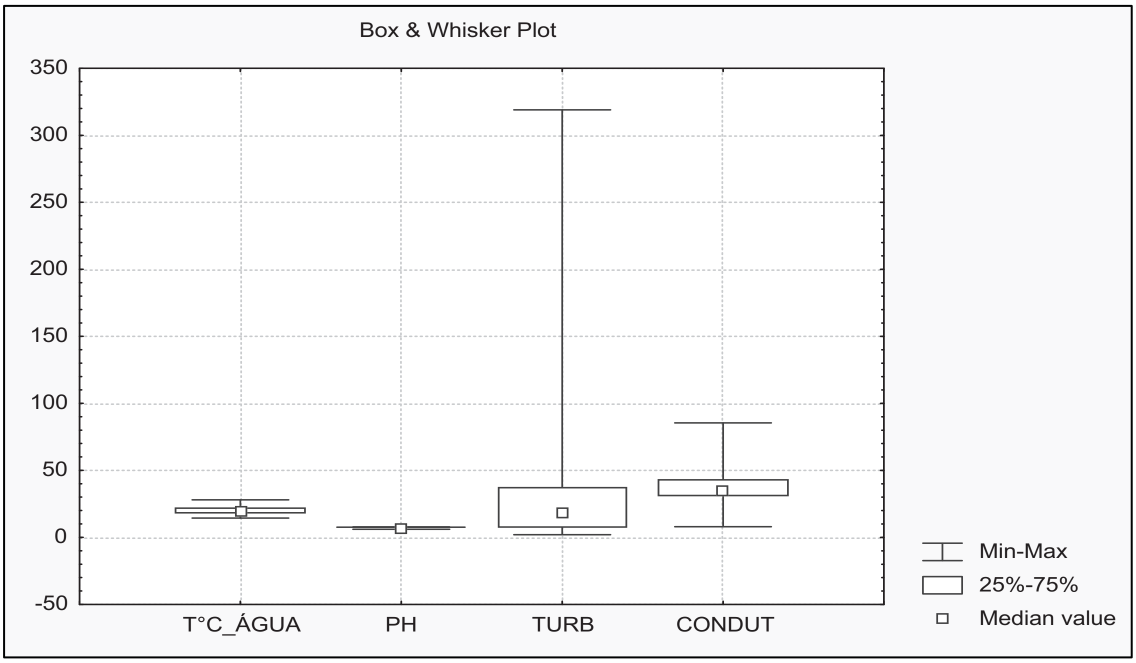
Figure 2: Screening parameters for environment and water quality CS river at different sections. JP - sub-basin 8; RSCS - sub-basin 7 e SCS – CS exit; SD – impacted watershed.

The sub-watershed SD was excluded of the monitoring program because of the severe impact to the environment quality caused by pasture and the scarcity of water during the dry season.

The selected monitoring points contemplate water springs in fragments, point along farming system, and confluence of each sub-watershed with the mainstream, and the outlet of the watershed.

The effect of intense erosion processes could be evaluated by the values of dissolved Al, Fe and Mn. At the same season the spring of sub-watershed NRS, the concentration of dissolved AL was 26.0 μg L^{-1}. The sample collected at the exit of SD was 312 μg L^{-1} for Al and 418 μg L^{-1} for Fe, much high than Class 1 of CONAMA 357/05 directive, 100 μg L^{-1} for Al and 300 μg L^{-1} for Fe.

Turbidity and electrical conductivity explained the great variability of water quality (Figure 3) for 55 case (15 sampling point) of the survey study during raining and dry seasons.



The results are in agreement with the crop system, the suppression of the riparian vegetation, crop activity at the flood plain, and cultivation at slopes. Dissolved cations (Fe, Mn, Al and trace elements) content pointed to the intense erosion process. Although all samples presented acceptable values for anion, the assessment shown that, taking the concentration of spring RS as threshold level, at the limit of the determination of the method, one can see in figures 4 and 5 the input of anions, especially nitrate.

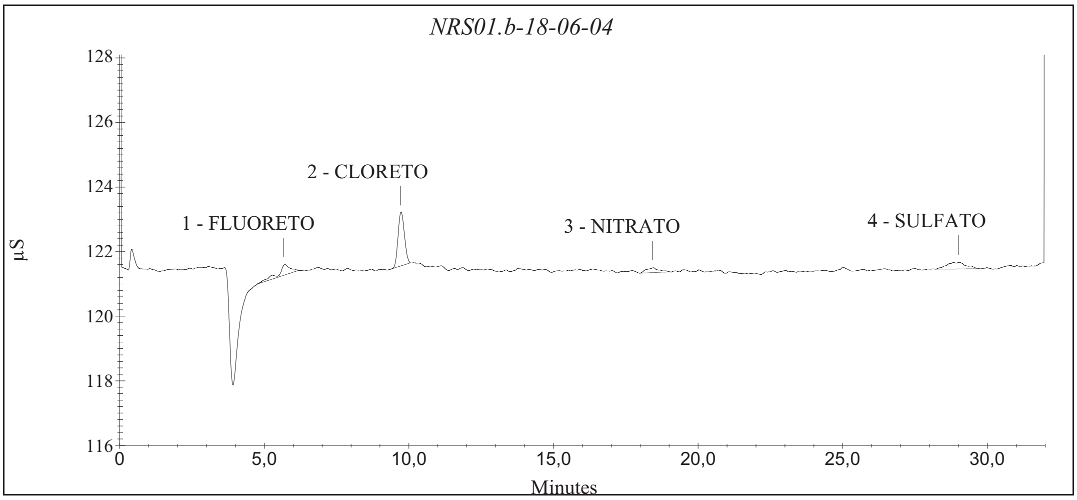


Figure 4: Ion-exchange chromatographic analysis of NRS spring. Column AS-9 HC volum injection: 25µL, mobile phase: Na_2CO_3 9 mM, 1 mL min-1.

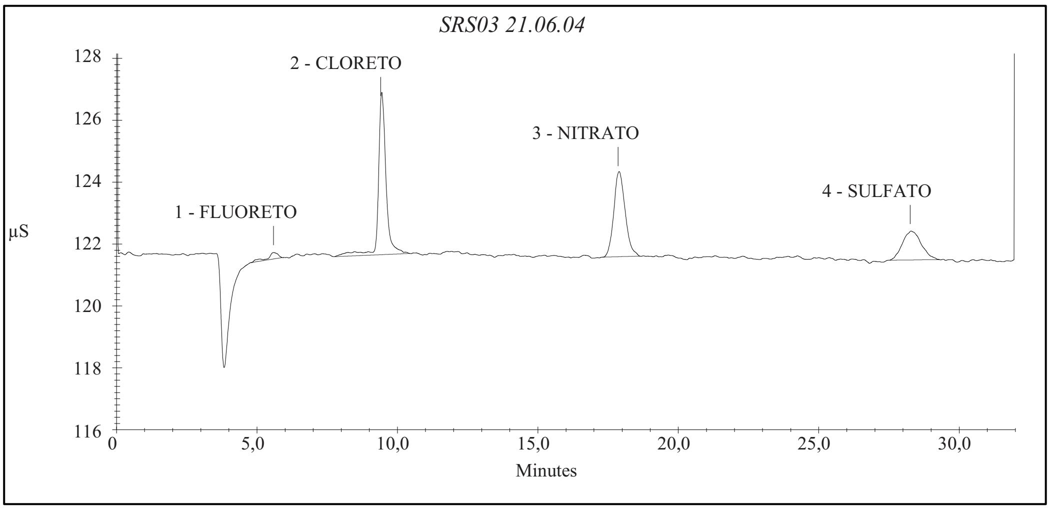


Figure 5: Ion-exchange chromatographic analysis of SRRS. Column AS-9 HC volum injection: 25µL, mobile phase: Na_2CO_3 9 mM, 1 mL min-1.

The directive CONAMA 357/05 deals with superficial waters as receiving effluent and in levels high above to the considered ones as natural base level, which is desires to compare (and keeping) to springs in not impacted areas. In this work the main objective was to study the actual status of Mata Atlântica rain forest at the Rio de Janeiro mountainous region, immersed in an agricultural matrix, and its ability to sustain the biodiversity and the production and quality of drinking water. Then as threshold for water quality in undisturbed environment, we compared the results with values of water of two protected areas monitored at the same period. Table 2 lists the parameter for water of two springs in conservation units, The National Park of Serra dos Orgãos – PARNASO and Três Picos Park (Pires 2004).

The mean, maximum and minimum values for the monitoring parameters in Córrego Sujo springs are represented in table 3.

The overall result of springs quality inside forest fragments in CS were in agreement to the specification of CONAMA 357/05 for Class 1, and comparing it to pristine waters of PARNASO same parameters shows the environment impact of these resources.

Of great concern is the systematic occurrence of the heavy metal Pb. The sample NORS06/05 collected at dry season presented value for Pb of 2.2 µg L-1, higher comparing to Beija-flor River - PARNASO (Table 2) 0.31 µg L-1, but lower than the maximum reported value in CONAMA 357/05 Directive of 10 µg L-1.

Table 2: Water quality guideline and background level.

	T °C	pH	Turb	Cond	Al	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn
			NTU	µS cm^{-1}					µg L^{-1}				
CONAMA 357/05			<40	-	100	1.0	50	9.0	300	100	25	10	180
PARNASO[1]	17	6.8	0.7	nd	56	0.18	<LD	0.85	26	2.65	0.57	0.31	1.26
Beija-Flor[2]	16	7.1	0.3	16	94	<LD	<LD	<LD	137	<LD	<LD	<LD	3.0
Penitentes[2]	16	7.1	0.3	16	137	<LD	<LD	<LD	137	<LD	<LD	<LD	3.0

[1] Beija-Flor river, March 2004
[2] Pires, 2004 – DL 1mg L^{-1}
[3] 5 NTU WHO, 2006 and MS 518/04
[4] LD: Limit Detection

Table 3: Mean, range and standard deviation values for measuring water quality parameters from spring of Córrego Sujo watershed.

Córrego Sujo springs	T °C	pH	Turb	Cond	Al	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn
			NTU	µS cm^{-1}					µg L^{-1}				
Maximum	24.0	7.9	12.0	42.8	26.8	0.60	1.1	2.2	292	45.4	4.9	2.2	6.4
Minimum	16.0	6.4	2.0	8.05	9.60	0.07	<0.005	<0.004	11.4	3.2	0.051	0.01	0.21
Average	**19.2**	**6.97**	**6.9**	**28.6**	**18.6**	**0.30**	**0.52**	**1.05**	**97.0**	**13.6**	**0.87**	**0.95**	**3.20**
Stand. Desv.	2.4	0.41	3.5	13.2	7.1	0.21	0.43	0.82	98.4	14.9	1.63	1.02	1.94

It was observed a great correlation between this element and turbidity as demonstrated in Figure 6 of the graphical representation of the principal components analysis for the studied parameters. The same occurred for Al, Fe, and Mn. These elements are strongly correlated what represents an evidence of erosion process.

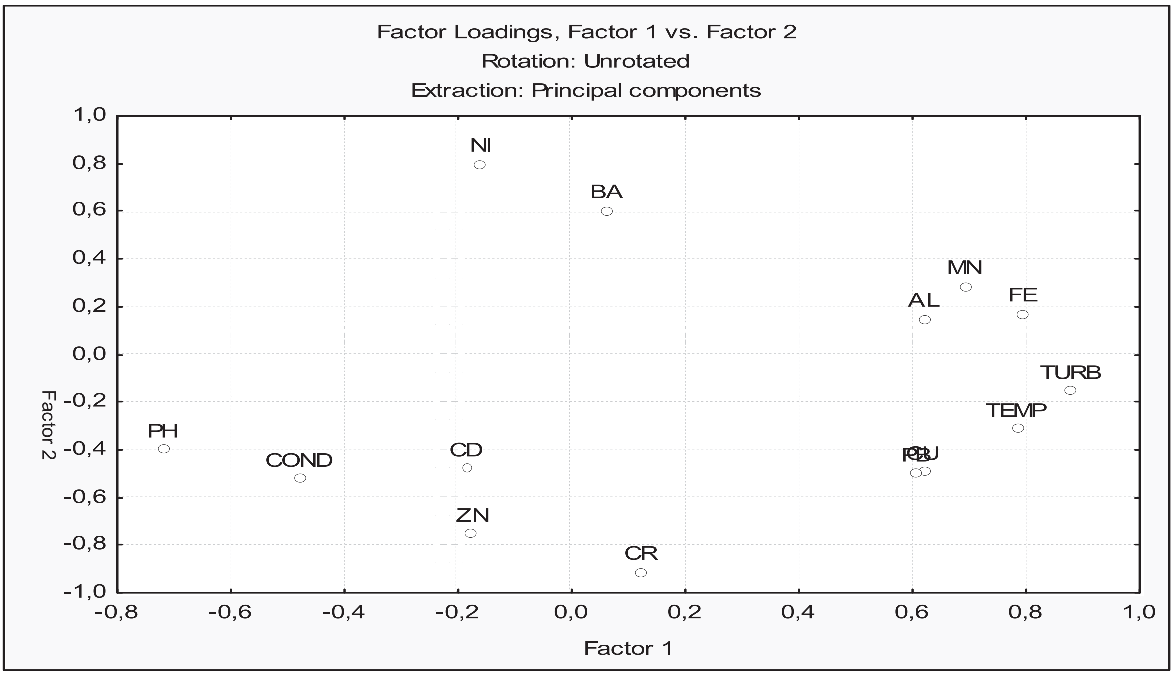


Figure 6: Principal component analysis for the water quality parameter for the three Córrego Sujo springs accessed.

Contamination of water bodies in crop areas by heavy metal is a consequence of soil pollution by agrochemical and their transport associated to sediment by hydro erosion (SANTOS et al. 2003, Pierangeli 2004).

Barros (2005) investigated metal content in soil at three representative land use: conventional tillage system (CT), organic production (ORG) and forest fragment (FF) of sub-basin 7 (RS). A sequential extraction procedure was the method of choice in order to determine the chemical forms of the elements and the potential environmental risk.

The content of metals Cd, Co, Cr, Mn, Ni, V e Zn was higher at the conventional tillage. But for the element Pb, the most expressive concentration (10.6 mg kg-1) was found in FF soils, and associated to the organic matter bound fraction.

We can point increasing of turbidity and the detection of Pb in samples collected shortly after rainfall in all sampling point. It is worthy to mention the equivalence of the quality of the spring of this sub-basin, when compared with waters of protecting areas.

Next we describe the main characteristics of the selected sites and present the result for two year assessment for each sub-basin.

Sub-watershed 9 – FSL

The characteristic land use is pasture, but this area preserves some of the larger and well protected fragments of Mata Atlântica at the higher slopes and the maintenance of the riparian vegetation throughout the river course. At this place water analysis shown that it satisfy the drinking water Class 1 (Table 4).

Sub-watershed 8 – JP

This area has scarce properties and the characteristic land use is conventional farming system. Table 5 reports the monitoring water quality parameter The effect of precipitation was observed on the value of turbidity in sample SJP02/05 and SJP24/11/05, 21 and 9.0 NTU respectively. Cations determinations show an expressive Mn concentration downstream when comparing to the spring of this sub-basin. The high value suggest contribution of agrochemicals, specially dithiocarbamates fungicide, which have in their composition the ions Zn e Mn (C4H6N2S4Mn) x (Zn)y, intensively used in this area. This hypothesis is corroborated by the speciation of these elements in soil with different land use. Barros (2005) observed that in soils with conventional system (PC) the concentration of zinc and manganese were high then forest fragments at the same sub-basin. It is important to notice the detection of Pb and Ni in water samples after precipitation event.

Sub-watershed 7 – RS

The sampling points are situated basically in two properties. The first one is representative of sustainable farm system and a very well preserved forest fragment. The other area it faithful follows the systems of production of the great part of the existing properties in the region: Irrigated, conventional, in flooding plains of the river and in hillsides with high declivity. The determination of cations did not reveal values above of Class 1 of CONAMA 357/05. However, in the case of the lead the presence of this element at levels close to the allowed limit was detected, that is of 10 μg L-1. The values for Pb in the points of collection Pt1RRS (upstream agroflorestal system, sub-watershed RS) and SRRS (confluence to CS main stream) was 11 μg L-1 and 9.8 μg L-1 respectively (Table 6).

Córrego Sujo - CS

We have monitored the main stream basin downstream the sub-watersheds monitored and at the outlet of the basin. At this point we observed a great variation of the parameters in function of the raining and dry stations, showing the effect of erosion processes in the periods of intense rainfall, as it can be observed by the values of turbidity, 27 NTU, july/04, period of dry season and the characteristic value of 319 NTU in january/05, wet season, of intense storm discharge (Table 7).

In the outlet of the Córrego Sujo during the raining period, the waters had reached values for turbidity and concentration of the elements Al, Cu, Fe and Mn that classify this water as Class III. In the case of trace elements, we can observe the presence of Pb in all the monitored points, particularly in high turbidity samples. Ni was also be detected in samples of dry months, SCS 06/04, 4.56 μg L^{-1} and SCS 07/04, 4.72 μg L^{-1}.

The variance in the results for cations reflects the high turbidity samples collected in November/2005. These results indicate degradation process of this watershed and the importance of the run off transport of contaminants associated to soil particles.

Investigation of the presence of OCs occurred during 2004-2005, bimonthly at all the same sampling points. The water sample analysis did not indicate the presence of POPs contaminants above the quantification limit of the analytical method which was in agreement with the Brazilian guidelines for drinking water (Brazil 2004).

The analysis for OP was conducted in the second year of the project, 2005 at same selected points. The first sampling was in June and the second in November 2005 after intense storm event. The sampling points were sub-watershed 8 –SJP, NORS and SRRS (test catchment), and Córrego Sujo main channel downstream sub-watershed 7 – CSRS and the outlet of the watershed – SCS.

The pesticides investigated are among the most applied molecules in minor crops as tomatoes and lettuce, the most representative products of this watershed, and the only two organophosphorous pesticides as water quality concern of CONAMA 357/05 guidelines, Parathion and Malathion, maximum admissible concentration (MAC) of 0.04μg L^{-1} e 0.1μg L^{-1} respectively.

Table 4: Water quality parameters for sub-basin 9 – FSL.

	T °C	pH	Turb NTU	Cond. µS cm^{-1}	Al	Cd	Cr	Cu	Fe µg L^{-1}	Mn	Ni	Pb	Zn
NFSL 09/04	20	7.1	4.0	22.6	10 ± 4	< 0,4	< 0.4	< 0.4	20 ± 3	1.8 ± 0,2	< 0.1	< 0.1	< 1.2
CSFSL 09/04	20	7.0	10	nd	6 ± 1	< 0.4	< 0.4	< 0.4	232 ± 30	113 ± 9	< 0.1	< 0.1	< 1.2
CSFSL 02/05	24	6.9	27	24.9	21 ± 4	< 0.4	< 0.4	< 0.4	113 ± 3	57.8 ± 0,5	< 0.1	1.6 ± 0.4	< 1.2
SRFSL 11/05	22	6.0	24	26.7	54 ± 16	< 0.4	< 0.4	14 ± 1	141 ± 31	24 ± 3	< 0.1	106 ± 0.2	2.5 ± 0.1
CSFSL 11/05	22	6.0	24	29.2	44 ± 6	< 0.4	< 0.4	30 ± 3	165 ± 16	41.6 ± 6	< 0.1	*40 ± 35*	2.6 ± 0.1

Note n = 3

Table 5: Water quality parameters for sub-watershed 9 – JP.

	T °C	pH	Turb NTU	Cond. µS cm^{-1}	Al	Cd	Cr	Cu	Fe µg L^{-1}	Mn	Ni	Pb	Zn
NJP03/04	18.0	6.95	2.0	20.1	11.0 ± 0.1	< 0.4	< 0.4	< 0.4	33 ± 2	4.2 ± 0.1	< 0.1	< 0.1	< 1.2
SJP 03/04	20.0	6.95	5.0	34.6	24.7 ± 0.4	< 0.4	< 0.4	0.8 ± 0.2	43 ± 9	14.6 ± 0.1	< 0.1	1.1 ± 0.2	< 1.2
SJP 06/04	18.8	6.38	5.0	35.3	49.0 ± 3	< 0.4	< 0.4	< 0.4	88 ± 2	79 ± 2	4.9 ± 0.4	< 0.1	3. 8 ± 0.8
SJP 07/04	16.0	6.58	6.0	34.1	49.0 ± 1	< 0.4	< 0.4	< 0.4	149 ± 4	77 ± 1	5.5 ± 0.6	< 0.1	6.8 ± 0.4
SJP 09/04	20.0	6.43	5.0	45.1	32.2 ± 0.4	< 0.4	< 0.4	< 0.4	114 ± 2	47.2 ± 0.5	< 0.1	< 0.1	< 1.2
SJP 02/05	22.0	6.90	21.0	37.7	30.2 ± 0.4	< 0.4	< 0.4	< 0.4	49 ± 7	58 ± 1	< 0.1	1.5 ± 0.3	< 1.2
SJP 06/05	18.0	7.00	6.0	46.8	36.0 ± 1	< 0.4	< 0.4	2.8 ± 0.8	42 ± 11	41 ± 1	< 0.1	3.0 ± 1.0	2.9 ± 0.7
SJP 08/11/05	21.0	7.10	4.0	35.2	32.0 ± 1	< 0.4	< 0.4	16. 0 ± 1	176 ± 1	73± 1	< 0.1	> LD	4.3 ± 0.1
SJP 24/11/05	21.0	6.20	9.0	50.0	31.0 ± 1	< 0.4	< 0.4	*37 ± 30*	149 ± 12	67 ± 1	< 0.1	> LD	2.6 ± 1

Table 6: Water quality parameters for sub-watershed 7 – RS.

	T °C	pH	Turb	Cond	Al	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn
			NTU	µS cm^{-1}					µg L^{-1}				
NRS 06/04	16.0	6.4	12.0	35.4	26 ± 4	< 0.4	< 0.4	< 0.4	292 ± 12	45 ± 1	4.9 ± 0.2	< 0.1	1.8 ± 0,4
CSRS 14/06/04	16.0	6.7	18.0	32.9	40 ± 5	< 0.4	< 0.4	< 0.4	196 ± 14	71 ± 1	4.9 ± 0.1	< 0.1	< 1.2
CSRS 30/06/04	19.4	6.3	16.0	30.2	41 ± 6	< 0.4	< 0.4	< 0.4	213 ± 31	64 ± 2	5.0 ± 0.3	< 0.1	1.6 ± 0.1
CSRS 07/04	16.6	6.7	17.0	29.5	59 ± 3	< 0.4	< 0.4	< 0.4	296 ± 24	65 ± 1	5.2 ± 0.4	< 0.1	3.6 ± 0.1
SCRS 09/04	20.0	6.8	16.0	39.0	27 ± 8	< 0.4	< 0.4	< 0.4	226 ± 16	42 ± 5	< 0.05	< 0.1	1.4 ± 0,7
CSRS 02/05	24.0	7.0	52.0	30.1	119 ± 94	< 0.4	< 0.4	< 0.4	162 ± 26	48 ± 1	1.6 ± 0.1	1.4 ± 0.4	< 1.2
NORS[1] 06/05	18.0	7.2	6.0	34.3	26 ± 3	< 0.4	< 0.4	*2 ± 1*	51 ±2	5.3 ± 0.1	< 0.1	*2 ± 1*	3.8 ± 0.3
SRRS 06/05	19.0	7.0	22.0	43.0	30 ± 11	< 0.4	< 0.4	2.8 ± 0.3	203 ± 18	44 ± 1	< 0.1	10 ± 3	*5 ±4*
CSRS 06/05	19.0	7.0	24.0	45.1	172 ±91	< 0.4	< 0.4	5.5	*422*	63 ± 18	< 0.1	16	3 ± 1
NORS 08/11/05	20.0	7.9	3.0	8.0	23.0	< 0.4	< 0.4	*15*	*56*	4.5	< 0.1	> LQ	4,2
SRRS 08/11/05	22.0	6.5	19.0	31.8	52.0	< 0.4	5	*63*	*364*	78	< 0.1	> LQ	4.3
SRRS 24/11/05	24.0	6.2	57.0	30.7	49 ± 2	< 0.4	< 0.4	3 ± 1	333 ± 37	30 ± 1	< 0.1	*21 ± 11*	1.9 ± 0.1

Table 7: Water quality parameters for Córrego Sujo exit.

	T °C	pH	Turb	Cond	Al	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn
			NTU	µS cm^{-1}					µg L^{-1}				
SCS 05/04	19.0	6.8	49	36.7	40 ± 14	< 0.4	< 0.4	< 0.4	161 ± 21	53 ± 1	< 0.1	1.2 ± 0.6	< 1.2
SCS 06/04	18.4	6.61	28.6	33.5	36 ± 1	< 0.4	< 0.4	< 0.4	270 ± 15	78 ± 4	4.7 ± 0.1	< 0.1	3.8 ± 0.1
SCS 07/04	15.5	6.97	27.1	33.3	52 ± 1	< 0.4	< 0.4	< 0.4	336 ±12	126 ± 2	4.6 ± 0.3	< 0.1	3.4 ± 0.2
SCS 09/04	20.0	6.9	34.4	43.7	23 ± 3	< 0.4	< 0.4	< 0.4	206 ± 7	48 ± 2	< 0.1	< 0.1	< 1.2
SCS 02/05	22.0	7.9	319	40.1	*307*	< 0.4	< 0.4	1.9 ±1	293 ± 34	36.3 ± 0.1	< 0.1	2.1 ± 0.4	< 1.2
SCS 11/05	24.0	6.3	229	33.5	118	< 0.4	< 0.4	93	263	20	< 0.1	> LQ	3.7

The optimum analytical conditions established for extraction procedure and chromatographic determination are presented in table 8.

Table 8: Organophosphorous (OP) pesticides; the detection and quantification limits (LD and LQ).

OP	LD $\mu g\ L^{-1}$	LQ $\mu g\ L^{-1}$
Dichlorvos	0.67	2.23
Diazinon	1.03	3.43
Malathion	3.38	11.3
Methyl Parathion	0.95	3.17

It was observed a great variability of the values found for the studied parameters due to the high quantity of suspended matter loaded in water samples. That was observed in reporting the results for trace metals as mean values.

The method of analysis used in our laboratory is solid phase extraction (SPE), but for samples with high content of suspended matter, the method of choice for trace-level determination of organic pollutants was liquid-liquid (LLE) (EPA 1998). In table 9 we report the individual result for duplicate samples collected in November 2005.

In all case the MAC limit was violated. Except for the sampling point CSFSL, we can observe the reproducibility of samples results. These results reflect the scenario of the land use, mainly in relation to erosive process and the transport of contaminants to the stream.

A sample of a dry period in May 2006 detected the pesticide Chlorpyrifos to a detection limit of 0.047 $\mu g\ L^{-1}$.

According to preliminary investigation, a great array of products were reported to be used by farmers as legally authorized formulations, or not, for the cultures developed in the CS. As the analytical procedure did not cover all pesticide listed in field survey, beyond the detection of not identified signal at the gas chromatograms of the investigated water, we used computer models to assess the potential risk of contamination of waters with the objective of comparing with the preliminary data observed and to determine priorities for future monitoring study.

Table 9: Organophosphorous (OP) pesticide concentration for samples collected in November 2005.

	Pesticide	**concentration ($\mu g\ L^{-1}$)**
SRRSa	Diazinon	0.88
	Methyl Parathion	13.2
SRRSb	Methyl Parathion	10.6
CSRSa	Methyl Parathion	9.18
CSRSb	Methyl Parathion	9.99
SJPa	Methyl Parathion	9.40
SJPb	Malathion	13.2
	Methyl Parathion	11.6
CSFSLa	Methyl Parathion	16.9
CSFSLb	Methyl Parathion	7.55
SRFSLa	Methyl Parathion	10.5
SRFSLb	Methyl Parathion	12.1

Site-specific criteria for pesticide transport potential proposed by Hornsby (1992), which reflect confidently the scenario of CS, was used to assess the risk of contamination of CS superficial water for the pesticides in use in the monitoring sites. The screening method proposed considers the runoff potential in function of the hydrophobicity (chemical group), permeability (soil) and slop (12%). The Runoff Relative Potential Indices (RRPI) expresses the mobility of a pesticide bounded to sediment, where Koc ≥ 1000, denotes a pesticide strongly associated to soil particle. According to this model the pesticides Benomyl, λ-cyhalothrin, deltamethrin, difenoconazole, fenitrothion, fluazifop, paraquat, methyl parathion and tebuconazole should be considered in a monitoring program.

Another model proposed by Goss (1992) estimates pesticides runoff losses in solution and sorbed to soil particles. The pesticides carbendazim, clorpirifós, linuron, diazinon e diclorvós presented a high potential of transport in solution. The pesticides λ- cyhalothrin, deltamethrin, ethion, fenitrothion, fluazinfop, indoxcarb, paraquat were identified as its potential of transport adsorbed on sediment in runoff.

As indicated by the field data, the models used as criteria for identification of pesticides to be considered in a monitoring program to this watershed are in agreement with the field data.

Conclusions

According to the results obtained with this study the following conclusion arise:

- This preliminary survey confirms runoff contribution as the most important process to superficial water pollution. That is in agreement to the agricultural practice.
- The results point to the importance of a monitoring program for water quality in agriculture basin.
- The observed results are in agreement to the screening models proposed to this preliminary survey.
- But due to the large variance of results, an optimized sampling design should be conduct for monitoring this watershed and assessment of the contamination risk for the local and downstream population.

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Chapter 11

EVALUATION OF PROTECTED AREA EXPANSION IN THE CASE OF THE SERRA DOS ÓRGÃOS NATIONAL PARK, RIO DE JANEIRO, BRAZIL

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Abstract: Manmade fragmentation of the Brazilian Atlantic forest poses a serious threat to the biodiversity of the various ecosystems of this unique biome. To counteract this fragmentation process, the Serra dos Órgãos National Park initiated an expansion project aiming at the inclusion of the adjacent Serra da Estrela mountain range into the National Park area. This work analyzes this region from two different points of view to define the most suitable expansion possibility. The protection suitability evaluation assesses the individual landscape patches according to their ecological value. The urbanization suitability evaluation assesses the same landscape patches according to their suitability for future urban growth. To calculate the suitability for protection, respectively urbanization, the method of Multi-Criteria Evaluation (MCE) is applied. The results of the two suitability evaluations are combined and analyzed to identify core areas and conflict zones of the potential expansion area of the National Park.

Keywords: Serra dos Órgãos National Park, protected area expansion, urban growth, suitability analysis, fuzzy sets, multi-criteria evaluation.

Introduction

To counteract uncontrolled and irregular urban growth, the management of the Serra dos Órgãos National Park started a project to expand the park area along the Serra da Estrela mountain range in direction to the Tinguá Biological Reserve to raise the protection status of this ecological corridor and prevent further human interference. This corridor is of major importance, as it connects the two protected areas – the Serra dos Órgãos National Park and the Tinguá Biological Reserve (Figure 1, at the end of this article).

This work contributed to the expansion project by analyzing the region to identify potential areas suitable for being incorporated into the Serra dos Órgãos National Park. The main objective was to evaluate the protection suitability and the urbanization suitability of the landscape patches within the research area to identify potential conflict zones between these two interests. Based on this evaluation it was possible to define a potential expansion area including patches which are highly suitable for protection and excluding areas which are prone to urbanization.

The protection suitability evaluation was conducted to get insight into the ecological value of the single landscape patches caused by the present vegetation cover and land use type. Based on this information the landscape patches could be assessed in view of their importance for being incorporated in the expansion area of the Serra dos Órgãos National Park.

The objective of the urbanization suitability evaluation was to identify those zones within the research area, which provide appropriate conditions for future settlement and urban expansion. Hereby, the landscape patches were analyzed according to criteria like vegetation cover and proximity to infrastructural facilities which make them favorable for settlers. The fragments could be then ranked according to their potential for being urbanized.

Finally, this work aimed to provide the Serra dos Órgãos National Park management with detailed information about the possibilities and limitations of the planned expansion project. A final map and an explicatory report pointed out the potential core expansion area, with landscape patches of high ecological value and the potential conflict zones caused by expanding urbanization. That way, this work contributed to the optimization of the expansion area and its sustainability.

Data and Methods

GIS Development

A GIS was developed basing on aerial photographs from 1999 at a scale of 1:10,000 provided by AMPLA (AMPLA Energia e Serviços SA). The raw GIS data was processed by the cooperative ESTRUTURAR, which also was involved in the expansion project of the Serra dos Órgãos National Park.

Protection suitability evaluation

As a first step, the protection suitability of the single patches of different land use was evaluated. Therefore the classes of a land use map were ranked according to their ecological potential. The resulting map allocates a suitability level to each patch within the landscape to assess the possibility of its incorporation into the National Park.

Starting point of the protection suitability evaluation was a land use classification of the research area with 14 different classes. The method chosen for classifying land use can be described as manual digitalization using aerial photographs as basis. This method was preferred to automate remote sensing classification methods, because there was a previous classification covering most of the research area provided by the cooperative ESTRUTURAR using this method. Therefore the land use classification map set had only to be completed and refined. Moreover, the chosen resolution for the raster model of the Multi-Criteria Evalution (MCE) of 10x10m did not allow for using available Landsat 7 satellite images with resolution of 30x30m. The resolution of 10x10m of the aerial photographs provided by AMPLA was chosen to identify also small land use features like single houses and small streets.

The single land use classes were grouped into general suitability classes according to their ecological value and their importance for the National Park. For higher differentiation of the 14 land use classes with respect to their protection suitability, the classes within the general groups were further processed applying a method common in decision support applications, the Analytical Hierarchy Process (AHP) (Eastman 1993, Granzol 2005, Banai-Kashani 2005).

This procedure bases on the technique of pairwise comparisons developed by Saaty (1977). The purpose of this technique is to rank criteria according to their weight or significance with respect to a specific objective or decision. The AHP breaks down the weighting by comparing only two criteria in pairs at each step of the procedure. Therefore ratings are provided on a 9-point continuous scale of comparison (Table 1).

Table 1: AHP 9-point continuous scale

1/9	1/7	1/5	1/3	1	3	5	7	9
extremely	very strongly	strongly	moderately	equally	moderately	strongly	very strongly	extremely
	less important					**more important**		

Afterwards the eigenvector and the maximal eigenvalue of the comparison matrix are calculated to get a best-fit of criteria weights. This method quantifies the verbal comparison and assigns a value to each criterion representing its weight. In the Weighted Linear Combination (WLC) concept this weight value is on a range between 0 and 1; the sum of all criteria weights sum up to 1.

Urbanization Suitability Evaluation

In the second phase of the project an urbanization suitability evaluation of the region was conducted. As a starting point the question was put: "Where are the areas of potential urban growth according to the present natural and infrastructural conditions?" In order to get quantitative results five suitability criteria for urban growth were defined: Existing land use, slope, proximity to existing settlements, proximity to roads and proximity to rivers. Afterwards the method of Multi-Criteria Evaluation (MCE) (Malczewski 1999, Florent et al. 2001) was applied to these criteria to get a map classifying the area of interest into zones of different urbanization suitability.

The first step of the urbanization suitability evaluation was to select the criteria which best represent the landscape's suitability for urban expansion. As this project was focusing on land use aspects no economic or property-related criteria were chosen. The criteria selection was based on the concepts of widely applied urban growth models like SLEUTH, SCOPE and the What If?-model, which use suitability criteria for the selection of developable sites (Candau 2002, Clarke 2003;

Jones 2005, Klostermann 1997). Hereby, suitability ratings are generally determined by proximity to infrastructure and services, topographic conditions, demographic patterns, etc. (Johnston and Shabazian, 2002).

After the literature review these basic urban growth modeling concepts were adapted to the local conditions of the research area. The major underlying idea was that urban expansion normally starts from existing settlements. In general, this expansion is oriented or influenced by the existence of transport system, rivers and characteristics of the landscape, like present land use and slope (Johnston and Shabazian 2002, Varanka 2006, Clarke 1998, Wilson Hurd, Civco 2002). This concept was the starting point for selecting the five criteria of urban expansion suitability:

Existing land cover (Code used within this project: **LAND**): The assumption was that people prefer to settle on land, which requires minimum effort of preparation for housing. For example, grass land is preferred to land covered with dense forest.

Slope (Code: **SLOPE**): This is one of the most common used criteria for settlement suitability in modeling urban growth. The ranges of slope suitability within the research area were defined by adjusting commonly used values to the special situation in the low-developed settlement of the reseach area.

Proximity to existing settlements (Code: **PROXSET**): Existing settlements provide better infrastructural, economic and social structures than areas far away from any development. Therefore the assumption was that urban growth has its starting point at existing settlements.

Proximity to roads (Code: **PROXROD**): This criteria, also known as road gravity, indicates that urban growth generally is orientated along existing roads due to good accessibility and economic possibilities.

Proximity to rivers (Code: **PROXRIV**): During the preliminary field trips it turned out that proximity to rivers plays an important role when settlements in rural Brazilian areas are concerned. Most of the small towns and villages in the research area have poor wastewater collection systems. One of the possibilities chosen by people to get rid of wastewater and garbage is to use rivers as natural sewers. For that reason proximity to rivers states a settlement advantage and was chosen as a criterion.

The five criteria had to be quantified and combined to get a single urbanization suitability value for each cell within a raster model. This model assigned a probability to each cell, which indicated the likelihood of the cell to be urbanized according to criteria. The cell state (value of urbanization suitability [0-255]) depended on the weighted combination of five the urbanization suitability criteria.

Before combining the values of the five criteria to one single value the different measuring units of the criteria (degree, land use type, and distance) had to be standardized. For the criteria standardization fuzzy set membership functions were applied (except for criterion 1). The gradual suitability representation of the fuzzy method was preferred to sharp suitability classes for all criteria except for criterion 1. Criteria 2 to 5 are of spatial nature and therefore it would have been difficult to set sharp boundaries of suitability classes.

Fuzzy logic is an alternative to traditional Boolean logic developed for modeling human knowledge and consideration in a mathematical way to make computation possible. Applying fuzzy logic, terms like “very steep”, “quite distant” and “extremely unsuitable” can be represented quantitatively and calculated mathematically (Kruse et al 1994). This method was first introduced to the scientific community when Lofti Zadeh published his essay “Fuzzy sets” (Zadeh 1965). In contrast to traditional sets (where an element can only be fully contained or not) fuzzy sets can contain elements also partially (Hall et al. 1992). If Boolean logic elements have only the values 0 (not contained) and 1 (contained) fuzzy set elements can also have values in-between 0 and 1. The degree of membership of an element to a fuzzy set is defined by the membership function.

For applying the Weighted Linear Combination method (WLC) to the standardized and quantified criteria a weighting was necessary. The task was to get a ranking of the criteria representing the significance of each criterion with respect to its influence on the urban expansion. One can think of the hypothetical decision problems of a settler: Do I settle close to the existing settlement or do I prefer proximity to the street? Do I settle on a plane area or do I prefer the steep hill with proximity to the river?

The used weights refer to commonly applied suitability ranges for urban expansion criteria (Yang and Low 2003; Johnston and Shabazian 2002; Clarke 1998). These values, ranging from 0 to 1 and summing up to 1 for all criteria, were adjusted to the situation within the research area through interviews with locals, geographers of the cooperative ESTRUTURAR (http://www.estruturar.com.br/) and the interpretation of fieldwork data.

The last step was to combine the criteria to get one single suitability value for each pixel. This was achieved by the weighted linear combination of the criteria according to the following formula (Eastman 1993):

$$S = \sum w_i x_i$$

where $S =$ suitability value
$w_i =$ weight of criterion i
$x_i =$ original value of criterion i

To get the maximal potential urban expansion area a worst case scenario was developed. Therefore four different scenarios are created by changing the weights of the criteria. Afterwards the highest urbanization suitability value of each cell was taken comparing the four scenarios.

Final Integrated Analysis

The results of the protection suitability evaluation and the urbanization suitability evaluation were combined resulting in a map representing potential core zones of protection and potential conflict zones. The potential core zones of protection are characterized by high protection suitability levels and low urbanization suitability levels. Within the potential conflict zones the levels of both, protection suitability and urbanization suitability, are high. As a final product a map was generated proposing the limits for the extension area considering the following requirements defined by the National Park Management:

- The area should be composed mainly land use classes which are of high protection value.
- The area should be as distant as possible from human infrastructure like settlements, roads and supply networks to reduce negative disturbance effects.

- The area should be as large and compact as possible to provide sufficient core area and to reduce negative edge effects.
- The contrast between the single patches and their surrounding environment should be as small as possible to stimulate corridor effects between these patches.
- The distance between the patches of the classes with high protection value should be as small as possible to stimulate animal movement and seed dispersal between these patches.
- The limit for the extension area should also represent natural barriers for future urban growth. They should be obvious and visible not only on maps but also in the field (steep hills, rivers, etc.).

Results and Analysis

Protection Suitability Evaluation

As input data for the protection suitability evaluation served a land use classification map provided by the cooperative ESTRUTRAR. This classification map covered about 80% of the research area. The remaining 20% had to be completed by using aerial photographs from AMPLA (Figure 2 at the end of this article).

The significance of the land use classes for the expansion project had to be evaluated. The single classes were assessed whether they were of interest for the National Park and whether they had an ecological value that justifies the incorporation of patches of this class into the expansion area. During this process four general suitability groups were defined and the single classes were assigned to one of the following groups:

Suitability Group 1 - High suitability: This group contains all classes, which are of high suitability for the expansion area. Campos de Altitude (High-altitude grassland) and Vegetação rupestre (Rock vegetation) in general contain high numbers of endemic species and protection of these ecosystems is a defined goal of the National Park (IBAMA, unpublished). Forest patches classified as Floresta em estagio avançado de sucessão (Forest advanced development stage) are considered as the most natural and undisturbed form of forest, which can be found within the region. Because of the abundance of orchids, bromeliales, asteraceae within even small patches of the class Vegetação rupestre the Afloramento rochoso (Rock) class was also classified as highly suitable.

Suitability Group 2 - Medium suitability: This group contains the forest types Floresta em estagiobmédio de sucessão (Forest in medium development stage) and Floresta em estagio inicial de sucessão (Forest in initial development stage). Both classes are not of highest priority for the National Park, but still have important values and functions to be considered. If incorporated into the expansion area, they can develop further without being endangered by human disturbance.

Suitability Group 3 - Low suitability: Patches of the classes within this group are either under permanent or periodic human use (Cultivos - Cropland, Gramíneas - Grassland, Silvicultura - Silviculture), suffered from human use (Solo exposto – Open soil) or were recently abandoned (Vegetação arbustiva – Shrub vegetation). None of these classes are of high ecological value for the National Park. They even may have a negative influence on other patches due to human activities and may represent barriers for ecological fluxes of flora and fauna. Yet, they were not considered of any ecological value. If a small patch of this group is surrounded by high-value patches, action-taking for improving the state of this patch could be considered.

Suitability Group 4 - No suitability: The classes of this group are not appropriate for incorporation into the National Park expansion area at all (Estrada – Street, Área urbana – Urban area, Área urbana de baixa densidade – Low density urban area). Their ecological value is considered zero or very low, their disturbance potential for communities of flora and fauna is high and SNUC regulations even prohibit their existence within the limits of National Parks (Senado Federal 2002).

After this first general grouping the Analytical Hierarchy Process (AHP) was applied for getting a more refined ranking of the classes. For establishing the pairwise comparison matrix the classes of the suitability group 1 and suitability group 4 were considered as one class, respectively. To weight the classes with the values of the 9-point comparison scale the following questions were put:

- Which class is of major interest for the expansion project?
- Which class is of minor interest for the expansion project?

After some re-consideration of the single pairs of comparison within the matrix (Table 6) a ranking with a reasonable Consistency Ration (CR) of 0.10 – Saaty (1977) recommends a CR value equal or smaller than 0.10 - could be achieved (Table 7).

Table 6: Pairwise comparison matrix of land use classes

	SutGrup	FlorMed	Florinic	Cultiv	Grami	Silvi	SolExp	VegArb	SutGrup4
SutGrup	1								
FlorMed	0.3333	1							
Florinic	0.1667	0.2500	1						
Cultiv	0.1111	0.1429	0.2000	1					
Grami	0.1111	0.2000	0.2000	3.0000	1				
Silvi	0.1111	0.2000	0.3333	3.0000	3.0000	1			
SolExp	0.1111	0.1429	0.1429	0.5000	0.3333	0.2000	1		
VegArb	0.1667	0.2500	0.3333	5.0000	3.0000	3.0000	5.0000	1	
SutGrup4	0.1111	0.1111	0.1111	0.2000	0.2000	0.2000	0.3333	0.1429	1

Table 7: Result of the AHP for protection suitability of land use classes.

Class	Code	Suitability score (Eigenvalue)	Suitability score (Ordinal Ranking)
Rock, High-altitude grassland, Forest (advanced development stage), Rock vegetation	SutGrup1	0.3863	1
Forest (medium development stage)	FlorMed	0.2219	2
Forest (initial development stage)	FlorInic	0.1329	3
Shrub vegetation	VegArb	0.0907	4
Silviculture	Silvi	0.0609	5
Grassland	Grami	0.0425	6
Cropland	Cultiv	0.0293	7
Open soil	SolExp	0.0214	8
Street, Low-density urban area, Urban area	SutGrup4	0.0141	9

Urbanization Suitability Evaluation

After the definition of the criteria, that are relevant for urban expansion, they had to be quantified and standardized. For that reason a scale from 0 to 255 (0 for not suitable and 255 for maximal suitable) was applied to each criterion. Using such a scale had technical reasons as the GIS software IDRISI, which was applied in this step, requires this scale as input.

Criterion 1 - Existing land use (LAND): The land use classification map served as the input for criterion of existing land use. The relevant question was, which classes are adequate for urban expansion due to the efforts one has to make to prepare the landscape patches of these classes for settling and housing.

***Table 8**: Urbanization suitability ranking of land use classes*

Class	Code	Suitability value (0 - 255)
Rock	AfloRo	0
Rock vegetation	VegRup	0
Forest (advanced development stage)	FlorAvan	32
Forest (medium development stage)	FlorMed	64
Silviculture	Silvi	98
Forest (initial development stage)	FlorInic	130
Shrub vegetation	VegArb	162
Cropland	Cultiv	194
Open soil	SolExp	226
Grassland	Grami	255

In the case of the criterion LAND a simple ordinal ranking of the classes was developed. Not suitable at all for housing and settlement structures are the both rocky classes AfloRo and VegRup due to the extremely steep slope of these terrains. The three forest classes FlorAvan, FlorMed and Silvi represent a relatively inappropriate terrain for settlement due to their dense vegetation cover. FlorInc, VegArb and Culti require relatively small effort for clearing. SolExp and Grami got the highest scores as they are practically ready for housing. Grami got the highest score due to the better soil stability as SolExp.

Criterion 2 - Slope (SLOPE): The slope of the terrain was derived from the Digital Elevation Model of the research area. The calculation of the membership function was achieved by applying the FUZZY module provided within the GIS software IDRISI. This module evaluates the possibility that each pixel belongs to the fuzzy set by applying the predefined membership function. In this project the Sigmoidal ("s-shaped") membership function was chosen which is perhaps the most commonly used function in fuzzy set theory (Eastman 1993). As input the FUZZY module requires the positions (along the X axis) of 4 points governing the shape of the curve. However, in a monotonically decreasing function as applied here only two control points are needed to define the fuzzy set membership function:

$$y = \cos^2 \alpha$$

with $\alpha = \dfrac{(x - \text{point}\,c)}{(\text{point}\,d - \text{point}\,c) * \pi / 2}$ if x < point c, y=1 and if x > point d, y=0

In the case of the criterion SLOPE the critical points c and d were derived by analyzing existing housing patterns within the research area. Therefore a raster with existing settlements was created and overlaid with the slope raster. Afterwards the distribution of the settlement area across the slope range of the research area's terrain was derived (Figure 3).

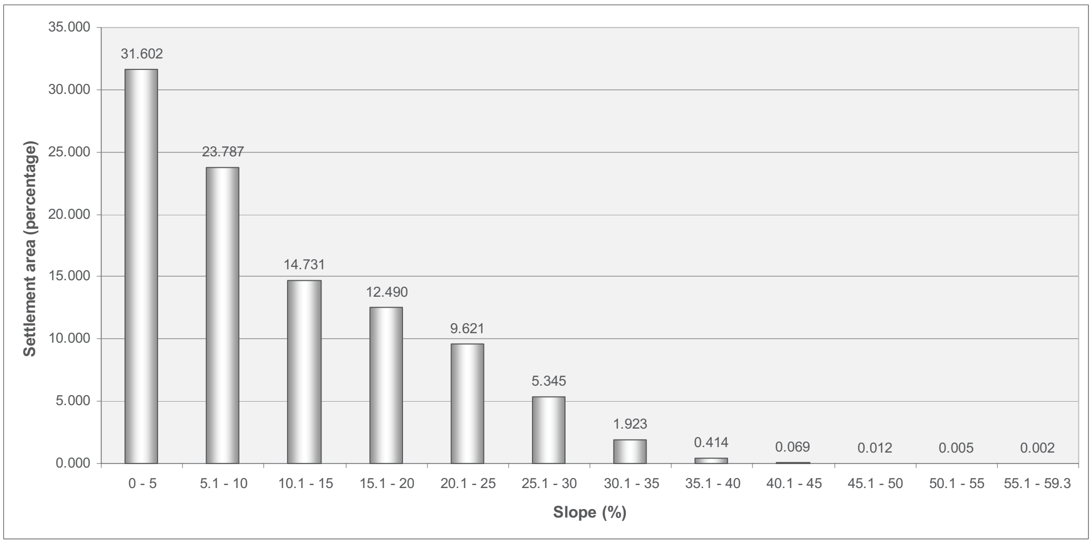

Figure 3: Distribution of settlement area over the slope range

The diagram shows that the greater part of the settlement area is located on slopes between 0 and 10 %. The remaining part is more or less linearly decreasing and distributed over the slopes from 10 to 40 %. It was suggested by the National Park management to rather calculate with exaggerated values of suitability for urban expansion to reduce the level of uncertainty when defining the final limits of the extension area:

- c = 15% (meaning 0 to 15% slope is highly suitable for urban expansion)
- d = 40% (meaning slopes > 40% are not suitable for urban expansion)

Criterion 3 - Proximity to settlement (PROXSET): For this criterion the two urban area classes - ArUrb, ArUrbBa - were applied. The same formula for the fuzzy set membership function was chosen as for the criterion SLOPE, however, with different units (m) and different critical points. The major question was, until which distance an urban pole has high influence on the decision of people to settle down in its surrounding. During several interviews with locals and the geographers from ESTRUTURAR it turned out, that the areas with a distance less than 100m to the next urban pole's boundaries are preferred by people to settle down. Main reasons for this are the close access to the urban centre, the advantage of (in general) paved roads, the connection to the storm water drainage system and electricity, and the social contact. As maximum distance to an urban pole most people state a distance of about 1km. These distances again were multiplied by 1.5 to eliminate uncertainties related to the final analysis:

- c = 150m (0 to 150 maximum suitability; value = 255)
- d = 1500m (> 1500m no suitability; value = 0)

Criterion 4 - Proximity to road (PROXROD): Proximity to roads or road gravity, as it is often called, is a major factor for urban growth (Johnston and Shabazian 2002; Varanka 2006; Clarke 1998). Fact is that urban expansion is oriented along existing roads or may even be stimulated by their existence. As with the PROXSET criterion the critical points for the fuzzy set membership function were derived form interviews with locals and resident experts. As area within direct influence of roads, the area up to 50m distance to the roads could be derived. Here economic opportunities are high and direct connection to the supply and wastewater network is provided. Within distances up to 500m the influence of roads are still given but decreasing. Above this value roads have no major influence on the people's choice to settle down and other factors become more important. Therefore as critical points were defined (again multiplied with 1.5):

- c = 30m (0 to 30m maximum suitability; value = 255)
- d = 500m (> 500m no suitability; value = 0)

Criterion 5 - Proximity to river (PROXRIV): Rivers play an important role for people within the research are as they provide the functions of wastewater disposal. In the upper parts of the rivers they also serve for fresh water supply. As direct influence distance of the rivers a relatively narrow strip of 30m was stated by the locals. Their major consideration is wastewater disposal directly into the river. Up to a distance of 100m the river could be used for that purpose, still with decreasing suitability. Above 100m the river was not anymore decisive regarding wastewater discharge. The critical points for the fuzzy set membership function were defined as follows (original values multiplied by 1.5):

- c = 45m (0 to 45m max. suitability; value = 255)
- d = 150m (> 150m no suitability; value = 09

To get only one index for urbanization suitability the method of Weighted Linear Combination (WLC) was applied. Four scenarios were developed where each criterion was assigned a weight according to its importance for the people's decision to settle down:

$S = \sum w_i x_i$ where S = final suitability value

w_i = weight of factor i

x_i = criterion score of factor i

with $\sum_{i=1}^{5} x_i = 1$

The criteria *proximity to existing settlements* (PROXSET), *proximity to roads* (PROXROD) and *slope* (SLOPE) were identified as criteria of greatest importance regarding urban growth. These findings were achieved during conversations with locals, resident geographers and reviewing relevant literature (Johnston and Shabazian, 2002; Varanka, 2006; Clarke 1998).

Scenario 1 - Dominance of POXSET, PROXROD and SLOPE: Within this scenario all of the three major criteria were assigned the same weight of 0.2666. This scenario served as a control scenario for the other scenarios. As for all three major criteria PROXSET, PROXROD and SLOPE is assigned the same percentage of influence on urban growth.

$$S = 0.2666 * x_{PROXSET} + 0.2666 * x_{PROXROD} + 0.2666 * x_{SLOPE} + 0.1 * x_{LAND} + 0.1 * x_{PROXRIV}$$

Scenario 2 - Dominance of PROXSET: Within this scenario the criterion PROXSET was considered as the dominant factor for urban growth. In this scenario potential urban growth areas are compacted around the settlement zones enclosing the Serra do Mar mountain range.

$$S = 0.4 * x_{PROXSET} + 0.2 * x_{PROXROD} + 0.2 * x_{SLOPE} + 0.1 * x_{LAND} + 0.1 * x_{PROXRIV}$$

Scenario 3 - Dominance of PROXROD: Within this scenario the criterion PROXROD was considered as the dominant factor for urban growth. The scenario 3 with dominance defined for the PROXROD-criterion consequently showed this weighting of the factors by assigning higher probability values to areas close to roads as within the other three scenarios.

$$S = 0.2 * x_{PROXSET} + 0.4 * x_{PROXROD} + 0.2 * x_{SLOPE} + 0.1 * x_{LAND} + 0.1 * x_{PROXRIV}$$

Scenario 4 - Dominance of SLOPE: Within this scenario the criterion PROXROD was considered as the dominant factor for urban growth. This scenario expressed urban growth tendencies, which reach far into the Serra da Estrela mountain range. The high urban growth probabilities of this scenario can be found mainly within all river valley of the Serra da Estrela due to relatively flat terrain.

$$S = 0.2 * x_{PROXSET} + 0.2 * x_{PROXROD} + 0.4 * x_{SLOPE} + 0.1 * x_{LAND} + 0.1 * x_{PROXRIV}$$

Worst case scenario of urbanization*:* For the final analysis the findings of the urbanization suitability evaluation were combined to a worst case scenario of a potential urbanization of the research area. The reason for doing so was to reduce the risk of neglecting potential urban growth areas as it might have occurred by taking only one of the scenarios described above. Technically the worst case scenario was developed by comparing the values of the four scenarios for each pixel and choosing the highest value of these four per pixel. This value entered the worst case scenario being the maximum urbanization suitability value for each pixel (see also Figure 3).

Final Integrative Analysis

For the final integrative analysis of the research area the results of the protection suitability evaluation and the urbanization suitability evaluation were combined to one single map. Goal was to identify the core zone of the expansion area where protection suitability is high and no urban growth can be expected. Furthermore, conflict zones were depicted where the levels of both suitability evaluations were high (Figure 4).

The major patch of the Protection Suitability Group 1, reaching from the National Park limit to the road RJ 107, was considered as the maximal potential expansion area. At several points, however, this area is confronted with urban growth tendencies towards the expansion core zone. Within the following three conflict zones the expansion effort collides with existing human occupation or with high suitability for future occupation.

Conflict zone 1 - Bottleneck along the National Park limit: The urban growth along the rivers Rio do Pico, Rio das Pedras Negras and Córrego do Caxambu narrows down the connection zone of the actual National Park area and the expansion area of the Serra da Estrela. Trespassing animals could be affected negatively through disturbance of artificial light and sound, and domestic animals. Especially big mammals like the Woolly Spider Monkey (Brachyteles arachnoids), which is frequently spotted within this area, needs wide areas of undisturbed habitat. Along the river Rio Pedras Negras there could be identified 26 properties from the RPPN El Nagual on into direction to the National Park. Some of these properties are weekend cottages, the majority of these properties, however, serve for small-scale agriculture producing for self-supply or for the markets in the close-by settlements. The area along the river Côrrego do Caxambú is dominated by agriculture. No roads reach far into the Serra as it appears on the aerial photos and satellite images. Most of these transportation ways are small trails used by farmers or they are used for reaching the transmission line for maintenance purposes.

Conflict zone 2 - River valleys along the road "Antonio Alem Bergara": Especially along the rivers Rio da Cachoeira and Rio Itacolomí, but also along the rivers Rio do Ouro and Rio da Cachoeirinha irregular housing and small-scale agriculture is reaching far into the Serra da Estrela. In the case of the rivers Rio do Ouro and Rio da Cachoeirinha these occupation tendencies do not affect the expansion area of the National Park directly. The proposed expansion area is protected by mountains North-west of these rivers. It is more likely that further urbanization occurs in northern and north-eastern direction without reaching into the expansion area. Yet, indirect effects of this development (hunting, irregular agriculture, domestic animals, plant extraction, artificial light, noise, etc.) has to be considered in future. Although not easily accessible due to unpaved roads in bad conditions irregular, settlements reach far into the Serra da Estrela along the rivers. Houses and agricultural fields, which are too small for being recognized during remote sensing, were spotted within the potential expansion area of the National Park.

Conflict zone 3 - Estrada da Serra da Estrela (RJ 107): This area does not represent a conflict zone for the actual expansion project but if long-term planning is considered the area along the road RJ 107 (Estrada da Serra da Estrela) is of major importance. This road with its adjacent settlements is located between the Serra dos Órgãos National Park and the Tinguá Biological Reserveand represents an ecological barrier. At the same time this area is another bottleneck of the ecological corridor between this two protection units narrowed by the outskirts of Petrópolis in the North and the settlements Inhomirim, Fragoso and Pau Grande in the South. Both of these urban areas show tendencies of growing further into the forests along the Estrada da Serra da Estrela.

Final proposal for the expansion area

For the final proposal of the expansion area of the Serra dos Órgãos National Park the findings of the protection suitability evaluation, the urbanization suitability evaluation and the final integrative analysis were combined to define the limits of the preliminary expansion area. During this phase the requirements defined previously were considered as overall guidelines for delimitating the expansion area:

The area should be composed mainly of the land use classes, which are of high protection value: As Figure 5 shows, the expansion area covers mainly (80%) landscape patches of land use classes, which were assigned to the suitability group with the highest protection potential. Another 18% are covered with patches of the suitability group 2. Together these two suitability groups represent almost 98% of the proposed expansion area.

The area should be as distant as possible from human infrastructure like settlements, roads and supply networks to reduce negative disturbance effects: Figure 6 shows that this requirement cannot be met in all parts of the proposed expansion area. Especially in the region of the outskirts of Petrópolis and in the southern part of the research area the expansion area reaches relatively close to existing urban areas. As examined during the urbanization suitability evaluation these settlements have a considerable potential for urban growth in direction to the Serra da Estrela and therefore may cause future conflicts. In this region special emphasis has to be put on choosing obvious limits for the expansion area.

The area should be as large and compact as possible to provide sufficient core area and to reduce negative edge effects: The main part of the expansion area is of considerable size and has a very compact shape reaching almost the ideal shape (square or circle) for reducing the proportion of edge (McGarigal and Marks

1995). Thereby, forest edge effects like differences in wind and light intensity and quality that alter microclimate and disturbance rates can be reduced.

The contrast between the single patches and their surrounding environment should be as small as possible to stimulate corridor effects between these patches: As stated before, almost 98% of the proposed expansion area is composed of natural resp. semi-natural vegetation representing a matrix of patches of different ecosystems. As the major part of this 98% is composed of classes of primeval land cover the contrast of ecological attributes that are relevant to organisms or process does not restrict flora and fauna.

The limits for the extension area should represent natural barriers for future urban growth. At the same time they should be obvious and visible not only on maps but also in the field: This guideline could not be followed at each point of the limit of the expansion area. In general the limit passes along hills, which represent natural obstacles for urban growth. At several points, however, the limitation has to cross river valleys, potential zones of conflict with urbanization activities. Especially in these regions educational projects with the local population could help to heighten people's awareness of the Serra dos Órgãos National Park and its importance both in a local and a regional nature conservation context.

Conclusions

This project contributed to the expansion project initiated by the management of the Serra dos Órgãos National Park. It focused on the the Serra da Estrela mountain range, which represents the last still existing connection between the Serra dos Órgãos National Park and the Tinguá Biological Reserve. The goals was to provide the National Park management with a working basis for subsequent project phases, to analyze the Serra da Estrela regarding the ecological potential of its landscape fragments and the suitability for urban growth, and finally to define a preliminary expansion area based on this analysis.

As working basis a Geographic Information System was developed by processing and incorporating existing data, and by creating new information about the National Park and its surroundings. The protection suitability evaluation lead to insights about the ecological potential of the landscape fragments of the Serra da Estrela. The urbanization suitability evaluation pointed out the urban growth tendencies of existing settlements towards the Serra da Estrela. The findings of both evaluations were combined and analyzed to identify core zones (where no urbanization can be expected) and conflict zones (where the suitability of both – protection and urbanization – is high) of the expansion area. Finally, an expansion area was delimitated including as many core zones as possible and excluding the potential conflict zones for the most part of the research area.

The methods of Geographic Information Systems (GIS) and Spatial Decision Support Systems (SDSS) applied during this work resulted in an informative insight into the research area's characteristics regarding its potential for protection and urbanization. Though very time-consuming, these methods guaranteed high data accuracy and consistency, important for further project phases, where legal aspects and landownership could play a major role.

The modeling technique of the Multi Criteria Evaluation (MCE), used for the suitability evaluations, turned out to be highly practical. No all-embracing model was required which include all aspects and factors of the complex phenomenon of urban growth. Due to limited time and resources a rather straight-forward approach was chosen by evaluating the urban growth within the research area based on five major criteria. In combination with the findings of the protection suitability evaluation, the urban growth model lead to a consistent proposal for the expansion area within the Serra da Estrela.

With the application of FUZZY SETS the amount of uncertainty was reduced. Instead of relying on "hard" data sets and decision rules of traditional GIS, the analysis was dominated by "soft decisions", expressed in probabilities, whether the phenomenon under consideration occurs or not. It is assumed that the reality of natural characteristics and processes could be modeled more realistic with this method.

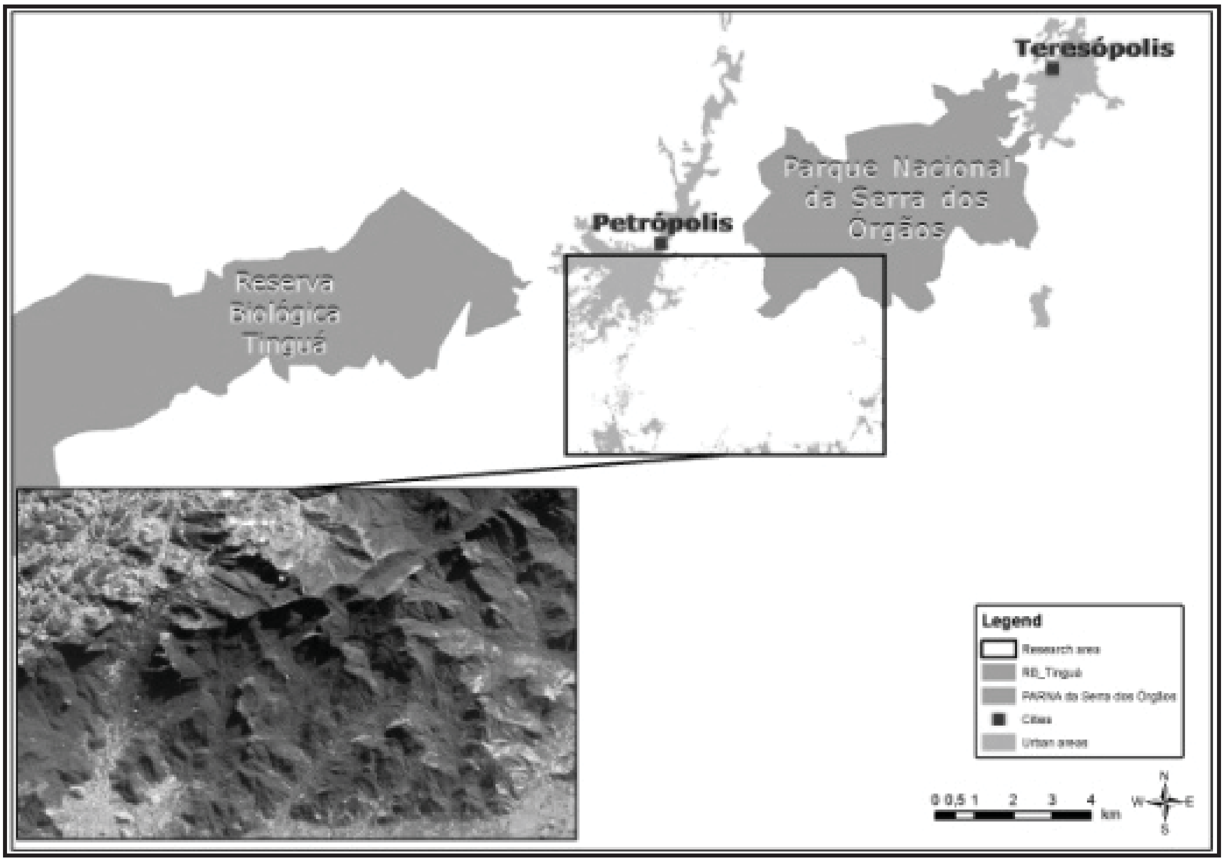

Figure 1**:** The research area of the project: Serra da Estrela

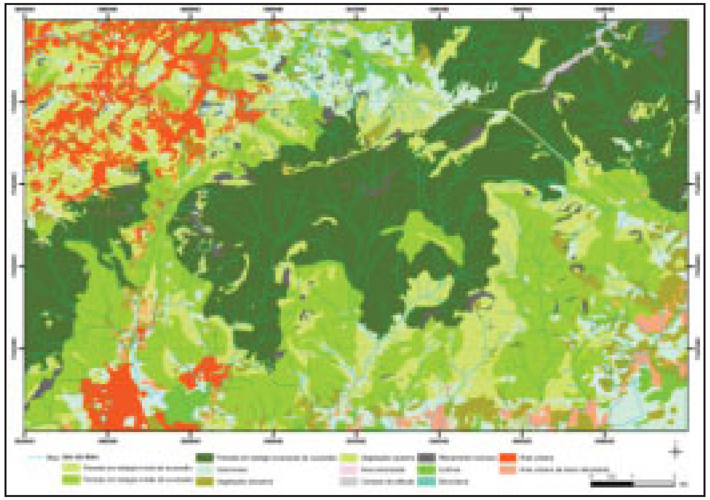

Figure 2: Land use map of the research area.

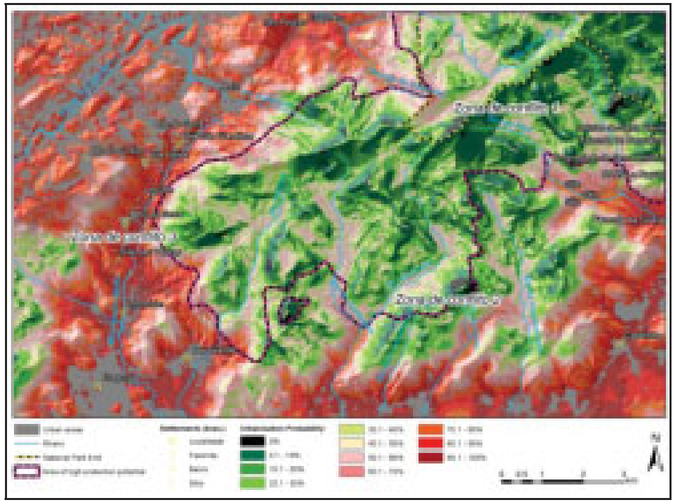

Figure 4: Protection core zone and conflict zones.

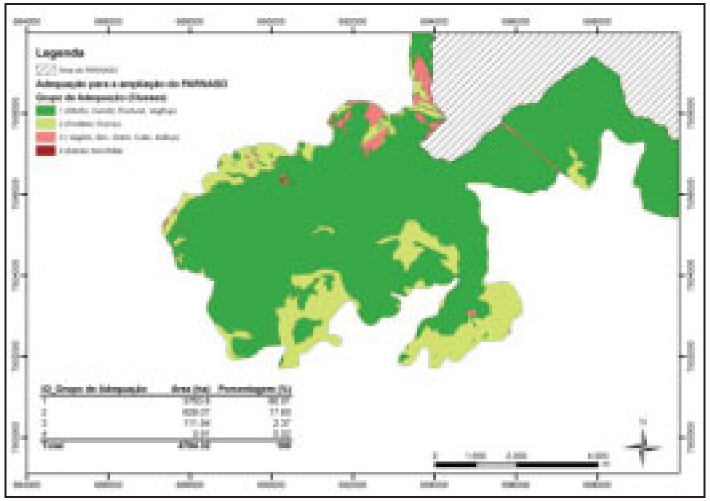

Figure 5: Protection suitability of landscape patches of the expansion area.

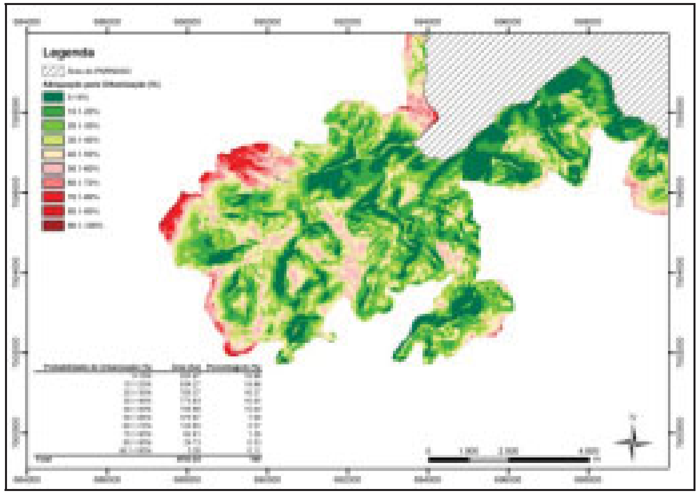

Figure 6: Probability of urbanization within the expansion area.

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PART IV

Biodiversity studies in fragmented landscapes

CHAPTER 12

BROAD-SCALE ANGIOSPERM DIVERSITY IN BRAZIL'S MATA ATLÂNTICA: USING MONOGRAPHIC DATA TO ASSESS PROSPECTS FOR CONSERVATION

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Abstract: The Brazilian part of the Atlantic forest, the Mata Atlântica, originally comprised all coastal forest from the states of Rio Grande do Norte to Rio Grande do Sul. To date, the remnant Mata Atlântica resembles a patchwork of scattered fragments, which in many cases are minuscule in size. Inspite of Mata Atlântica's reputation as a 'hot' hotspot, detailed distribution patterns for many of its plants are widely unknown. Of special importance for the conservation of the Mata Atlântica are endemic species with a narrow distribution, since they are most prone to extinction by forest destruction. In this research, we explore the distribution patterns of angiosperm species within the outer borders of today's remnant Mata Atlântica at 1° grid resolution. Based on monographic data, we identify centres of species richness and narrow endemism. To identify areas under risk we contrast these centres with information on their current protection status, their remaining forest

cover and their integration in biodiversity corridors, as well as with scenarios on population development and potential deforestation.

Introduction

Biogeographic patterns in the Mata Atlântica

Among the South American biogeographic provinces, the Mata Atlântica is not exceptionally large, but has a considerable latitudinal extension: flanked by the savanna-like biogeographic provinces Caatinga and Cerrado in the northern part and the Paraná Basin in the southern part (Lomolino et al. 2006), the extant Mata Atlântica encompasses the coastal forests of Brazil, Argentina and Paraguay. The largest part of the Mata Atlântica is located along the Brazilian coast, stretching over the length of almost 4,000 km (Fig. 1). The width of this coastal belt varies between a few kilometres to more than 700 km. Several mountain ranges cross Mata Atlântica, like the Serra Geral, the Serra da Mantiqueira and the Serra do Mar, separating the coastal lowlands from the hinterland. From south to north, these ranges become more distant from the coast and decrease in altitude (Oliveira-Filho and Fontes 2000).

One prominent mountain range which directly comes up to the sea is the Serra do Mar, running parallel to the coast over the length of ca. 1,500 km from the state of Santa Catarina up to the south, with the highest peaks reaching more than 2,000 m above sea-level. The Serra do Mar is not a continuous mountain range and is divided into various sub-ranges, like the Serra dos Órgãos close to Rio de Janeiro, where the Serra dos Órgãos National Park is located (Cronemberger and Castro 2009). To the east of the Serra do Mar there is a gap in the coastal mountain ranges. The *tabuleiros*, low coastal upland formations between 30 and 200 metres high, extend from northern Rio de Janeiro state to north-eastern Brazil, protruding the more distantly located northern mountain ranges (Câmara 2003, Oliveira-Filho and Fontes 2000). This latitudinal border between northern and southern part of the Mata Atlântica is also visible in the forest formation: due to a drier coastal climate of the Cabo Frio region in northern Rio de Janeiro state, the coastal rain forests are replaced by semideciduous forests, with rainforests re-emerging only in Espírito Santo state (Oliveira-Filho and Fontes 2000).

The latitudinal gradient in combination with the topographical gradient from coastal lowland to mountains of high-altitude and to hinterland woodlands provides an array of different ecosystems (Câmara 2003, da Fonseca et al. 2005). These ecosystems lie in spatial proximity and vary considerably due to altitude and associated temperature, distance to the ocean, rainfall regime and soil properties.

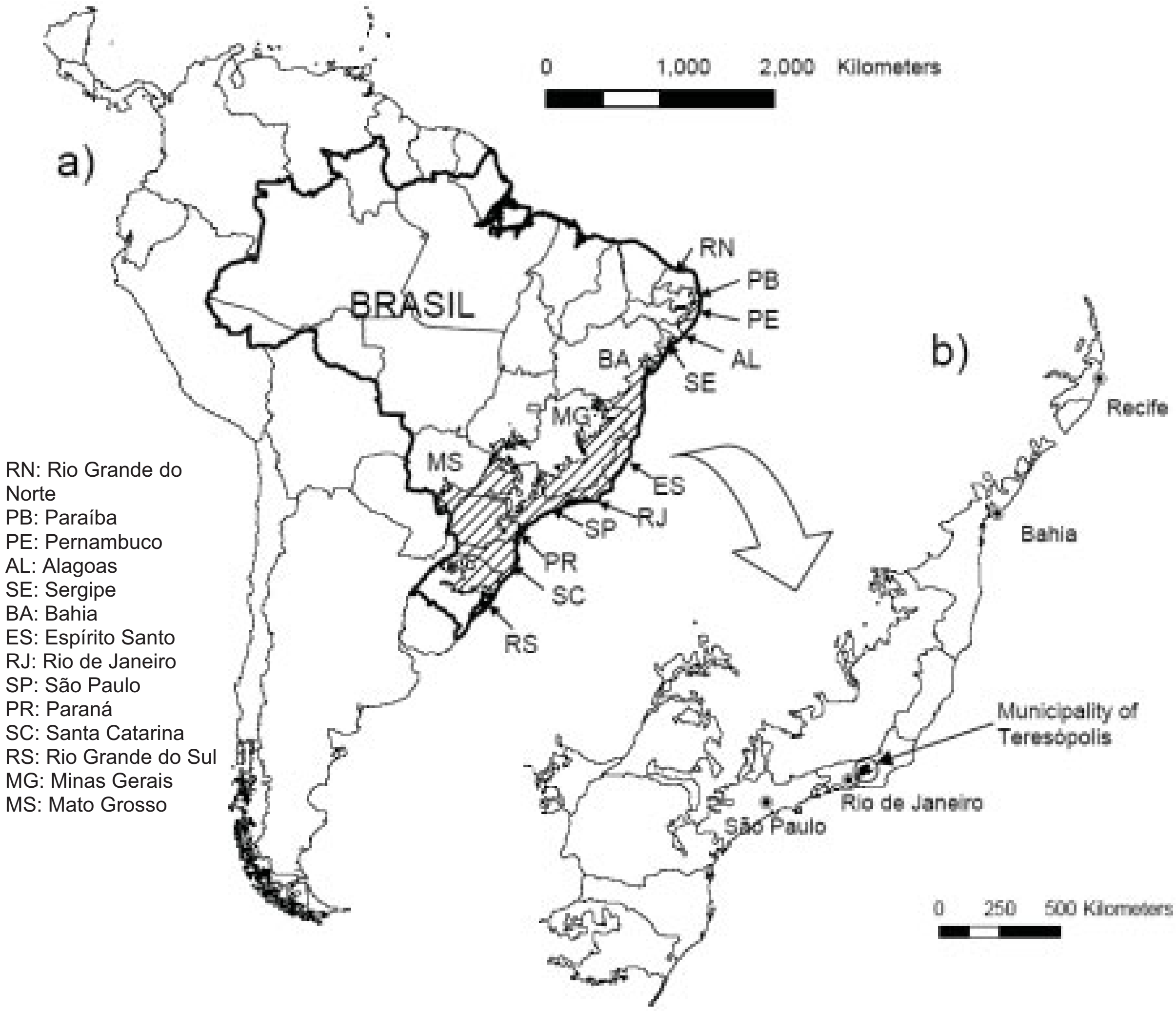

Figure 1: The Brazilian Mata Atlântica. a) Location of the Mata Atlântica (hatched) in South America. The outline of the Mata Atlântica is taken from Conservation International (2004). b) Mata Atlântica enlarged showing states borders, the four major cities and the municipality of Teresópolis, where the BLUMEN study area is located. Projection: Aitoff, Central Meridian 60° W.

Typical coastal ecosystems are sandy beaches, mangrove swamps and so-called *restingas*, sandy-soil forest and scrub systems (da Silva and Casteleti 2003). These are followed by coastal rainforests, growing on flatlands, submontane and montane terrains (often referred to as '*dense or open ombrophilous forests'*, according to IBGE 1993). Behind the mountain tops follows the hinterland, which is covered by deciduous and semideciduous seasonal forests of very variable composition (often referred to as *'mixed ombrophilous forests'*, Câmara 2003, IBGE 1993).

The eastern slopes of the coastal mountain ranges are characterized by constant humidity brought by the ocean and by strong precipitation events especially in the south (Câmara 2003). These slopes harbour rainforests of great diversity. The dominant families of the tree flora are Myrtaceae, Fabaeceae, Rubiaceae, Melastomataceae and Lauraceae (Negrelle 2002, Oliveira-Filho and Fontes 2000), with Myrtaceae as the most diverse family occurring with more than 300 species in the entire Mata Atlântica (da Fonseca et al. 2005). Further important angiosperm families are the Bromeliaceae and the Orchidaceae (Davis et al. 1997, Mori et al. 1981, Negrelle 2002). Along the altitudinal as well as the latitudinal gradient, the rainforests change in composition. With increasing altitude, the proportion of the families of e.g. Chrysobalanaceae, Fabaceae, Rutaceae and Moraceae decreases, whereas the relative importance of Asteraceae, Solanaceae, Monimiaceae and Myrsinaceae increases (Oliveira-Filho and Fontes 2000). Based on the commonly recognized definition of the Tropics, the forests lying south of the Tropic of Capricorn (approximately corresponding to the latitude of São Paulo) would not be classified as tropical. However, the southern parts of the Atlantic forest show similar characteristics as the more northern forests and have been categorized as tropical forests (Negrelle 2002). Nevertheless, non-tropical forest elements like the two native genera of gymnosperms *Araucaria* and *Podocarpus* and laurel genera like *Nectandra* increase towards the south (Câmara 2003). On the western slopes of the coastal mountains in the hinterland, the floristic composition is different although the predominant families of the tree flora remain the same as in the rainforests. Thus, unlike in the eastern slopes, with increasing altitude, the proportion of the families of e.g. Solanaceae, Monimiaceae and Myrsinaceae decreases (Oliveira-Filho and Fontes 2000). Over the entire Mata Atlântica, the forests of the hinterland show a very variable floristic composition (Câmara 2003).

One non-coastal mountain range crossing Mata Atlântica is the Serra do Espinhaço. This mountain range is separated from coastal Rio de Janeiro by the Rio Paraíba do Sul, which builds together with its tributary Rio Paraibuna the natural border between Minas Gerais and Rio de Janeiro state, and the foothills of the Serra da Mantiqueira. The Serra do Espinhaço extends from the Serra do Ouro Branco, which lies southeast of Belo Horizonte in Minas Gerais, for about 1,200 km towards the northern region of Bahia. The highest peaks of the Serra do Espinhaço reach more than 2,000 m above mean sea-level. The Serra do Espinhaço borders to the Cerrado in the west and to the Caatinga in the northeast and separates thereby three adjoint biogeographic provinces. It is a discontinuous mountain range, with sub-ranges such as the Chapada Diamantina and Serra do Cipó in the south and the Serra do Sincorá in the north. The central area of the Serra do Espinhaço is lower than its southern and northern parts and is crossed by large river systems such as the Pardo river (Davis et al. 1997).

Plant species distribution patterns

The multitude of ecosystems along the latitudinal and topographical gradient, in combination with variation in rainfall, adds to the extraordinary plant species richness of the Mata Atlântica (Câmara 2003, Oliveira-Filho and Fontes 2000, Ribeiro et al. 2009). Current estimations of plant species richness of the Mata Atlântica amount to 20,000 species, whereof 8,000 species are estimated to be endemic for the Mata Atlântica (Myers et al. 2000). In an inventory-based analysis of global centres of vascular plant diversity, Barthlott et al. (2005) identified the area extending from Porto Alegre in Rio Grande do Sul to Bahia as the Eastern Brazil centre of species richness. They suggested the coastal area located between São Paulo and Rio de Janeiro as one of the five centres of global plant diversity, reaching more than 5,000 species per 10,000 km^2.

Endemic species are of particular importance for conservation purposes, because they only exist in the respective area and nowhere else. The smaller the area occupied by a species, the higher the importance for protecting at least a part of the corresponding area is. Mori et al. (1981) analyzed distribution patterns of 127 tree species occurring in the Mata Atlântica and found more than 50% of the species being endemic. They identified at least two centres of endemism, one in the eastern part of Rio de Janeiro state and the other in the Bahia/Rio Doce region stretching from Rio Doce in central Espírito Santo to southern Bahia. In an analysis covering the entire South American tropics, Prance (1987) identified three centres of plant endemism for Mata Atlântica: Pernambuco, Bahia and Rio-Espírito-Santo. This analysis relied on distribution patterns of five woody angiosperm families. Thomas et al. (1998) used these three areas of endemism with slight modifications, mainly enlarging the southernmost centre of endemism to the São Paulo-Rio de Janeiro centre. Thus, proposed centres of plant endemism differ, although overlapping areas exist. So far, a broad-scale analysis of distribution patterns based on individual species ranges of angiosperm species in the Mata Atlântica, including non-tree species, is lacking.

In view of its remarkable species richness and endemism, the actual environmental state of the Mata Atlântica is alarming. The originally contiguous rain forests have almost entirely vanished. From the original forest cover of Mata Atlântica, estimated to range between 1 and 1.5 million km^2 (Galindo-Leal and Câmara 2003), only about 5-12% remain (e.g., Oliveira-Filho and Fontes 2000, Ribeiro et al. 2009, SOS Mata Atlântica and INPE 2008, Tabarelli et al. 2005). These remaining forest areas are severely fragmented, posing a particularly high threat to the extant species assemblages. With decreasing size and increasing isolation of fragments, the risk of extinction for species increases, due to the diminishing connectivity between genetically different populations. This risk is especially high for species with very narrow distribution, the so-called narrow endemic species.

In the entire Brazilian Mata Atlântica, the Serra do Mar is the only region left with forest areas larger than 10,000 km^2 (Galindo-Leal and Câmara 2003). Thus, the Serra do Mar was appointed as a biodiversity corridor (*Serra do Mar Corridor*), with the purpose to provide connectivity for an entire region to preserve biodiversity (Galindo-Leal and Câmara 2003, Ayres et al. 2005). Further corridors within the Mara Atlântica are the *Central Corridor* stretching from Espírito Santo to Bahia and the *Corridor Nordeste* covering the area between Alagoas and Rio Grande do Norte (Aliança para a conservação da Mata Atlântica 2009). The core units of these corridors are the protected areas (da Fonseca et al. 2005), whose connectivity should be improved by linking protected areas and the remaining forest fragments. Until recently, the montane areas were regarded as safekeepers of forest remnants, since they are difficult to reach and of little use for agriculture. Nowadays however, settlement is a growing threat even to these areas. The highest city in Brazil, Campos do Jordão in São Paulo state with 46.332 inhabitants (IBGE 2008), is located at the height of 1,628 m. If cities "climb" the mountains, new settlements cause further forest destruction.

The Atlantic coast of Brazil has a long history of human land use change. When the European settlers arrived in the sixteenth century, parts of the coastal areas were already cultivated (Nehren et al. 2009). Today, this area is the most populated area of Brazil, with eight of the 14 cities with over one million inhabitants concentrated here. The two largest cities, Rio de Janeiro and São Paulo, together have almost 18 million inhabitants (IBGE 2008). Even though a large network of protected areas covers the Mata Atlântica (Myers et al. 2000, Tabarelli et al. 2005, WDPA 2008), it is not surprising that high population density collides with protected areas. High population density is not the only major threat to the last forest fragments: deforestation is also caused by further human impacts such as urban sprawl, unsustainable land use systems, rapid expansion of biofuel crops, industrialization, and will be further aggravated by climate change (e.g., Aguiar et al. 2003, Laurance 2009, Raven 1988, Tabarelli et al. 2005).

The aim of this article is to identify centres of angiosperm species richness and narrow endemism in the Mata Atlântica based on monographic data of 667 species occurring in the Mata Atlântica. These centres are then analysed regarding their forest cover, their protection status and their connection to biodiversity corridors. Further, forecasted population developments and prognosticated deforestation patterns are used to estimate the threats these centres have to face in the future.

Methods and data

The tropics in general are under-collected, and the taxonomical identification of the specimen collected is often difficult, hampering the detection of broad-scale distribution patterns. Reliable broad scale species and species distribution information is available from monographs (Hopkins 2007, Morawetz and Raedig 2007, Thomas 1999). However, this distribution information is prone to heterogeneous sampling effort. We used therefore a tailored interpolation approach to analyze monographic data of angiosperm species occurring in the Mata Atlântica.

This approach consists of five steps. In a first step, for each species the locations at which the species has been observed were mapped to the predefined 1° grid (point-to-grid map), the smallest units being 1° x 1° quadrats. In the next step the species ranges for each species were interpolated from the species occurrences using a modified alpha-hull approach (Burgman and Fox 2003, Edelsbrunner et al. 1983). The interpolation was performed for varying distances of 1 to 10 quadrats. In a third step, these interpolated species ranges for all species were combined to one grid for each interpolation distance. Subsequently, these grids were combined to the species richness map using an inverse-distance weighted scheme. Following this scheme, interpolation results derived for higher interpolation distances were down-weighted. In the last step, this map was adjusted for heterogeneous spatial sampling effort. Since the true sampling effort was not known for each quadrat, we used the relationship between the number of species in each quadrat to the quadrat with the maximum number of species in the original point-to-grid map as a proxy. Accordingly, in the resulting map of species richness adjusted for sampling effort, probably poorly sampled quadrats got a higher weighting in relation to better collected quadrats.

The same approach was used to generate a map of species richness of the narrow endemic species. From all species, we selected those, which had species ranges of less than five adjoining quadrats in the interpolated species richness map. This threshold area roughly resembles the 50,000 km^2 given by Gentry to define local endemism (1986). For these species, a map of species richness adjusted for sampling effort was created following the approach as outlined above. Both maps were used to identify centres of species richness and centres of narrow endemism. For a more detailed explanation of this approach see Raedig et al. (submitted).

The underlying data for this research originate from a database of 3,803 Neotropical angiosperm species introduced in Morawetz and Raedig (2007) and supplemented in Raedig et al. (submitted). The species occurring in the Mata Atlântica were filtered using the outline of remaining Mata Atlântica forest as given by Conservation International (2004). This outline was further used to derive the 168 quadrats constituting the spatial representation of Mata Atlântica in this research study. Although the terrestrial proportion of marginal quadrats was often smaller, we considered these quadrats because their species composition is often particularly revealing due to the coastal ecosystems included (e.g. mangroves or restingas) or due to border zones with other biogeographic provinces.

The resulting maps of species distribution patterns were contrasted to the biodiversity corridors which have been designated for the Mata Atlântica. The outlines of the biodiversity corridors were taken from Aliança para a Conservação da Mata Atlântica (2009). The maps of species distribution patterns were further overlaid with maps of forest cover and mean fragment size, as well as with scenarios of deforestation and human population density. For the calculation of forest cover per 1° quadrat, the 'Atlas of forest remnants in the Mata Atlântica' (Atlas dos remanescentes florestais da Mata Atlântica, period 2000-2005, SOS Mata Atlântica 2008) was used. This enormous dataset considers forest fragments starting from a minimum size of 3 ha and comprises fragment data of forest (including secondary forest), restinga and mangrove ecosystems of the Mata Atlântica. Along with the extant forest cover per quadrat, mean fragment size and fragment density were determined. Fragment density was defined as the ratio of the number of fragments in a quadrat to its terrestrial area, in reference to 1 km^2. The consideration of mean fragment size and fragment density allowed a better distinction between intact and severely fragmented forest remnants than forest cover alone.

The data on deforestation were taken from Scholze et al. (2006), who combined different models simulating different levels of global warming to derive predictions of biome change from forested to nonforested area for the period 2071 to 2100. We selected the prediction based on models simulating a medium level of global warming (between 2° and 3°C). The prediction of human population density for the year 2015 was taken from Ciesin and Ciat (2005). The World Database on Protected Areas 2007 (WDPA 2008) was used to calculate the coverage of protected areas per quadrat. For this calculation, only protected areas with a stricter protection status according to the IUCN management categories Ia to IV were considered.

Results

Of the 68 families contained in the entire Neotropical angiosperm database, 45 families occur in the Mata Atlântica. The most species-rich families are listed in Table 1. In parallel to the proportion of 80% of woody species in the Neotropical database, the highest proportion of the 667 species recorded in the database belongs to woody species (540 species). Of the 667 angiosperm species, 287 (43%) are endemic to the Mata Atlântica.

Table 1: The families contained within the database occurring with more than 10 species.

Annonaceae	Chrysobalanaceae	Melastomataceae
Arecaceae	Connaraceae	Meliaceae
Bignoniaceae	Fabaceae	Myrtaceae
Bromeliaceae	Lauraceae	Rubiaceae
Burmanniaceae	Lecythidaceae	Rutaceae
Caesalpiniaceae	Malpighiaceae	Sapotaceae

Distribution patterns based on a simple point-to-grid mapping of all species occurrence data in the Mata Atlântica are shown in Fig. 2a. Names of locations which are frequently used to refer to quadrats are given in Fig. 2d. The most species-rich quadrats are located along the coast, the quadrats at Rio de Janeiro (-43.5° longitude, -22.5° latitude; 229 species) and Ilhéus (Bahia state, -39.5°, -14.5°; 151 species). One exception to this pattern is the occurrence of 111 species in the quadrat at Belo Horizonte in Minas Gerais (-43.5°, -19.5°), which is located in the south of the Espinhaço mountain range. The result of our interpolation approach is the distribution pattern shown in Fig. 2b. In comparison to Fig. 2a, two distinct distribution centres emerge. One large distribution centre stretches from São Paulo to Cabo Frio region, which is located approximately in the centre of Rio de Janeiro state at the coast, and from there to the Espinhaço mountain range in the north. The second centre stretches along the coast from Porto Seguro to the south of Bahia. Furthermore, a single quadrat with 107 species lies approximately in the centre of Espírito Santo at Linhares (-40.5°, -19.5°).

Essential for conservation are centres of narrow endemism, where endemic species are concentrated locally. From the angiosperm species of the Mata Atlântica recorded in the database, 177 species are narrow endemic species (26.5%). Most of these occur along the coast. Their centres are located largely within the centres of species richness (Fig. 2b-c). Three quadrats exceed these centres, one lying at the utmost northeastern tip of Rio de Janeiro state and two stretching in southwestern direction from Bahia. The quadrats with most narrow endemic species are located at Rio de Janeiro (38 species), Teresópolis, which is located at the border to the quadrat at Rio de Janeiro (-42.5°, -22.5°, 24 species), and Ilhéus (22 species). The centres of narrow endemism occur in three bands (Fig. 2c). One of these bands ranges from São Paulo to the northeast of Rio de Janeiro state, one lies in Bahia state stretching from Porto Seguro to the quadrat southwest of Bahia and one is located in Minas Gerais stretching from Ouro Preto (south of Belo Horizonte) to the north. One quadrat not falling into these bands lies at Linhares in Espírito Santo, and was already identified as single quadrat with an elevated level of species richness in Fig. 2b.

The centres of narrow endemism found to some extent lie in the biodiversity corridors designated for the Mata Atlântica (Fig. 2d). Nevertheless, parts of the hinterland of São Paulo state and Rio de Janeiro state as well as the southern part of the Serra do Espinhaço are not included into these corridors. The Corridor Nordeste

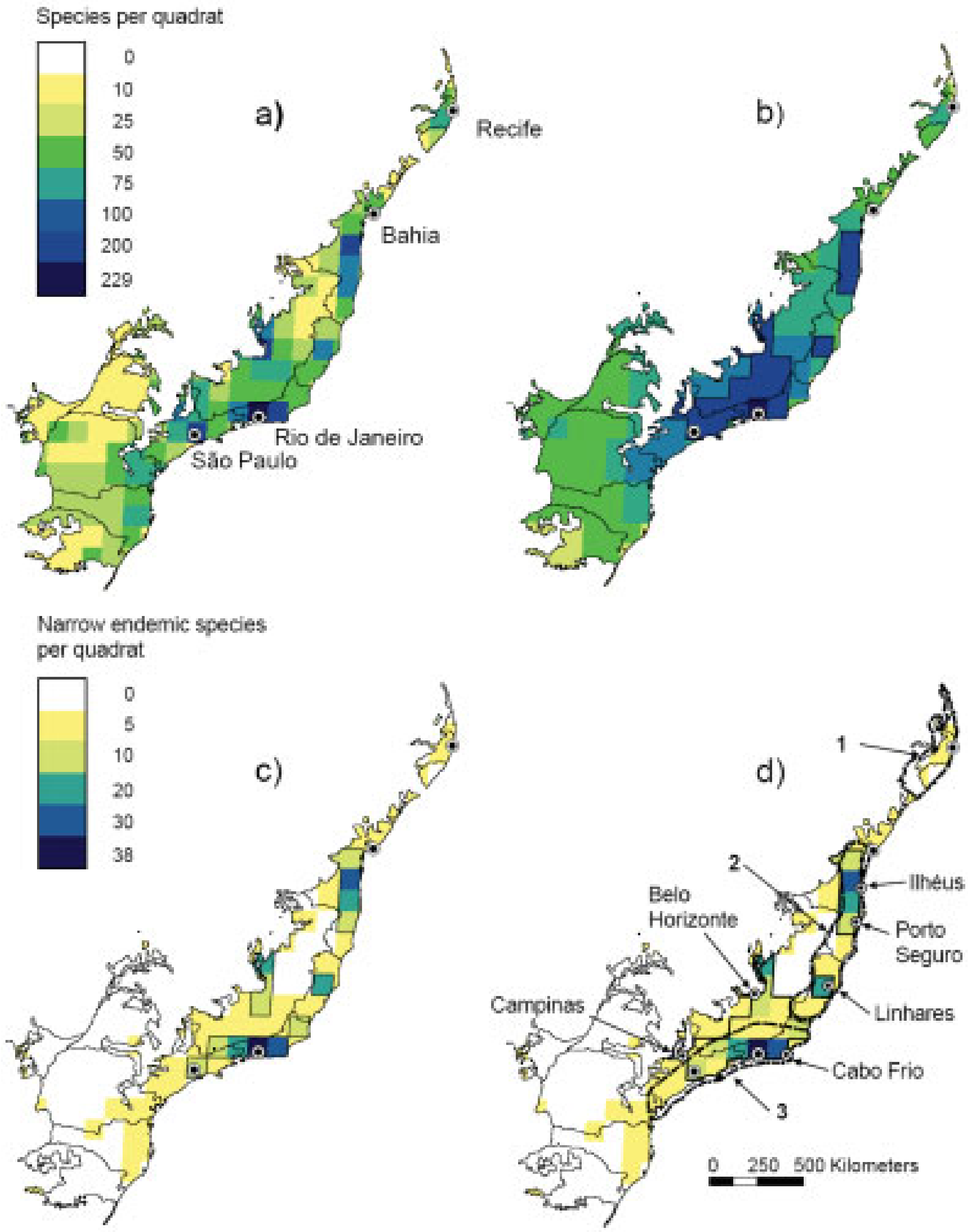

Figure 2: a-d: Distribution patterns of angiosperm species in the Mata Atlântica. a) Point-to-grid species richness b) Species richness adjusted for sampling effort. The two centres and the single quadrat of high species richness are outlined. c) Species richness of narrow endemic species. The centres of narrow endemism are outlined. d) Biodiversity corridors within the Mata Atlântica according to the Aliança para a Conservação da Mata Atlântica (2009): 1) Corridor Nordeste, 2) Central Corridor, 3) Serra do Mar Corridor. Projection: Aitoff, Central Meridian 60° W.

Encompasses almost the entire coastal area of northern forest remnants of the Mata Atlântica. For this area, our dataset shows medium levels of species richness and lower levels of narrow endemism.

The distribution patterns of the angiosperm species of the Mata Atlântica are inevitably linked to the distribution of extant forest fragments. The map of forest cover (Fig. 3a) based on the Atlas of Remaining Forests of the Mata Atlântica (SOS Mata Atlântica 2008) shows that especially areas of the hinterland of Paraná, Mato Grosso, São Paulo state and Minas Gerais are almost devoid of extant forests, the forest cover of the quadrats being less than 10%. In the southwest of São Paulo and Mato Grosso, the forest cover in some quadrats is less than 5%. At the coast, in Espírito Santo both at the southern and the northern state border, equally few forest remnants remain. Furthermore, in northern Bahia only few forest fragments persist, and Pernambuco and adjacent areas have a forest cover of less than 5%. The only quadrats left with a forest cover of more than 50% stretch from the coast of Santa Catarina and Paraná to the south of São Paulo state. The quadrats with the highest proportion of forest cover are located at the coast of Paraná and at the border between Paraná and São Paulo state (86.5% and 88.0%).

The overlay of predicted forest conversion for the year 2100 with extant forest coverage shows that particularly the hinterland of Paraná, adjacent Mato Grosso, São Paulo state and Minas Gerais will be affected by deforestation (Fig. 3a). The area from Minas Gerais up to the coast of Bahia and parts of Alagoas and Pernambuco will be likewise concerned. Similar to the distribution of predicted deforestation, mean fragment size is lowest in the areas of the hinterland, particularly in the hinterlands of Rio do Sul, Santa Catarina, Paraná and Minas Gerais (Fig. 3b). However, coastal quadrats in northern Rio de Janeiro state and in Espírito Santo exhibit low average fragment size as well. Average fragment size is lowest in the marginal quadrats of Rio Grande do Sul (0.09-0.12 km^2). The highest number of fragments is found in the quadrat at the southern border of Espírito Santo (21,900 fragments in 11,580.9 km^2 of quadrat area), which also has a small average fragment size (0.126 km^2).

Whereas predicted deforestation and low fragment sizes are more concentrated on the hinterland, the areas of highest human population density, in parallel to the areas containing the largest forest remnants, are located at the coast (Fig. 3c). Quadrats with a population density of more than 400 inhabitants per km^2 are associated to the cities of São Paulo, Rio de Janeiro, Bahia and Recife. Quadrats with a low population density of five or less inhabitants per km^2 are mainly found in Santa Catarina, Paraná and Mato Grosso as well as in northern Minas Gerais and adjoining quadrats in Bahia. It is remarkable, that most of the protected areas in the Mata Atlântica are located along the densely populated coast (Fig. 3d).

The quadrats with the highest protected area coverage are located along the coast of Paraná to southern São Paulo state, between São Paulo and Rio de Janeiro, and further up north extending from the quadrat at Linhares to the quadrat south of Ilhéus. Accordingly, the coverage of the quadrats within the corridors by protected areas is better than of most quadrats outside of the corridors. However, even some quadrats within the corridors have low protected area coverage (lesser than 5%, Fig. 2d). This is the case for e.g. the quadrat at Ilhéus which shows a high level of species richness and narrow endemism, as well as for the quadrat at the northeastern border of Rio de Janeiro state, which harbours many narrow endemic species. For the entire Mata Atlântica, 57 quadrats have no protected areas at all. This corresponds to more than a quarter (27.4%) of the total area. Further 80 quadrats, corresponding to 54.3% of the total area, have less than 5% coverage with protected areas. Taken together, the proportion of the Mata Atlântica with no or low protection status adds to more than 80%.

For the centres of species richness and narrow endemism, the results of Figs. 2 and 3 are summarized in Table 2. Deforestation is predicted for almost half of these centres, namely for the quadrat at Campinas (-47.5°, -22.5°), the hinterland of Minas Gerais and coastal Bahia. All quadrats of the Bahia centre have a rather high forest cover (more than 25%), with the highest forest cover found at Ilhéus (44.9%). This quadrat encloses the largest fragments (mean size 1.53 km^2, Table 2). In the large São Paulo-Rio de Janeiro-Minas Gerais centre (SP-RJ-MG centre), the quadrats with more than 30% forest cover are located in the Serra do Mar region and in the most northern quadrat belonging to the Serra do Espinhaço. But the overall fragment size is low compared to Bahia (mean fragment size for the SP-RJ-MG centre: 0.36, for the Bahia centre: 1.01). However, the fragment density is slightly lower in the SP-RJ-MG centre (mean fragment density 0.59 compared to 0.62 in the Bahia centre). The quadrats north of Rio de Janeiro have the smallest fragments (mean size 0.13) and exhibit low protected area coverage (0.0 and 0.1%). Only the quadrat south of Ilhéus combines high forest cover with a larger fragment size, low population density and high protection status (41.8%). All other quadrats either exhibit low forest cover, low fragment size, high fragment density, high human population density, low coverage by protected areas, or are

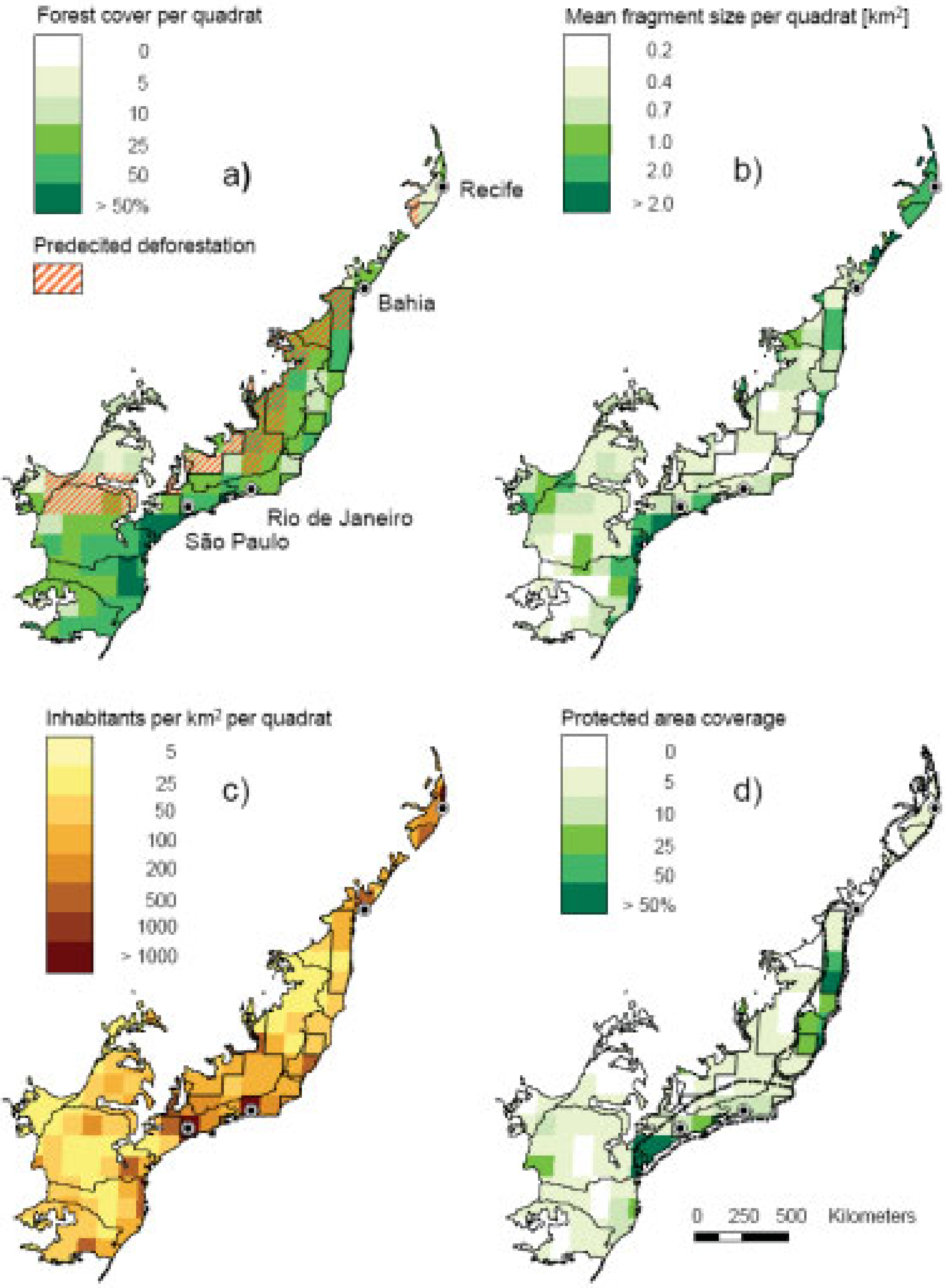

Figura 3 a-d: Threats to species richness and protected areas. Centres of species richness and narrow endemism are combined (solid black lines). a) Extant forest cover (SOS Mata Atlântica and INPE 2008) and deforestation estimates for 2100 (Scholze et al. 2006). b) Mean fragment size (SOS Mata Atlântica and INPE 2008) c) Human population density estimated for 2015 (Ciesin and Ciat 2005). d) Protected areas coverage according to the categories Ia-IV of the World Database on Protected Areas 2007 (WDPA 2008). Black outlines (dashed lines) show biodiversity corridors. Projection: Aitoff, Central Meridian 60° W.

Predicted to undergo deforestation. For most quadrats, a combination of several of these conditions applies (Table 2).

Discussion

Defining the extent of the Mata Atlântica

One challenge when starting this work was determining the extent of the Mata Atlântica to be used. There has been considerable dispute about the original extent of the Mata Atlântica, and two main views exist: the strict classification of the Mata Atlântica comprises only the coastal rainforests within the distance of *c.* 300 km from the coast, whereas the broad classification comprises additional forest formations including forests up to 700 km inward from the coast (Oliveira-Filho and Fontes 2000). In 1992, the '*Mata Atlântica domain'* was introduced by the National Council of the Environment of Brazil (Câmara 2003). Their definition of the Mata Atlântica was comprehensive, considering not only dense coastal rainforests, but also associated ecosystems like restingas and mangroves, and semideciduous and deciduous forests of the hinterlands. Some of the latter lie in mountainous areas surrounded by Cerrado and Caatinga today, but are supposed to have been part of a former connection between the forests of the Mata Atlântica and the Amazon basin (e.g., Câmara 2003, Mori et al. 1981, Prance 1987). In a comprehensive study comparing tree species assemblages at different locations (low/high montane locations in coastal and hinterland forests, and locations in western forests) within the area between Paraná and Bahia, Oliveira-Filho and Fontes (2000) recommended a comprehensive definition of the Mata Atlântica. Their recommendation was based on the findings that the elements of the different locations examined were rather similar, although their respective composition was different. Furthermore, the tree species of semideciduous forests were found to resemble a subset of the more diverse rainforest flora. Likewise, Scarano (2009) recommended a comprehensive definition of the Mata Atlântica, based on the co-occurrence of plant species specialised to the canopy habitat of the rainforests of the Mata Atlântica (e.g. epiphytes) in adjacent non-rainforest areas like restingas.

For our work, we decided to use the outline given by Conservation International (2004; Fig. 1a), which integrates areas of the hinterland of the Mata Atlântica domain. Due to small sizes or scarcity of data, we omitted areas not directly connected to the coastal main body of the Mata Atlântica (the Brejos Nordestinos, the area situated between Cerrado and Caatinga and the central Bahian area surrounded by Caatinga). In comparison to most previous studies on floral

Table 2: Relevant attributes of the 24 quadrats of the two centres of species richness and narrow endemism combined. Quadrats for which biome change to non-forested area is predicted for 2015 are labelled with an '!' behind the current forest cover data.

Longitude, Latitude [°]	Quadrat size [km2]	Species richness & narrow endemic species richness		Forest cover [%], (!)	Fragments contained	Mean fragment size [km^2]	Fragment density [Nr./km^2]	Population density [Inh./km^2]	Protected areas coverage [%]	Location (state, cities, rivers or mountain ranges)
SÃO PAULO-RIO DE JANEIRO-MINAS GERAIS CENTRE (SP-RJ-MG CENTRE)										
-43.5, -18.5	8,337	118	12	30.2 **!**	5,769	0.44	0.7	13	2.8	MG, Serra do Espinhaço
-44.5, -19.5	1,772	104	1	16.4 **!**	778	0.37	0.4	249	0	MG, Serra do Espinhaço
-43.5, -19.5	6,317	138	9	17.8 **!**	3,508	0.32	0.6	261	2.8	MG, Serra do Espinhaço, Belo Horizonte
-43.5, -20.5	11,581	119	6	25.1 **!**	7,578	0.38	0.7	59	0.9	MG, Ouro Preto
-42.5, -20.5	11,581	102	2	14.0 **!**	6,526	0.25	0.6	53	1.1	MG, Serra da Mantiqueira
-44.5, -21.5	11,504	101	2	7.6	6,583	0.13	0.6	27	0	MG, Serra da Mantiqueira
-43.5, -21.5	11,504	119	3	15.4 **!**	13,584	0.13	1.2	87	0.1	MG, Serra da Mantiqueira
-42.5, -21.5	11,504	105	4	11.1	7,405	0.17	0.6	63	0	MG, RJ, Serra da Mantiqueira
-41.5, -21.5	11,344	76	7	8.5	3,950	0.24	0.3	67	2.2	RJ, ES, Serra da Mantiqueira
-47.5, -22.5	4,979	105	0	3.2 **!**	582	0.27	0.1	349	0.3	SP, Campinas
-46.5, -22.5	10,019	111	4	10.3	4,564	0.23	0.5	122	0	SP, MG, Serra da Mantiqueira
-45.5, -22.5	11,423	109	6	19	4,798	0.45	0.4	101	0.8	SP, MG, Serra da Mantiqueira
-44.5, -22.5	11,254	133	3	34.5	11,384	0.34	1	93	9.6	SP, RJ, MG, Serra do Mar, Serra da Mantiqueira
-43.5, -22.5	10,580	229	38	21.1	6,520	0.34	0.6	1039	5.1	RJ, Rio de Janeiro, Serra do Mar
-42.5, -22.5	10,820	136	24	24.2	5,147	0.51	0.5	191	5.9	RJ, Teresópolis, Serra do Mar
-46.5, -23.5	10,912	142	6	33.3	5,313	0.68	0.5	2149	6.7	SP, São Paulo, Serra do Mar
-45.5, -23.5	8,096	102	5	31.5	2,088	1.22	0.3	190	19.8	SP, Serra do Mar

Longitude, Latitude [°]	Quadrat size [km2]	Species richness & narrow endemic species richness		Forest cover [%], (!)	Fragments contained	Mean fragment size [km^2]	Fragment density [Nr./km^2]	Population density [Inh./km^2]	Protected areas coverage [%]	Location (state, cities, rivers or mountain ranges)
BAHIA CENTRE										
-40.5, -13.5	3,101	53	7	28.7 !	706	1.26	0.2	20	0	BA, Jequíe, Rio de Contas
-39.5, -13.5	11,837	67	0	37.5 !	16,012	0.28	1.4	52	0.2	BA, Southwest of Bahia
-39.5, -14.5	11,629	151	2	44.9 !	3,423	1.53	0.3	63	0.8	BA, Ilhéus
-38.5, -14.5	86	38	8	42.9	25	1.48	0.3	19	0	BA, North of Itacaré
-39.5, -15.5	11,897	120	14	39.5	4,450	1.06	0.4	20	41.8	BA, Rio Pardo
-39.5, -16.5	11,021	108	8	25.5	6,190	0.45	0.6	39	59.2	BA, MG, Porto Seguro
ESPÍRITO SANTO										
-40.5, -19.5	11,419	107	11	14.9	6,867	0.25	0.6	43	17.5	ES, Rio Doce, Linhares

distribution patterns, this selection implies a larger investigation area. In difference to previous studies we considered non-woody species in addition to woody species. While woody species are dominant in the database, non-woody species account for 20% of our species.

Problems of identifying large-scale distribution patterns

Studies of plant diversity carried out at local scale often seek to identify as many species as possible in a given area. At the best, the result would be the complete inventory of an area. This is sufficiently difficult for smaller areas, and gets increasingly difficult with increasing size of the area considered. In this study, the aim is not to estimate a complete inventory of species of the Mata Atlântica, but to deduce distribution patterns from the subset of angiosperm species that occur in the Mata Atlântica and for which we have distribution data. From the 20,000 plant species estimated to occur in the Mata Atlântica, our dataset covers only 667 angiosperm species (roughly 3.5%). Thus, the number of species estimated to occur in a quadrat times 100% / 3.5% would correspond to a more realisitic estimation of the species richness. For the quadrat at Rio de Janeiro where most species have been found (229 species), the corresponding projected value of *c.* 6,500 species would be slightly above the estimations of Davis et al. (5,000-6,000 plant species for the mountain ranges of Rio de Janeiro; 1997) and Barthlott et al. (more than 5,000 plant species per 10,000 km^2; 2005).

The basis of our analysis are monographic data, which have been collected by various collectors and over a long time period, but were critically reviewed by the experts of the respective taxon. Accordingly, these data are the most reliable data available with regard to taxonomic accuracy (Hopkins 2007, Morawetz and Raedig 2007, Thomas 1999). However, monographic data are difficult to interpret in broad scale analyses because they are prone to heterogeneous sampling effort. Sampling effort results from the different accessibility of areas for the collectors (spatial sampling effort; e.g. Hopkins 2007, Nelson et al. 1990), from the degree of difficulty which is involved for the collector in finding the respective species and from the collectors' bias toward certain species (taxon-related sampling effort; Morawetz and Raedig 2007). Thus, because trees are rather conspicuous elements of many ecosystems, they are the focus of the major part of plant distribution studies. There is no pattern which would allow to adjust for taxon-related sampling effort. In our study, we aimed to adjust the distribution patterns we found for heterogeneous spatial sampling effort. Therefore, we introduced an extra weighting factor to assign more weight to quadrats that have low species numbers in relation to the best sampled quadrat with the highest species number.

Distribution patterns of angiosperm species in the Mata Atlântica

Our approach to compile the species richness map (Fig. 2b) differs in three aspects from previous approaches: 1) We used a comprehensive outline of the Mata Atlântica, 2) we integrated non-tree species and 3) we used monographic data in combination with the weighted interpolation approach. In contrast to the centres of plant diversity identified by Barthlott et al. (> 5,000 species per 10,000km^2; 2005), areas of highest species richness are not only concentrated on the coastal area between São Paulo and Cabo Frio, but likewise occur in Espírito Santo and Bahia state. A further difference is the extent of the Rio de Janeiro richness centre, which in the present study extends from São Paulo to Rio de Janeiro and northwards into Minas Gerais, henceforth referred to as SP-RJ-MG centre. Although the centres of species richness of both studies are not congruent, the map of Barthlott et al. (2005) reveals an elevated level of species richness (4,000 - 5,000 species per 10,000km^2) for the area north of Rio de Janeiro towards the Serra da Mantiqueira and the Serra do Espinhaço, and further for the area ranging from the centre of Espírito Santo to Bahia. These areas are partly reflected in the species richness centres identified in Fig. 2b, although the quadrats surrounding the quadrat at Linhares show a lower level of species richness. While these quadrats have higher species counts due to the interpolation approach (e.g. the western quadrat gains a plus of 69 species counts to the 11 species of the point-to-grid quadrat), the total numbers of species in all adjoining quadrats are remarkably lower than in the quadrat at Linhares (Fig. 2b) and do not suggest an inclusion either into the SP-RJ-MG centre nor into the Bahia centre of species richness.

Likewise, our centres of narrow endemism (Fig. 2c) differ from centres of endemism identified in previous studies. The two centres suggested by Mori et al. (1981) in an analysis of monographic data of 68 coastal tree species endemic to the Mata Atlântica are partly reflected. The Rio de Janeiro/Itabapoana centre is resembled by the eastern part of the centre stretching from São Paulo to Rio de Janeiro. The Bahia/Rio Doce centre is reflected by the southern part of the Bahia centre and the single quadrat at Linhares (Rico Doce delta, Fig. 2c). Thus, the single quadrat pattern already found in the maps of species richness (Figs. 2a, b) is consistent in the map of narrow endemism. This quadrat contains one of the main remnants of dense and diverse tabuleiro forests contributing to the high species richness and high number of narrow endemic species found (Aguiar et al. 2003). The patterns of endemism found by Prance (1987) and Thomas (1998) are rather similar, and the centres of São Paulo-Rio de Janeiro and Bahia-Espírito Santo roughly correspond to the coastal parts of the centres found in the present study. The main difference lies in the existence of a centre of narrow endemism in the south of the Serra do Espinhaço, distant from the coast (Fig. 2c). This is not surprising, since Mori (1981), Prance (1987) and Thomas (1998) only considered coastal forests in their studies. Furthermore, the Pernambuco-Alagoas centre found in the latter studies is not evident in our dataset. Narrow endemic species are found in this area, like along the entire Mata Atlântica coast, but only with low numbers per quadrat.

Although we considered more species than previous floral analyses based on species ranges, our analysis relies on the same data type and consequently is committed to the same limitations as already acknowledged by Mori et al. (1981), mainly heterogeneous sampling effort. The correction for heterogeneous spatial sampling effort introduced in our method adjusts species ranges of species for which occurrences have been documented. However, this method does not adjust the total number of species for an area. Narrow endemic species will be soonest overlooked because they occur - per definition - only in a confined area. One implication for conservation purposes is that further botanical collections and monographic research are necessary, both in hardly accessible areas as for taxonomically underrepresented taxa (e.g., Hopkins 2007, Morawetz and Raedig 2007, Thomas 1999). Therefore, the inclusion of data on additional narrow endemic species might lead to the identification of further centres of narrow endemism. All the same, our maps point towards areas where further sampling activities should focus to decrease the uncertainty of estimated distribution patterns of narrow endemic species, in particular when viewed against the background of extant forest cover. Areas of special interest can be divided in two groups: One group is located in regions with high forest cover, such as the last large contiguous forest fragments in the south of the Mata Atlântica (Ribeiro et al. 2009) which are not included in the centres of species richness or narrow endemism (Fig. 3a). The second group consists of regions which are not located in the immediate vicinity of research centres (e.g. Rio de Janeiro) but have adjacent quadrats supposed to be similarly rich in narrow endemic species (like the study area of BLUMEN project in Teresópolis).

Outlook for conservation in the Mata Atlântica

At first view, the inclusion of the coastal centres of narrow endemism in the designated biodiversity corridors seems almost complete (Fig. 2d). Although it would be desirable to connect all quadrats harbouring narrow endemic species, which are most threatened by deforestation due to their narrow-ranging distribution areas, at least a substantial part of the quadrats with a high level of narrow endemic species is included into the corridors. However, the forests of the hinterland are not considered by these corridors, in particular the centre of narrow endemic species in Minas Gerais, in the southern part of the Espinhaço Range. The exclusive occurrence of many narrow endemic species as well as the high level of overall species richness suggests an inclusion of this area into conservation concepts. However, the implementation of a connection of the Serra do Espinhaço to the Serra do Mar Corridor poses a serious challenge, because the interjacent Rio Paraíba valley belongs to the most industrialized areas of Brazil (Aguiar et al. 2003). Biome change to nonforested area is predicted for all quadrats north of Rio de Janeiro, and only few forest fragments in this area remain (Fig. 3b), most of which are small, isolated and located on hilltops and other remote areas (Aguiar et al. 2003).

In general, the success of biodiversity corridors in connecting extant forest fragments is highly depending on the quality of the forest remnants. The quality of the remnants depends on fragment size and the degree of fragmentation. The quadrat southwest of Bahia serves as an example for hyper-fragmentation, with more than 16,000 fragments contained within 11,837 km^2 and an associated high fragment density of 1.4 per km^2 (Table 2). Further examples of hyper-fragmentation in the SP-RJ-MG centre are the two quadrats adjoining Rio de Janeiro to the north and west with small fragment sizes (mean size < 0.13; Table 2). Whereas the quadrat northwest of Rio de Janeiro shows a medium fragmentation (0.6 per km^2), the northern quadrat is severely fragmented (1.2 per km^2). In such hyper-fragmented areas, which contain high proportions of small and degraded fragments, edge effects increase in such that the functional diversity traits of tree species assemblages become eroded (Lopes et al. 2009, Santos et al. 2008). For their study area in northeastern Brazil, Santos et al. (2008) and Lopes et al. (2009) found that reproductive traits of tree assemblages in forest edges and small fragments were similar to those of early second-growth forest stands and questioned the effectiveness of conservation services provided by such edge-affected habitats.

For the Plateau of Ibiúna in the Serra do Mar region in São Paulo state, Metzger et al. (2009) found that due to the time-lag in biological responses of species, extinction will affect species assemblages in secondary forests in such a way that only generalist and edge-related species will persist in the long run, at the cost of strictly-forest species. The trend of conversion of tropical forests into secondary forests has already been described as a global phenomenon (Wright and Muller-Landau 2005), and is aggravated by a low average age of secondary forests, which has been determined as less as five years for the Amazonian rainforest (Metzger 2009, Neeff et al. 2006).

The probably largest part of the forest remnants of the Mata Atlântica is composed by secondary forests in various stages of regeneration (Câmara 2003). Basically, young secondary forest has a great potential for conservation. But two contrasting development directions are possible: towards a degraded forest with depauperated species assemblages, or towards a mature forest with a high level of species richness. The path of development is dependent on the quality of the forest fragments such as size and isolation as well as on the quality of the surrounding matrix area, which in turn depends on the land use applied (Laurance et al. 1997). For the Macacu River watershed in Rio de Janeiro state, impacts of land use in matrix area (economic activity and property ownership) have been compared to the influence of forest fragment size and isolation on the diversity of small mammals (Vieira et al. 2009). Species richness was lowest in fragments surrounded by matrix area used for agriculture, but fragment size and isolation turned out as most important variables to explain variation in species richness. Fine nuances of species composition could be attributed to property ownership, and fine nuances of species richness were associated with isolation and economic activity. In consequence, for a development from young secondary forest toward mature and species-rich forest, important prerequisites are a sufficient size of fragments and a low degree of isolation of these fragments. For many areas of the highly dynamic forest remnants of the Mata Atlântica, quite the reverse is true (Fig. 3b).

In recent times, land use dynamics in the Mata Atlântica have become increasingly dependent on the world market. Traditional forms of land use like the *cabruca* (cacao cultivation) in southern Bahia were a more sustainable form of land use (Nehren 2009), since the cultivation of cacao required the plantation of shadow trees (Aguiar et al. 2003). These native trees increased the biodiversity in and improved the connectivity of the cultivated area. With falling prices on the world market, large parts of these areas were transformed first into pastures for cattle ranching, together with an expansion of these pastures into more remote areas. After further changes on the world market, these pastures have been converted for the cultivation of biofuel crops (Aguiar et al. 2003, Laurance 2009). The resulting matrix areas are less suitable for the connection of forest fragments.

Along with other land use changes, increasing human settlement areas are a major cause for the isolation and degradation of forest fragments. Not only the high population densities found in the coastal area of the Mata Atlântica (Fig. 3c) threaten remaining forest fragments but also the lower human population densities of the hinterland. According to Wright and Muller-Landau (2005), rural settlements have been found to have great impact on extant tropical forests and we expect that this applies to the Mata Atlântica as well.

On the whole, establishing the connectivity among the last forest fragments within the designated biodiversity may be complicated, even for the centres of diversity identified in this work. Overall forest cover for the SP-RJ-MG centre is at a medium level, at the average 19.3% per quadrat. For the Bahia centre, average forest cover is higher (36.5% per quadrat). Although most of the quadrats inside the corridors are predicted to escape deforestation (Fig. 3a), threat to these fragments is deducible by the small size of forest fragments and their elevated density. In the SP-RJ-MG centre, fragments are small and often associated with high fragment density. Fragments are larger in the Bahia centre, but exhibit a slightly higher fragment density. Although a high fragment density could mean a lower isolation of fragments, and therefore an enhanced connectivity between fragments, biodiversity of the corridors will benefit less if the fragments are small and edge-affected (Lopes et al. 2009). However, small forest fragments have been proven to be important for conservation, e.g. they can harbour narrow endemic species, act as stepping stones, provide genetic exchange for declining populations in nearby fragments, and they conserve local populations of trees and propagules, which are indispensable for reforestation efforts (Laurance et al. 1997).

With regard to the biodiversity corridors, it will be difficult to improve the connectivity in particular between small forest fragments surrounded by an intensively used matrix area. The improvement of the connectivity between forest fragments necessitates a change of land use in such matrix areas toward more sustainable land use systems (Torrico et al. 2009). Further, it is essential to protect ecologically important small forest fragments. The protected areas are the core units of the corridors, and a high coverage of protected areas within the corridors contributes to an easier connection of forest fragments. However, in particular the marginal areas of the corridors exhibit rather low protected area coverage, as well as the entire Corridor Nordeste (Fig. 3d). Between Rio de Janeiro and Belo Horizonte, protected area coverage is less than 5%, and the Rio Paraíba Valley is entirely devoid of protected areas. A high protection status as in the quadrats at Porto Seguro (more than 50%), at Rio Pardo (Bahia), west of São Paulo and at Linhares represents a better basis for the connection of fragments. However, the quality of protected areas also differs, and protected areas do not necessarily consist of pristine forests, but often include secondary forest areas. Furthermore, due to the lack of financial support, protection of protected areas often is insufficient (see chapter 5). Nevertheless, the protected areas present the best opportunity to secure large core tracts of mature forest which are vital for conservation of biodiversity in the Mata Atlântica (Lopes et al. 2009, Metzger et al. 2009, Ribeiro et al. 2009), and essential for the successful implementation of the concept of biodiversity corridors.

Ribeiro et al. (2009) identified the elongated fragment extending from the south of São Paulo state along the coastal mountain ranges to the south of Rio de Janeiro state as the largest forest fragment of the Mata Atlântica (11.095 km^2), roughly corresponding to the area of one 1°quadrat. Such fragments need to be protected, and serve as valuable backbones for the biodiversity corridors. Furthermore, Ribeiro et al. (2009) showed that most of the remaining forest fragments of the Mata Atlântica are located farther than 25 km away from natural reserves, with the exception of the Serra do Mar region, where the remaining forest is less than 10 km away from natural reserves. These distances illustrate the difficulties when putting biodiversity corridors in practice. For a successful implementation of biodiversity corridors in the Mata Atlântica, we suggest that first the corridors should be enlarged to comprise not only the coastal, but the hinterland areas as well. Likewise, the network of protected areas as the core units of the biodiversity corridors has to be enlarged. Here, conservation has to focus on old forest tracts. The conservation of smaller and younger forest fragments is also important, under the premise that connectivity between these fragments is enhanced to lessen edge effects and to improve overall connectivity in the biodiversity corridors. For the identification of areas suitable to act as core units of biodiversity corridors, and for the identification of suitable matrix areas, more research at local scale is needed, which has to combine detailed taxonomic investigation with landscape analysis.

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CHAPTER 13

ON THE INFLUENCE OF CLIMATE SEASONALITY ON LEAF AREA INDEX AND CANOPY OPENNESS OF A FRAGMENTED TROPICAL MONTANE FOREST IN RIO DE JANEIRO, BRAZIL

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Abstract: We examined the influence of the seasonal climate on LAI and Canopy Openness in a mature forest stand and in a forest remnant of the Brazilian Atlantic Forest in Rio de Janeiro. We recognised a significant variability of LAI / Canopy Openness between the central parts and the border region of the forest fragment. There was no comparable variability in the mature forest. In the forest fragment we recorded a highly significant increase of LAI with a mean of 0.45 which is about 12% at the end of the wet season. The higher influence of seasonality on LAI/Canopy Openness resulting in perspicuously higher within-canopy dynamics in the forest remnant have been put down to a structural response to temperature and absolute humidity, due to the low species diversity and a higher abundance of deciduous tree species. The high species richness in the mature forest site with a lower abundance of deciduous pioneer species may prevent such impact on the canopy structure and its spatiotemporal dynamics. We observed an obvious “edge

effect" according to the structural changes by the seasonality in Canopy Openness: decreasing difference of Canopy Openness with increasing distance from the edge. A possible reason could be the distribution of deciduous tree species in the fragment with concentration on the forest edge. There was no such effect in LAI, which demonstrates that there is no conclusive dependency between LAI and Canopy Openness.

Introduction

Structural attributes of forest stands such as DBH distribution, Canopy Openness and Leaf Area Index provide basic information on forest development, succession stage and disturbance regimes. The assessment of forest structure is an essential tool traditionally used for forest management to evaluate the productivity of a stand (Moser et al. 2007, Bolstad et al. 2001). For ecologists they are an essential source for habitat characterization. Leaf-Area-Index (LAI) is the total one-sided area of leaf tissue per ground unit. It is a key parameter in ecophysiology and in contiguity with the Canopy Openness an important value for the description of the canopy structure and temporal and spatial heterogeneity in forest stands (Williams et al. 2003, Luo et al. 2002, Bolstad et al. 2001, Frazer et al. 2000, Trichon et al. 1998). These two parameters are suitable tools and often used for indirect measurements of relevant abiotic factors such as light availability and radiation which are essential to understand the forest structure and regeneration (Jin & Zhang 2002, Cournac et al. 2002, Engelbrecht & Herz 2001, Gelhausen et al. 2000, Kabakoff & Chazdon 1996). LAI and Canopy Openness can easily be provided by the analysis of hemispherical photographs, which is a widely used method for indirectly assessing canopy characteristics (Jonckheere et al. 2004, Fassnacht et al. 1994, Chen et al.1991, Chason et al. 1991).

We addressed the following questions: i) how can structural differences between forest sites be quantified using LAI / Canopy Openness? ii) how do these parameters change in response to climate seasonality? iii) are fine scale differences in forest structure detectable by LAI / Canopy Openness?

Material and Methods

Study site

We selected two sample sites in the Brazilian Atlantic Forest in the State of Rio de Janeiro, municipality of Teresópolis. One 1ha plot was located at 1200 m asl. in an 11.000ha forest reserve ("Parque Nacional Serra dos Òrgãos"; 22°25'-22°32'S, 42°59'-43°07'W) with montane coastal rain forest. This area is already 65 years under protection (Fig.1a). Another 1 ha plot was selected in a 63ha forest fragment. This forest fragment is in about 25km air-line distance northeast to the National Park, surrounded by small agricultural patches and at 900m asl (Fig.1b). The forest of the fragment can be classified as secondary, dominated by semideciduous tree species such as Piptadenia gonoacantha (Fabaceae-Mim). The general climatic conditions of the area are tropical humid with a pronounced wet season. Long-term annual rainfall is 2821mm in combination with high relative moisture and a mean annual temperature of 17.8°C (Guimãres & Arlé 1984, Rizzini 1954).

Climate logging

To provide basic forest climate data (temperature and relative/absolute humidity) we mounted several Onset-Hobo data-loggers (temp/rH) in the forest stands. One logger was installed inside the plot of the national park and three loggers were used along a spatial gradient from the edge to the forest interior.

Hemispherical Photography

As hemispherical photographs offer a very good and comparably cheap tool to replace instruments like LAI 2000 (Leblanc et al. 2002) and allow digital storage for future analyses of data when improved models become available (Beaudet & Messier 2002) we used it in a grid-based approach. In both study sites we established 10x10m subplots with a total of 80 photo-points where two series of hemispherical photographs were taken. We used a NIKON Coolpix 4500 digital camera with a NIKON FC-E8 fisheye-lens, mounted on a levelled tripod 1.30m above the ground. Pictures were only taken under overcast conditions to avoid overexposed regions around the sun and to reduce reflections on leaves that could be construed as canopy openings. To capture the effects of climate seasonality on the variability of leaf- and tree crown development we took each photo series at the end of a season, respectively. The first series was taken at the end of the dry season in November 2004 and another one at the end of the wet season in June 2005.

Analysis

The program WinSCANOPY 2005a,b by Regent Instruments Inc. was used to analyze the hemispherical photographs and to derive data about Canopy Openness and LAI, whereby the Licor "LAI 2000 generalized method" was selected for the LAI calculations. To create the interpolated contour maps the data were processed with SURFER 8.0 (Golden Software, CO, USA). Spatiotemporal changes in LAI were calculated and displayed by subtracting values of the dry season map from those of the wet season map. All significances are based on Mann-Whitney-Rank-Sum-Test.

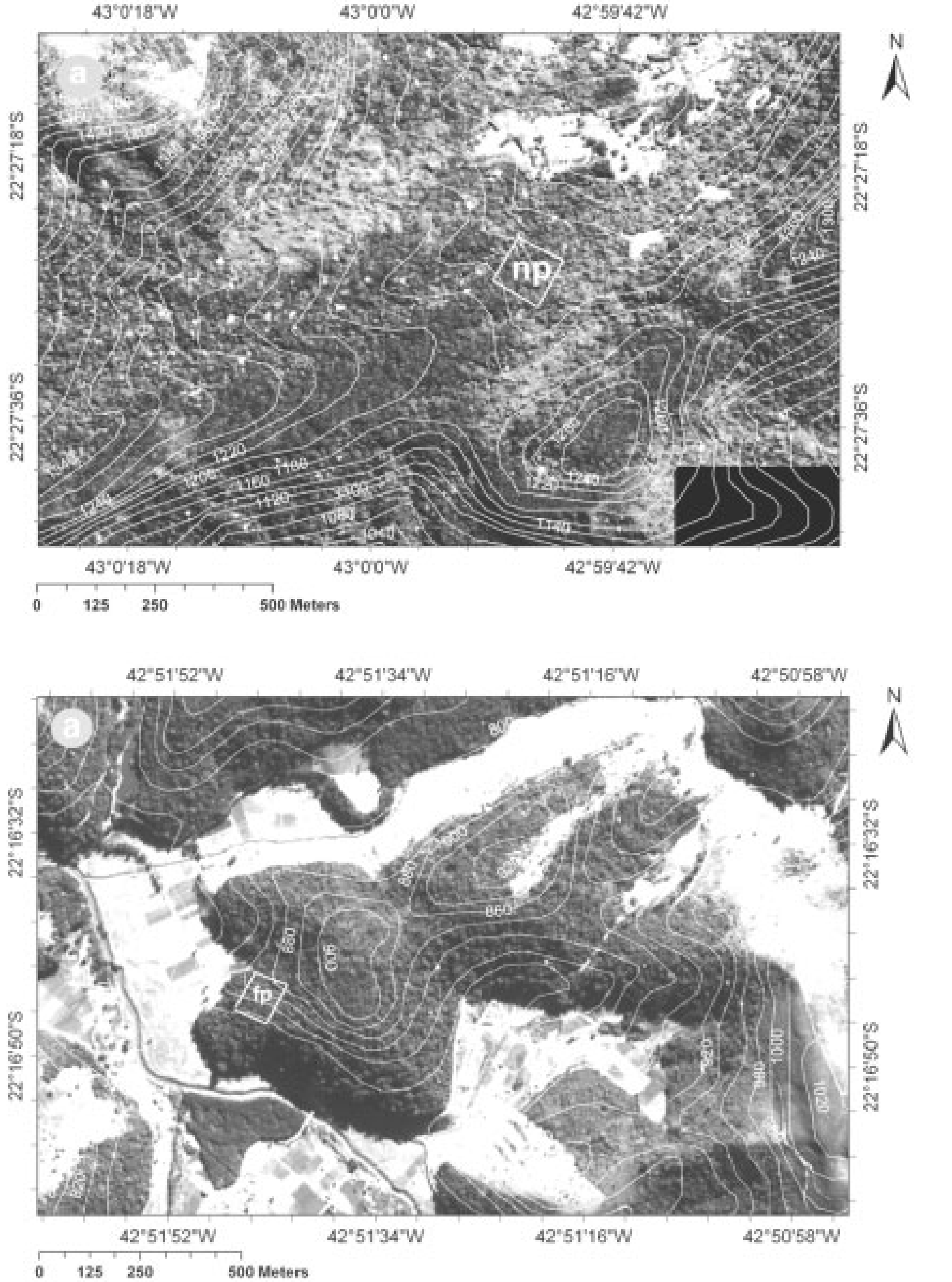

Figure 1: Location of the study sites in the National Park (a) and in the “sorvete” forest fragment (b). IKONOS image.

Results

Seasonal variation in LAI and Canopy Openness

We found a significant difference ($p<0.001$; $n=80$) in Canopy Openness values measured in the mature forest and in the forest fragment at the end of the dry season (November 2004). At the same time, differences of LAI values were not significant. At the end of the wet season (June 2005) there were no significant differences between the two study sites with regard to LAI and Canopy Openness.

On the other hand, we recognised a significant variability of LAI and Canopy Openness in the forest fragment plot between the dry and the wet season. There was no comparable variability in the national park plot. In both research areas, we could record an increase of LAI after the end of the wet season, which was significant in the forest fragment (Tab. 1). The area with a LAI increase >1 was almost twice as high in the fragmented area (576m², 7.2%) than in the national park (296m², 3.7%), see Fig.2.

Although there was no such seasonal change in mean LAI in the national park, the local maximum changes at the individual points of measure were higher (increase up to 2.07 and decrease down to -0.83) in comparison to the fragmented area (increase up to 1.65 and decrease down to 0.6), see Fig.2. The results of local seasonal changes in Canopy Openness in the two different sites show an almost inverted situation. The greater variability has been observed in the forest fragment (increase up to 2% and decrease down to -7.93%) in comparison to the national park (increase up to 2% and decrease down to -2.09%).

Table 1: Seasonal changes in mean Canopy Openness and mean LAI within the study plots (each plot with n=80).

	Parameter	**End of dry season (Nov 04)**	**End of wet season (Jun 05)**	**Significance (p)**
Forest fragment plot	CO (%)	7.92 (± 2.77)	7.18 (± 2.00)	0.024 *
	LAI	3.43 (± 0.74)	3.88 (± 0.83)	<0.001 ***
PARNASO plot	CO (%)	6.67 (± 0.93)	6.75 (± 0.70)	0.38 (ns)
	LAI	3.53 (± 0.52)	3.77 (± 0.68)	0.05 (ns)
Parameter difference between sites	CO(%)	1.25 *	0.43 *	
	LAI	0.1 (ns)	0.11 (ns)	

Seasonal changes in forest edge structure

We observed an obvious “edge effect” in the forest fragment according to the structural changes by the seasonality in Canopy Openness: decreasing difference of Canopy Openness with increasing distance from the edge. There was no such effect in LAI, which demonstrates that there is no conclusive dependency between LAI and Canopy Openness.

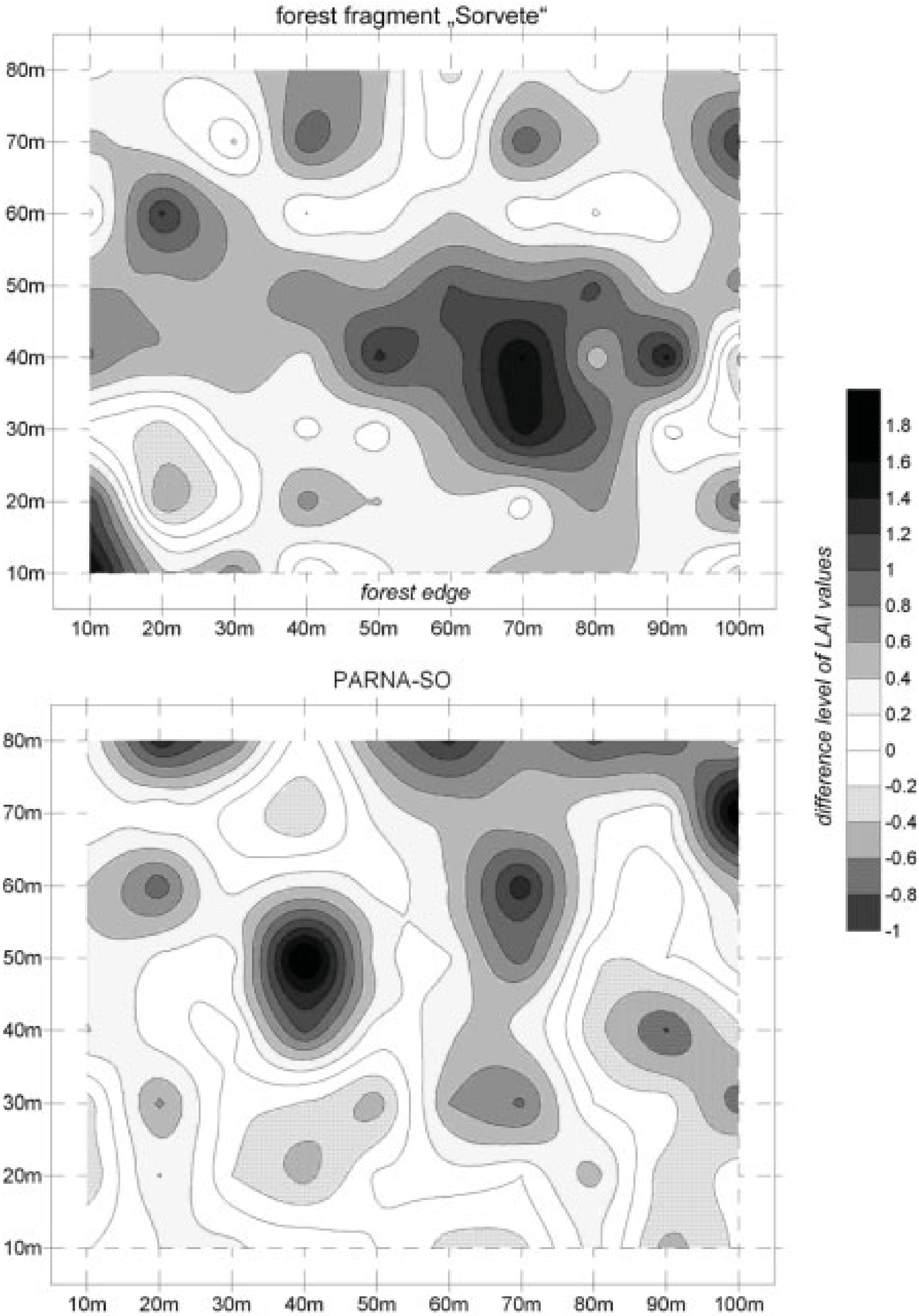

Figure 2: Contour map of the seasonal LAI differences within the study sites.

The mean temperature within the whole forest fragment for the time period from September 2004 to September 2005 was 17.9 (±3.85)°C, the mean relative humidity for the same time period was 92.6 (±10.6)%. Climate measurements at different locations within forest fragment are demonstrating a distinct difference in microclimate between the forest edge and the forest stand during the wet season. The mean daily temperature and mean daily relative humidity were significantly higher at the edge than in the forest stand (Fig. 3). However, within the dry season, only the temperature showed a weakly significant difference (0.4K) between the edge and the forest interior.

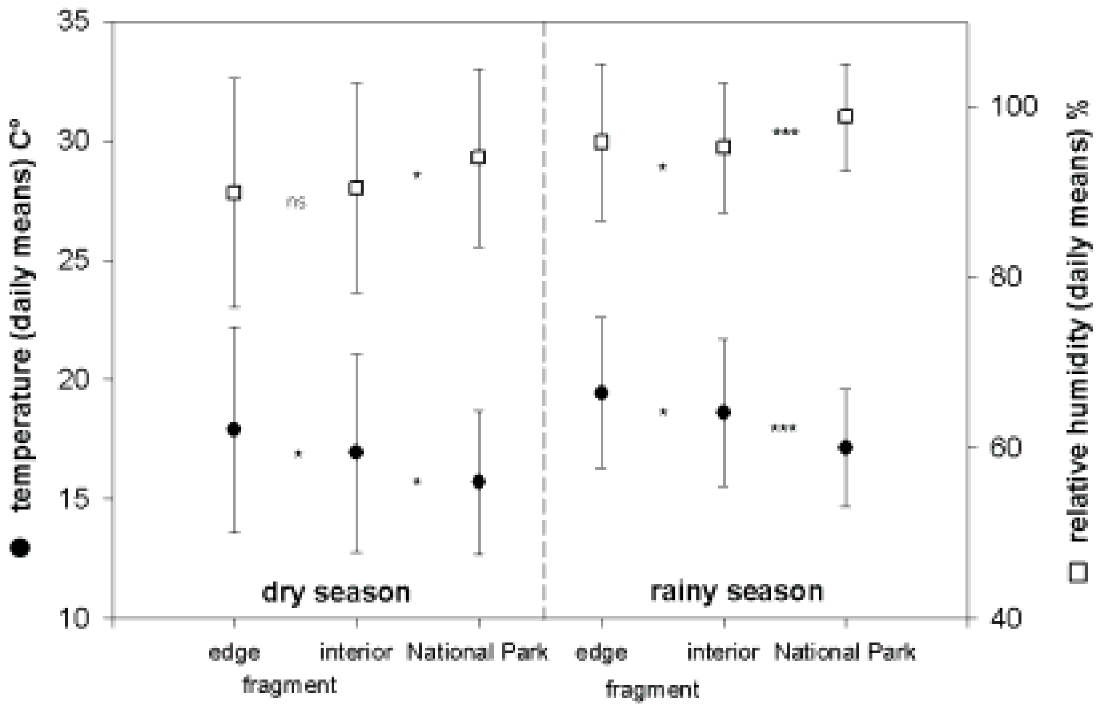

Figure 3: Mean values and standard deviation of temperature (black dots) and relative humidity (outline boxes) in the study areas. The values are based on measures realized between September 2004 and September 2005. Significances given are related to the adjacent data, respectively. There are no edge data from the PARNA-SO plot.

Discussion

Only in the forest fragment, we could observe a significant variation of the LAI values between the climate seasons. Within this forest, an increase of LAI values up to 12% has been recorded at the end of the wet season. In the national park plots, a mean LAI of 3.65 has been recorded in the course of one year, which is a relatively low value compared to other mountain rain forests of South America (Scurlock et al. 2001). We recorded as well a certain seasonal variability in the LAI values, but it was too small to be significant. These findings are comparable to the results of Wirth et al. (2001). For a forest are in Panama, the authors report mean LAI values for bigger areas tending to show small absolute variation. However, on a small scale LAI-variation frequently is much higher. In our study, the local maximum changes of LAI at the individual points of measure in the National park plot were as well higher than those recorded in the forest fragment plot. A high heterogeneity of LAI values at a small and local scale has also been described especially for tropical forests with low climate seasonality as, for example, in tropical Asia (Trichon et al 1998). Thus, for the evaluation of structural variation in forest canopies local small-scale LAI changes are more adequate to describe functional changes in canopy structure.

One of the main reasons for the observed LAI differences in the forest fragment could be the occurrence of certain deciduous tree species like Piptadenia gonoacantha (Fabaceae – Mim.) and their response to climate seasonality. The predominance of this tree species (called 'caiman tree') in initial stages of succession can be explained by its requirements for regeneration. The seedlings of this species can only survive under sunny conditions. In contradiction to species that are more characteristic for late succession stages, the seedlings of Piptadenia gonoacantha are not tolerant to shade (Pereira De Souza & Válio 2001). Being a deciduous tree species, the caiman tree abates the local LAI, increases the Canopy Openness of a forest and favours the growth of the proper seedlings.

As reported by Wasseige et. al. (2003) for an African tropical forest, a seasonal reduction of LAI of 0.34 has been found to be in harmony with the dry season. In this study, the minimum values of LAI (5.13) have been registered some weeks after the end of the driest period of the year. Nevertheless, foliage regeneration in tropical forests that are mixed with semi-deciduous or deciduous tree species is a complex and poorly described process (Barone 1998, Aide 1993, Leigh & Windsor 1982) and linking all local changes in LAI to distinct phonological events remains difficult.

The smaller difference in seasonal LAI change in the national park is probably resulting from the diverse and abundant occurrence of evergreen canopy trees (Wesenberg & Seele 2009, Rizzini 1954) that renew foliage at irregular and unpredictable intervals as described by Croat (1978). Even though there were no statistically significant differences in LAI related to climate seasonality, a comparably high LAI heterogeneity at a small local scale was observed, similar to the results of Trichon (1998).

Known as a good indicator of basic geometry of the canopy and the potential penetration of solar radiation, Canopy Openness is closely related to the microclimatic conditions of a forest stand (Walter & Torquebiau 1997, Whitmore et. al. 1993). In comparison to the forest fragment, the impact of the climate seasons on the spatiotemporal dynamics of the forest structure (e.g. Canopy Openness) of the national park site is much lower. This is possibly due to the tree species richness in the more mature forest of the national park and a lower abundance of semi-deciduous species. Thus, a complex canopy structure and species composition buffers the impact of climate seasonality on structural changes of the forest canopy and causes a more homogeneous microclimate within the forest stand throughout the year. A more or less complex and continuously closed forest canopy allows the regeneration of tree species which are typical for late succession stages and mature forests, because their seedlings are, in contrast to those of the pioneer species, shade tolerant (Pereira De Souza & Válio 2003).

Secondary gap phases, defined as recent disturbances without vegetation re-growth, usually show high Canopy Openness values greater than 7%, whereas mature forest comes with much lower values, even if small natural gaps are included (Trichon et. al. 1998). But within a dense understorey having large tree branches near the camera or a high density of lianas (conditions found in the investigated forest fragment), photographical measurements can lead to high LAI (resp.: PAI – plant area index) values in combination with low Canopy Openness. However, this parameter combination is rather typical for mature forests. In cases like this, the upper canopy layer has a much lower effect on the LAI measurements based on hemispherical photography (Trichon et. al. 1998). Phases of succession showing such structural features are difficult to analyze with the methods we used, because there is no conclusive dependency of low Canopy Openness values on high LAI values in this case (Frazer et al. 2000, Kabakoff & Chazdon 1996).

Even though we recorded an obvious edge effect in the forest fragment according to the seasonality in Canopy Openness (decreasing seasonal difference of canopy-openness with increasing distance from the edge), there was no comparable trend in the LAI values. This points out the complex and non-linear relationship between LAI and Canopy Openness (Anderson 1981), because factors like the spatial distribution and the size fractions of canopy gaps are finally influencing the LAI calculations based on hemispherical photography (Chen et al. 1991, Weiss et al. 2004). In general, canopy openness is a more sensitive parameter expressing the spatial heterogeneity of a forests structure. It is closely related to the spatial distribution of solar radiation and small-scale disturbances and therefore a very useful parameter for studies on forest regeneration (Trichon 1998).

The results of our study and the future studies, which are planned to be carried out in the lower regions of the Mata Atlântica of Rio de Janeiro, will help to understand the impact of the forest structure on the seasonal dynamics and the regeneration of forest communities. Especially the consideration of the heterogeneity of the canopy structure caused by climate seasonality will improve studies on forest fragment edges and forest fragmentation. To facilitate more detailed information on the importance of Canopy Openness and LAI as indirectly used parameters in rapid assessments of forest structure in the Mata Atlântica it is essential to carry out similar studies on a larger spatial and temporal scale (Asner et al. 2003). Furthermore, the inclusion of phytosociological and phenological studies within a joint and long term research area is indispensable to obtain more significant and holistic results.

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Chapter 14

FLORISTIC-STRUCTURAL COMPOSITION AND DIVERSITY OF TREE AND WOODY UNDERSTOREY VEGETATION IN THE MONTANE ATLANTIC FOREST OF THE SERRA DOS ÓRGÃOS NATIONAL PARK, TERESÓPOLIS, RJ, BRAZIL.

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Abstract: In this study we analyzed the floristic-structural composition and diversity of the tree and the woody understorey vegetation in the Montane Forest in the eastern part of the Serra dos Órgãos National Park, Teresópolis, federal state Rio de Janeiro, Brazil. Within 17 study sites we inventoried a total of 1,602 trees (DBH $\geq$ 5 cm, sampled in 400 m² plots) and 2,132 woody understorey plants (DBH < 5 cm, growth height $\geq$ 1 m, sampled in 100 m² plots) belonging to 190 and 187 species respectively. Nearly the half of all species registered (121 out of 256) were found in both studied vegetation components. The ecological most important family are the Myrtaceae, which excel by their extraordinary high diversity (60 species). Furthermore Arecaceae, Lauraceae, Rubiaceae, Nyctaginaceae, Melastomataceae and Fabaceae are among the ten most important families in both

investigated vegetation strata. The most important species in both components of the surveyed vegetation is *Euterpe edulis*. Beside this arborescent palm, tree strata and understorey vegetation shares further 4 species (*Guapira opposita*, *Psychotria suterella*, *Sorocea bonplandii*, *Ocotea disp*ersa) among the respective 10 most important. Three of the ecological most important species of the woody understorey (*Psychotria pubigera*, *Geonoma schottiana*, *G. wittigiana*) were found exclusively in this vegetation layer. Diversity is comparable high in both investigated vegetation components, but, as well as the structural parameters (individual density, basal area), within the study area it varies more in the understorey than in the tree vegetation.

Introduction

The Brazilian Atlantic Forest, or Mata Atlântica, is a unique series of South American rainforest ecosystems and one of the worlds most outstanding and most threatened ecosystems (Myers 1990, Myers et al. 2000, Mittermeier et al. 2004, 2005). It is considered one of the world's biodiversity hotspots since Myers (1990) selected for the first time 18 priority regions for the conservation of vascular plants. The ecosystem presents not only a very diverse flora, but also an elevated number of endemic plants. More than 8.000 of an estimated 20.000 species of plants (40 %) are thought to be endemic (Brooks et al. 2002, Fonseca et al. 2004, Mittermeier et al. 2004, 2005). Especially the tree species show an exceptionally high degree of endemism. The estimates for this ecological group vary from 53 % (Mori et al. 1981) to about 70 % (Gentry 1992).

The insufficient knowledge about ecosystems, their species and dynamics is widely accepted to be an important obstacle for effective conservation efforts. In this context it must to be emphasised that the floristic-structural composition of Neotropical montane rain forests in general is relatively poor known (Bussmann 2001, Madsen & Øllgaard 1994). This is true also in the case of the Mata Atlântica, although the first phytosociological studies in Brazil (Davis 1945, Velloso 1945) were realized in this ecosystem (Guedes-Bruni et al. 1997, 2009). Concerning the vegetation formations of the Serra dos Órgãos National Park only few studies have been published as well. Rizzini (1954) provides a general description of these vegetation formations and an extended species list. More recently Silva Matos et al.

(2007) published some general results regarding the floristic composition of the tree flora in a 1 ha plot established in the Ombrophilous Dense Montane Forest. The later study was carried out in same part of the National Park as our investigation.

By contrast to Silva Matos et al. (2007) our study was realized in several smaller study sites more widely scattered within the Montane Forest of the area, and includes the woody understorey vegetation in the study approach. The understorey vegetation is an important component of the plant communities which provide a considerable part of the species and functions of the ecosystem (e.g. Croat 1978, Dodson & Gentry 1987, Duque et al. 2002, Fleming 1985, Gentry & Dodson 1987, Gentry & Emmons 1987, Snow 1965, Stiles 1981). As the next generation of the species belonging to upper vegetation strata are forming part of the understorey as well, this vegetation component in fact contains also the information about future developmental tendencies of the whole plant community. In spite of its importance, understorey vegetation is often ignored and the knowledge about the floristic-structural diversity of this vegetation stratum in tropical montane forests is especially scarce (Bussmann 2001, Cavelier 1996).

Methodology

The investigation was carried out in the eastern part of the Serra dos Órgãos National Park (headquarter Teresópolis). The whole study area was localized between 22°27’50’’- 22°26’53’’ S and 43°00’48’’- 42°59’17’’ W, and covered an area of approximately 500 ha and an altitudinal gradient of about 500 m (1.100 m - 1.600 m a.s.l.). The largest part of the study area is covered by Ombrophilous Dense Montane Forest (port.: Floresta Ombrófila Densa Montana, Velloso et al. 1991), whilst the highest parts are characterized as Ombrophilous Dense High-Montane Forest (port.: Floresta Ombrófila Densa Alta-Montana). For general information about geology, soils, climate and vegetation of the study area see for example Cronemberger & Viveiros de Castro (2007), Rizzini (1954, 1997), Seele (2005).

Within the study area a total of 21 sample sites (20 m x 20 m each) were established following a random stratified sampling design (stratified regarding altitude). But in order to limit the results presented in this paper to well defined general vegetation formations we excluded four study sites from the analyses. These are two sites localized in the high-montane forest and further two localized in a transition zone between montane and high-montane forest. The so called transition zone, although to be physiognomically somewhat similar to the montane forest, is floristically much stronger related to high-montane forest (Engelmann 2005, Engelmann & Wesenberg 2009, Engelmann et al. 2006, Seele 2005, Seele et al. 2006, Wesenberg unpublished data). Hence, in the analyses of the present publication were included 17 study sites, situated between approximately 1,100 m and 1,500 m a.s.l.

Within the whole area of each study site (400 m²) we sampled all free standing woody spermatophytes with a diameter at breast high (DBH) ≥ 5 cm. Hence, this part of the inventory includes trees and treelets, arborescent palms, free standing stranglers and shrubs, if the basal area of all trunks of a plant summed up at least 3,93 cm² (basal area corresponding to DBH = 5 cm). All free standing woody spermatophytes (young trees, treelets, shrubs, palms) with a DBH < 5 cm and a growth height (h) ≥ 1 m were sampled only in a 10 m x 10 m subplot established in the centre of each study site. The arborescent ferns weren't included in the sample because the pteridophytes were studied separately (Engelmann 2005, Engelmann et al. 2006, 2007, Engelmann & Wesenberg 2009). In order to distinguish the two studied vegetation components, in the following we will use the terms "understorey" for the totality of the plants with DBH < 5 cm, and "tree flora/vegetation" respectively "tree strata/layers" for the totality of plants with DBH ≥ 5 cm. In this context we would like to emphasize that the applied differentiation is individual based but not species based. Hence, the "tree strata" includes also individuals from species with low growth heights, which could be considered rather as understorey elements if a species based definition would be applied. In the same way the "understorey" comprises also young individuals from species of upper vegetation strata.

All inventoried individuals were tagged, measured (height, DBH respectively basal diameter of understorey plants with trunk heights < 1.3 m) and identified or collected and herborized. The collected plants were subsequently identified as far as possible using taxonomic literature, consulting specialists and by comparisons with specimens of the herbarium of the Botanical Garden Rio de Janeiro. The families were classified according to APG II (Stevens 2001 onwards). Voucher specimens were deposited in the herbaria of the Botanical Garden Rio de Janeiro (RB), of the Serra dos Órgãos National Park and of the University of Leipzig (LZ).

In order to analyze the floristic-structural composition of the sampled vegetation we calculated the Family Importance Value (FIV, Mori et al. 1983) of each family and the Importance Value Index (IVI, Curtis & McIntosh 1951) of all species. To describe the diversity we calculated Shannon Index (H'), Shannon Evenness (J') and the species richness estimators Chao2, Jackknife 1 and 2. All diversity statistics were performed using the software package BioDiversity Professional Beta version 2 (NHM & SAMS 1997) and follow definitions provided in Magurran (2004). The relation between species richness and sampling effort were analyzed with sample based and individual based rarefaction using EcoSim version 7.72 (Gotelli & Entsminger 2009).

Results and discussion

Within the 17 study sites established in the Ombrophilous Dense Montane Forest we inventoried 1,602 free standing woody plants with DBH ≥ 5 cm and 2.132 free standing woody understorey plants (DBH < 5 cm, h ≥ 1 m) (table 1). The total of 3.734 individuals belongs to 256 species from at least 49 families. A list of the inventoried species is provided in Appendix 2: Table 1. Ten of the collected species couldn't be identified not even to family level, but only 12 individuals, three trees and nine understorey plants, belong to these species. The flora of the tree strata (all individuals with DBH ≥ 5 cm) comprises 190 species from at least 48 families (3 species unidentified) (table 2). In the woody understorey vegetation we found 187 species belonging to at least 39 families (8 species unidentified).

Nearly the half of the total species set (47.3 %, 121 species) were inventoried in the tree layers as well as in the understorey. Among the 69 species (26.6 %) found only in the tree strata (DBH ≥ 5 cm) the great majority showed little abundance and might be found in the understorey as well if sampling effort will be enhanced. About a quarter of the species (25.8 %, 66 species) was inventoried only in the understorey. Even if some of these species, like *Cinnamomum riedelianum* (Lauraceae) or *Chrysophyllum viride* (Sapotaceae), may become tree layer elements, the greater part of these taxa are surely true understorey plants. Some examples of such understorey elements, which hardly reach higher vegetation strata, are *Psychotria pubigera*, *P. leiocarpa*, *P. appendiculata*, *P. nuda*, *Rudgea francavillana*, *Stylogyne pauciflora, Cybianthus glaber, Justicia polita, Piper* *translucens, Geonoma wittigiana and G. schottiana.* The two other sampled species of *Geonoma* (*G. pohliana, G. spec.*), as well as *Piper richardiifolium* and *P. lhotzkyanum* can also be considered as understorey plants, instead we found one individual of each species with DBH ≥ 5 cm. As stated out by Guedes-Bruni et al. (1997) the sampling of woody plants with DBH ≥ 5 cm leads easily to the inclusion of understorey elements into the species inventory.

According to other studies in the Neotropics the understorey may contribute with 20 % to more than 50 % to the local vascular plant diversity (Duque et al. 2002, Gentry & Dodson 1987, Gentry & Emmons 1987). Therefore our result emphasise the importance of the understorey vegetation for the local biodiversity in the study area. Furthermore, the inclusion of understorey vegetation in comparative analyses of species communities may enhance the exactness of their outputs (Wesenberg & Seele unpublished data).

In table 1 some observed, calculated and estimated structural parameters are resumed. For the tree vegetation (DBH ≥ 5 cm) the estimated average individual density per hectare matches very well with the results obtained by Guedes-Bruni et al. (1997) for a well preserved forest in the Serra de Macaé de Cima.

*Table 1: Number of individuals inventoried in the 17 study sites, corresponding total basal area and derived area related average values of these structural parameters. The variability of the parameters within the whole sample is expressed by means of standard deviation (SD). (*Average values per study site refers to an area of 400 m² in case of tree vegetation (DBH ≥ 5 cm) respectively 100 m² for the understorey vegetation (DBH < 5 cm, h ≥ 1 m) Hence, observed total values refer to an area of 0,68 ha for the tree vegetation respectively 0.17 ha for the understorey.)*

Structural parameter	**Tree strata (DBH ≥ 5 cm)**	**Understorey (DBH < 5 cm, h ≥ 1 m)**
Total number of individuals inventoried	1,602	2,132
Average number of individuals per study site and observed variability (SD) between sites*	94 ± 18	125 ± 58
Estimated density and variability (Individuals/ha)	2,356 ± 456	12,541 ± 5,818
Total basal area observed (m²)	32,79	0,74
Average basal area per study site and observed variability (SD) between sites (m²/area)*	1.93 ± 0.47	0.04 ± 0.01
Estimated basal area and variability (m²/ha)	48.22 ± 11.77	4.36 ± 1.25

Table 2 provides an overview about observed species number, calculated diversity indices and species richness estimators. The results demonstrate that diversity is comparable high in both investigated vegetation components. The values of Shannon index and evenness are nearly the same like those given by Guedes-Bruni et al. (1997) for the vegetation component with DBH ≥ 5 cm of a well preserved forest in the Serra de Macaé de Cima and only little higher than those calculated by Pessoa et al. (1997) for the same vegetation component in a secondary forest of the same region. Like these authors stressed out these values are very similar to indices obtained in other studies realized in the Atlantic Forest of Rio de Janeiro and São Paulo.

*Table 2: Number of species inventoried in the 17 study sites and derived diversity measures and species richness estimates. The variability of the average number of species per site is expressed by means of standard deviation (SD) (*Average values per study site refers to an area of 400 m² in case of tree vegetation (DBH ≥ 5 cm) respectively 100 m² for the understorey vegetation (DBH < 5 cm, h ≥ 1 m) Hence, observed total values refer to an area of 0,68 ha for the tree vegetation respectively 0,17 ha for the understorey.)*

Diversity measure/Richness estimator	**Tree strata (DBH ≥ 5 cm)**	**Understorey (DBH < 5 cm, h ≥ 1 m**
Total number of species inventoried	190	187
Average number of species per study site and observed variability (SD) between sites*	32 ± 8	33 ± 11
Shannon index (H´)	3.910	4.048
Maximum diversity (H_{max})	5.247	5.231
Shannon evenness (J´)	0.745	0.774
Richness estimator Chao 2 ($S_{Chao\ 2}$)	278	276
Richness estimator Jackknife 1 ($S_{Jackknife\ 1}$)	268	262
Richness estimator Jackknife 2 ($S_{Jackknife\ 2}$)	309	303

The different species richness estimators as well as the interpolated species accumulation curves (figure 1) shows, that the inventory presented here is far away to represent the whole species set of the study area. Due to habitat heterogeneity on meso- and microscale, vegetation dynamics and rarity of a large number of species (see below), much more species are expected to be found if sampling effort will be enhanced.

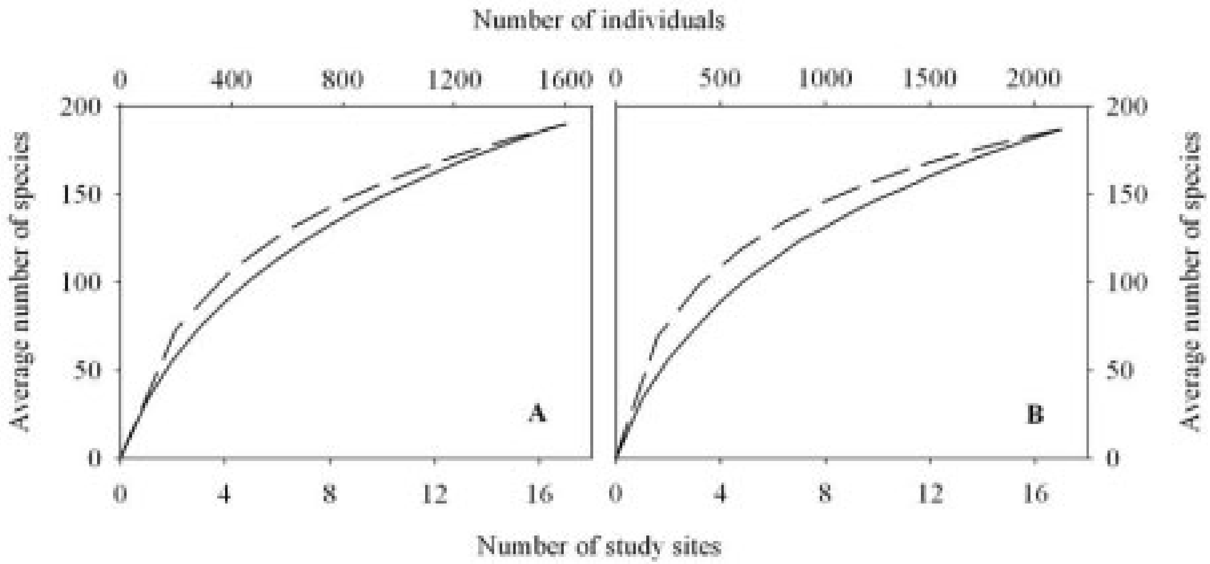

Figure 1: Interpolated species accumulation curves obtained by sample based (incidence based, continuous line) and individual based (abundance based, dashed line) rarefaction. A: Tree strata (DBH ≥ 5 cm), B: Woody understorey (DBH < 5 cm, h ≥ 1 m).

The observed variability of structural parameters and species richness between the single study sites is considerable high (table1, 2) and may be explained by habitat heterogeneity within the study area. With regard to basal area this variability is only slightly higher in the understorey (coefficient of variation CV = 28.7 %) than in the tree strata. By contrast, concerning the individual density and the species richness, it is much more expressed in the understorey (CV = 46.4 % respectively 34.2 %) than in the tree vegetation (CV = 19.4 % respectively 23.6 %). This indicates that understorey vegetation is more sensitive to spatial habitat heterogeneity on mesoscale. The environmental variability seems to affect stronger the species composition and the relation between individual density and individual growth rates of the understorey than of the tree strata. Hence, it can be concluded that understorey vegetation would be more suitable to analyze and describe vegetation patterns as well as vegetation-environment-relationships on smaller spatial scale.

According to their Family Importance Value (FIV, Mori et al. 1983) the ten most important of all inventoried families are in descending order Myrtaceae, Rubiaceae, Lauraceae, Arecaceae, Nyctaginaceae, Fabaceae, Melastomataceae, Meliaceae, Euphorbiaceae and Sapotaceae (figure 2A). More than the half of the species (57.8 %) and about two third of the individuals (62.6 %), the total basal area (69.1 %) and consequently also the sum of all Family Importance Values (68 %) fall to these 10 families. On the other hand, 26 (53.1%) of the identified plant families contribute with less than 1 % to the sum of all FIV. The FIV of all families are provided in Appendix 2: Table1.

As basal area, expressed by relative dominance, is one of the parameters composing the FIV the rank order of family importance of the whole data set is clearly more influenced by tree flora than by the understorey taxa. Therefore the ten most important families in the tree strata are the same as in the whole sampled vegetation, although some changes in rank order can be observed (figure 2B). Nevertheless seven of these families are also among the ten most important in the understorey (figure 2C). The three families, which are more important in the understorey than in the tree layers, are Monimiaceae, Moraceae and Clusiaceae. Especially the later are poorly important within the higher vegetation strata and contribute only less than 1% to the sum of all FIV of the tree vegetation. The Monimiaceae (rank 12) and Moraceae (rank 14) are at least among the 15 most important families also in the tree strata.

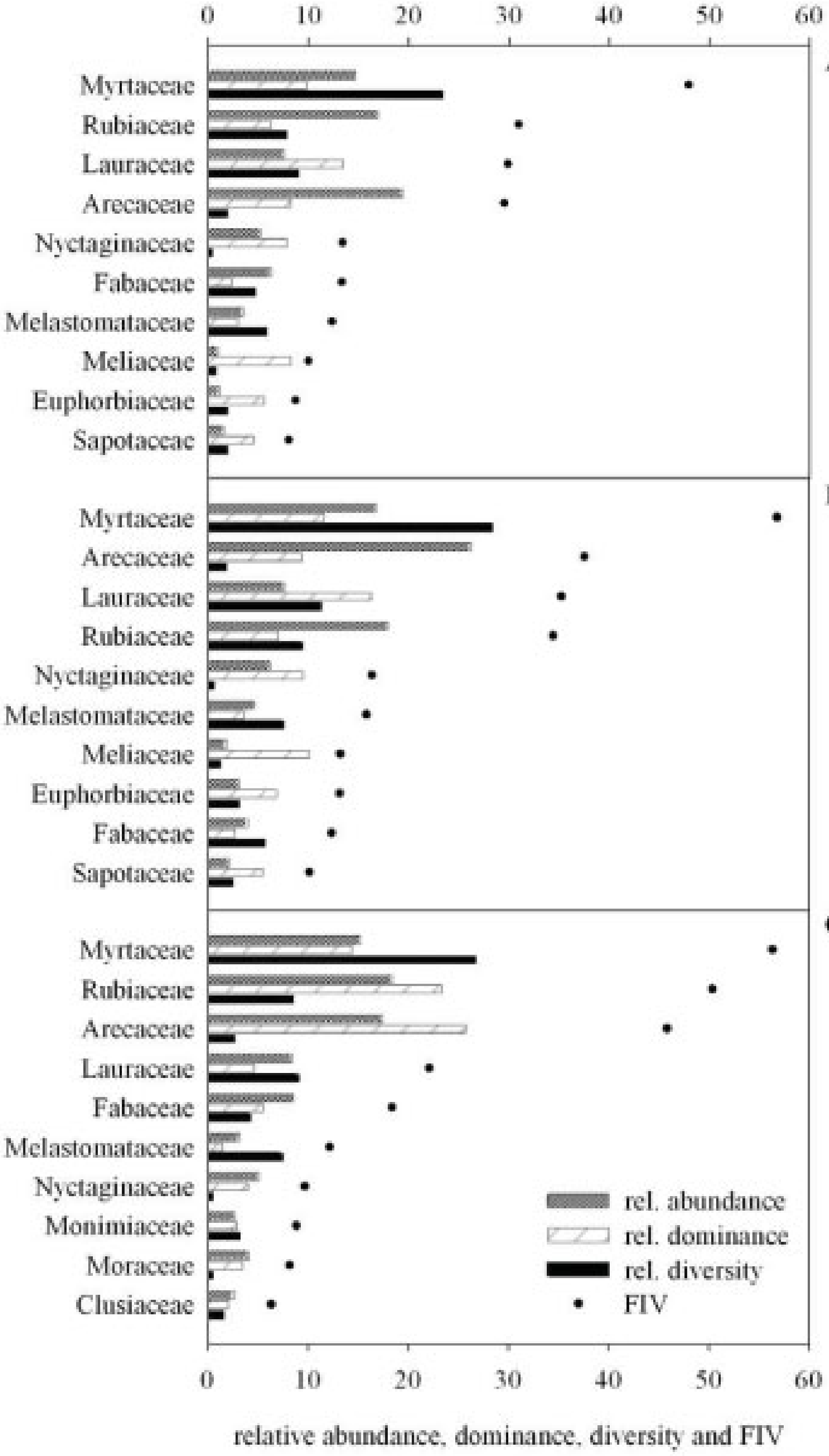

Figure 2: Family Importance Values, and relative values of abundance, dominance and diversity of the 10 ecological most important families in (A) the whole sampled flora, (B) the tree flora (DBH ≥ 5 cm) and (C) the woody understorey (DBH < 5 cm, h ≥ 1 m).

The majority of the named families, e.g. Myrtaceae, Lauraceae, Rubiaceae, Melastomataceae, Arecaceae, Fabaceae (all subfamilies), Monimiaceae, Euphorbiaceae and Meliaceae, are known to show a high ecological importance in the montane forests of SE-Brazil, at least among the tree strata (Guedes-Bruni et al. 1997, Oliveira-Filho & Fontes 2000).

The Myrtaceae were identified as most important family in the tree as well as in the understorey vegetation. They excel by their extraordinary high diversity. In all 60 species of this family have been recorded, 35 in both vegetation strata and 10 respectively 15 solely in the tree respectively the understorey vegetation. Barroso & Peron (1994) describes the species of Myrtaceae as especially characteristic elements of the tree layers. The results presented here indicate that this family is also extraordinary characteristically for the understorey vegetation, even if we can't verify if all species found only in the understorey are really true understorey plants, because all of them could been identified so far only to family level.

With regard to species richness the Myrtaceae are followed by Lauraceae (23 species), Rubiaceae (20), Melastomataceae (15) and Fabaceae (12). All these families were found also among the most diverse in a study performed in a 1 ha-Plot in the same study area (Silva Matos et al. 2007). Only in four other families - Solanaceae (10 species), Monimiaceae (8), Myrsinaceae (6) and Piperaceae (6) – we found more than five species. These later families are all more important in the understorey than in the tree strata.

The elevated diversity of Myrtaceae, Lauraceae and Melastomataceae in the Serra dos Órgãos region were stated out yet by Velloso (1945) and Rizzini (1954) and proved later also for the nearby forest of Macaé de Cima (Guedes-Bruni et al. 1997, Lima & Guedes-Bruni 1997). The authors interpreted the high species richness of these families as indication for advanced successional stages. Especially in the case of Myrtaceae this is supported also by a study realized in three forest fragment in the rural zone of the Municipality Teresópolis (Thier 2006, Thier & Wesenberg 2009). In these remnants, characterised as secondary forest in early to middle successional stages, only five species of Myrtaceae could been registered. A comparable effect of forest conservation stage on the diversity of Myrtaceae has been observed in the Serra de Macaé de Cima. While in a well conserved study site were found 30 species, a secondary forest harboured only seven species (Guedes-

Bruni et al. 1997, Pessoa et al. 1997). Probably the extraordinary noticeable lower diversity of Myrtaceae in secondary forests can be explained by the low population density of a great number of species (Guedes-Bruni et al. 2009, compare also results presented below), because rare species should underlie a greater risk to be locally extinct than common species. This example emphasizes the importance of well preserved, spaciously large continuous forests for biodiversity conservation.

Especially Myrtaceae and Lauraceae are pointed out as very important and characteristic elements of the south-eastern Brazilian montane forest by various authors (e.g. Leitão Filho 1987, Mori et al. 1983, Peixoto 1992, Vattimo 1959). The Mata Atlântica of SE-Brazil is supposed to be a diversity and evolution centre of these families (Mori et al. 1983, Vattimo 1959). In general Aiba & Kitayama (1999) assume that regions with a very heterogeneous topography, like the coastal mountains of SE-Brazil, may provide very good conditions for species diversification. Another important taxon of our study, which is supposed to have a diversity centre in the south-eastern Mata Atlântica, is the genus *Mollinedia* (Peixoto 2002). All eight inventoried species of Monimiaceae belong to this genus.

The most species rich among the most important families are generally also between the most abundant and/or dominant families. On the other hand we have found among the most important families also taxa those high FIV is caused mainly or solely by the high abundance and/or dominance of one or in some cases the unique species inventoried. Consequently, these species of Arecaceae, Nyctaginaceae, Meliaceae, Euphorbiaceae, Sapotaceae and Moraceae are among the ecologically most important species (figure 2).

With regard to their IVI (Curtis & McIntosh 1951) the ten most important of all observed species are in descending order *Euterpe edulis* (Arecaceae), *Guapira opposita* (Nyctaginaceae), *Psychotria suterella* (Rubiaceae), *Cabralea canjerana* ssp. *canjerana* (Meliaceae), *Sorocea bonplandii* (Moraceae), *Alchornea triplinervia* var. *triplinervia* (Euphorbiaceae), *Inga lanceifolia* (Fabaceae-Mimosoideae), *Ocotea dispersa*, *O. elegans* (Lauraceae) and *Micropholis crassipedicellata* (Sapotaceae) (figure 3A). Somewhat less than the half of the individuals (44.0 %) and the total basal area (42.8 %), and about one third of the sum of all Importance Values (34 %) fall to these 10 species. On the other hand 241 species (94.1 %) contribute with less than 1 % to the sum of all IVI. This is caused by the low abundance and/or frequency of a great number of species. Of 72 species (28.1 %) we found only one individual. Further 32 species (12.5 %) were presented only with two individuals. The lowest frequency (occurrence in only one study site) was registered for 103 species (40.2 %). The observed species density and frequency pattern reflects the well known phenomenon of tropical forests that few species are very abundant and frequent but the majority are rare (Hubbel 2005). Guedes-Bruni et al. (2009) concluded that the contribution of rare species (less than 1 individual/hectare) to the floristic composition of Ombrophilous Dense Atlantic Forests may reach 50 % of the flora. The IVI, abundance and frequency of all species are provided in Appendix 2: Table 1.

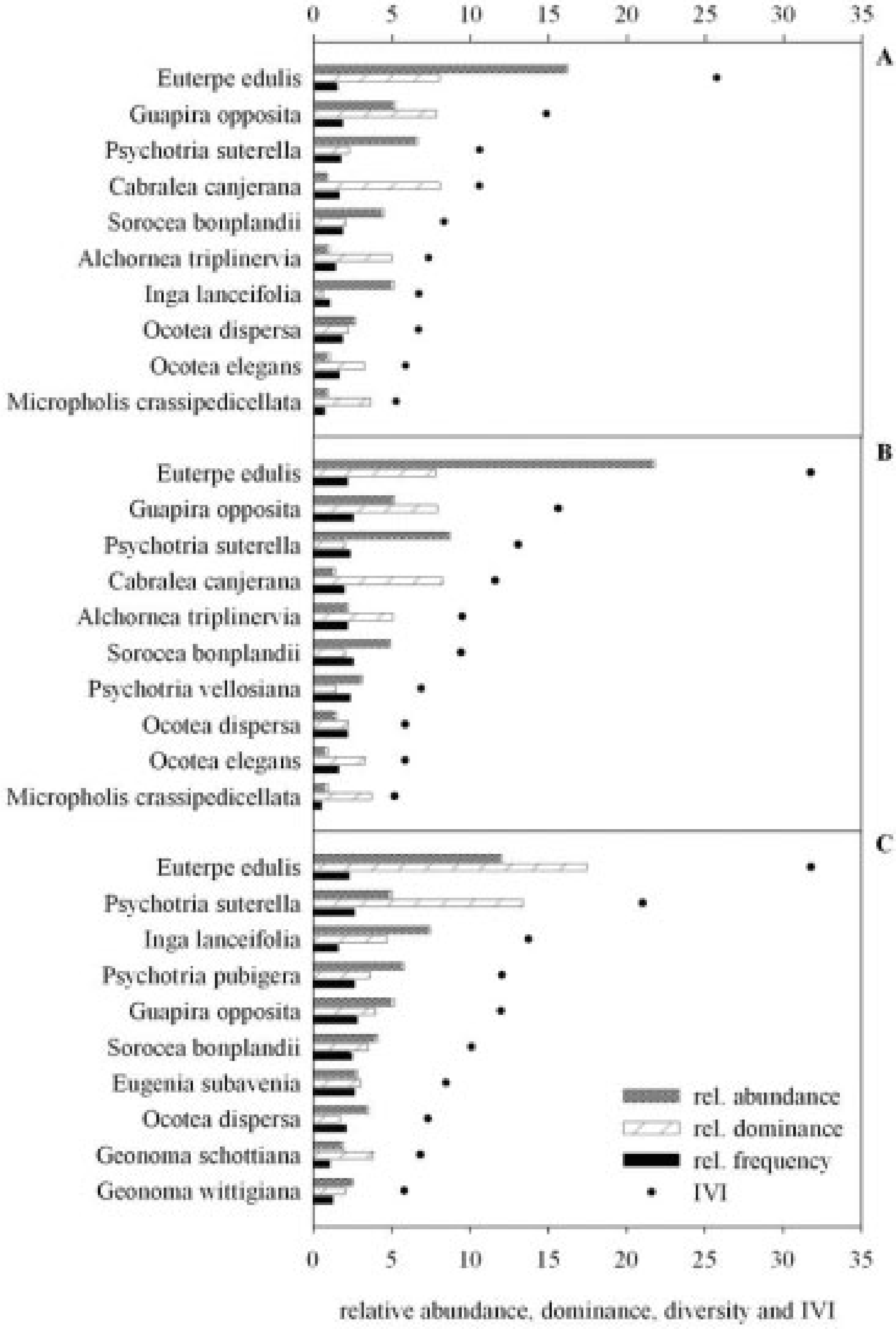

Figure 3: Importance Value Index and relative values of abundance, dominance and diversity of the 10 ecological most important species in (A) the whole sampled flora, (B) the tree flora (DBH ≥ 5 cm) and (C) the woody understorey (DBH < 5 cm, h ≥ 1 m).

Also in the IVI the basal area is one of the composing parameters. Therefore, again the rank order of species importance of the whole data set is more influenced by tree layer than by understorey taxa. Nine out of the ten most important species in the tree strata are the same as in the whole sampled flora, although one change in rank order can be observed (figure 3B). Only *Psychotria vellosiana* (Rubiaceae), the 7th most important species among the trees, is not found among the ten most important of the whole investigated flora. This common species of the lower tree stratum is replaced in the data set concerning the whole sample by *Inga lanceifolia*. This legume species is also a frequent treelet of the lower tree layer, but showed a clearly more elevated importance in the understorey than *Psychotria vellosiana* (Figure 3C).

Among the ten most important species of the understorey are further five species (*Euterpe edulis*, *Guapira opposita*, *Psychotria suterella*, *Sorocea bonplandii*, *Ocotea dispersa*), which were listed also between the most important of the whole species set (Figure 3C). All of these are also among the most important of the tree flora. As tree strata elements (DBH $\geq$ 5 cm) they were inventoried mainly in the lower and/or middle tree layer. By contrast the four species which are only among the most important of the tree and the whole flora (*Cabralea canjerana*, *Alchornea triplinervia*, *Ocotea elegans*, *Micropholis crassipedicellata*) were found more frequently as upper canopy elements. Consequently their high IVI is based especially on their high dominance. They are all present as young individuals also in the understorey, but *Alchornea triplinervia* seems to regenerate hardly in the study area. Among the tree flora this Euphorbiaceae occurred with 36 individuals in 12 study sites, while in the understorey the species was found only once (Appendix 2:Table 1). This finding may be interpretable as a result of former disturbances and followed successional processes. *Alchornea triplinervia* is described as heliophilous to semi-sciophilous species and characteristic element of anthropogenically disturbed areas, which rarely occurs in climax forests (Lorenzi 2002, Oliveira et al. 1997). Hence the high importance of the species in the tree strata may indicate disturbances that took placed in the studied area a longer time ago, whilst the poorly presentation in the understorey indicate a actually more advanced successional stage and a better conservation status of the forest. On the one hand this example shows that the analysis of population structure of selected species may be a powerful tool for the monitoring of conservation efforts. On the other hand it demonstrates that it should be paid more attention to the inclusion of understorey vegetation in floristic-structural surveys.

Three of the species among the ten most important of the understorey, one Rubiaceae (*Psychotria pubigera*) and two palms (*Geonoma schottiana*, *G. wittigiana*), are true understorey elements, which wasn't inventoried in the tree layers. By contrast, the fourth species listed only between the most important understorey plants, *Eugenia subavenia* (Myrtaceae), were found also as treelet (DBH ≥ 5 cm) in the lower tree stratum. It is the most abundant (94 individuals) and most widespread (occurrence in 15 study sites) Myrtaceae in the study area and also the most important represent of the family in the tree flora (rank 11). In all, only 14 Myrtaceae (23.3 %) occurred in at least five sample sites and only 11 of them (18.3 %) presented an abundance of more than 10 individuals. By contrast 23 species of Myrtaceae (38.3 %) were inventoried with less than 3 individuals and 25 species (41.7 %) occurred only in one study site. This species density and frequency pattern reflects that rarity is a common phenomenon in tropical forests also at family level. Guedes-Bruni et al. (2009) showed that rarity is common in different habitats of the Mata Atlântica in diverse families, like Myrtaceae, Lauraceae, Fabaceae and Melastomataceae, even if the degree of rarity may vary between different sites.

The ecological most important species in the tree strata as well as in the understorey of the study area is *Euterpe edulis* (figure 3), which contributes substantially to the high family importance of the Arecaceae (figure 2). From various studies this shade tolerant arborescent palm species is well known as one of the most frequent and abundant species of advanced successional stages of the Ombrophilous Dense Atlantic Forests (Aidar et al. 2001, Brade 1956, Guedes-Bruni et al. 1997, Kurtz & Araujo 2000, Silva Matos et al. 2007, Moreno et al. 2003). Nevertheless this palm was found also as most important species in a relatively young secondary forest (Pessoa et al. 1997). In our study this palm is clearly the most abundant and one of the most dominant species, although it doesn't occur in all study sites. Within the study area the species reached the limit of their altitudinal distribution and therefore it is absent in the most elevated study sites, located above 1.400 m a.s.l. Furthermore, a descending abundance of *Euterpe edulis* with ascending altitude could be observed (Seele 2005). Between 1,100 m and 1,200 m a.s.l. up to more than 100 individuals per site were inventoried, whilst between

1.200 m and 1,300 m a.s.l. the abundance felt to 15-46 individuals per site. The most elevated sample sites where the species occurred are located at approximately 1,380 m a.s.l., but only 1-3 individuals of the palm species were found in each site. Hence we can conclude that the upper distribution limit of *Euterpe edulis* in this region of the Serra dos Órgãos is located at ca. 1,400 m a.s.l.

Some other of the most important tree layer species ((DBH ≥ 5 cm) of our study were found also among the most important or at least the most abundant in the preserved forest of the Serra de Macaé de Cima (Guedes-Bruni et al. 1997). These are *Cabralea canjerana ssp. canjerana*, a species very frequently detected in various floristic-structural studies realized in the Atlantic Forest (Guedes-Bruni et al 1997), *Alchornea triplinervia*, *Psychotria vellosia*na and *P. suterella*. As well as *Euterpe edulis* the later three were also found among the 20 most important species in a secondary forest of the Serra de Macaé Cima (Pessoa et al. 1997).

Conclusion and Outlook

The diversity and the floristic-structural patterns of the investigated tree vegetation match well with the results obtained in other studies carried out in the Ombrophilous Dense Montane Forest. Especially the high quantity of rare species emphasizes the importance of well preserved, spaciously large continuous forests for biodiversity conservation.

Furthermore our results demonstrate that the woody understorey vegetation shows to a certain degree comparable patterns as the tree vegetation, but also certain distinguishing characteristics (e.g. occurrences of species, ecological importance of taxa, variability of structural parameters and diversity). Therefore the stronger inclusion of understorey vegetation in floristic-structural surveys is desirable. This would not only provide a much more complete knowledge concerning phytodiversity and vegetation patterns, but probably also facilitate the detection and evaluation of possible indicator species.

Further results of our study concerning the floristic-structural differentiation of the vegetation along abiotic gradients and possible indicator species will be published elsewhere.

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Chapter 15

DIVERSITY, FLORISTIC COMPOSITION AND SIMILARITY OF THREE FOREST FRAGMENTS IN THE MATA ATLÂNTICA OF RIO DE JANEIRO.

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Abstract: Three forest remnants of the Brazilian Atlantic Rainforest were investigated regarding to diversity, floristic composition and similarity of the tree flora. According to the ecological importance values FIV (Mori et al. 1983) and IVI (Curtis & McIntosh 1951), the most important families were Fabaceae and Myrtaceae, and within these families, *Piptadenia gonoacantha*, *Piptadenia paniculata* (Fabaceae) and an unidentified Myrtaceae were the most important species. Diversity of one fragment was high (Shannon-Wiener index H_s = 3,49) as typical for the Mata Atlântica. Although the fragments were close together, floristic similarity was low. This is probably the result of different successional stages of the fragments.

Introduction

The vanishing Brazilian Atlantic Rainforest (Mata Atlântica) is one of the highest global priorities for conservation (Myers et al. 2000). The biggest part of the remaining forest consists of comparably small and only partially protected fragments (Lima & Capobianco 1997, Gascon et al. 1999) in different successional stages. Despite of this fact, the Mata Atlântica is still one of the 25 biodiversity hotspots worldwide (Tabarelli et al. 2005). Among others, the natural environmental variability of the landscape leads to an enormous species richness.

A basic precondition for the planning of effective and sustainable conservation activities in a fragmented landscape is the profound knowledge of the actual variability of species diversity and species composition. In order to support actions to protect and restore the environment we realized a floristic-structural study in the fragmented rural area of Teresópolis, Rio de Janeiro. In this paper the results concerning floristic composition, diversity of the tree species and floristic similarity of three Atlantic Forest remnants are presented.

Methods

Study site

The study area is located in the municipality of Teresópolis in the central part of Rio de Janeiro state (S 22° 17’ 61’’ and W 42° 52’ 58.6’’). Originally the middle elevation areas (500 to 1500 a.s.l.) of the region were covered mainly by Ombrophilous Montane Rain Forest (Ministério das Minas e Energia 1983), which is characterised by a dense understorey, a mean canopy height of about 20 m and a diverse liana and epiphytic vegetation (Lima & Guedes-Bruni 1997). After a long history of human impact, remaining forest remnants are restricted to hills and steep slopes, and are surrounded mainly by pastures (still used or abandoned). Furthermore, the area is used for horticulture near riversides and few eucalyptus plantations.

The study was carried out in three forest fragments (Table 1): David, Maturano (named after landowner) and Sorvete (named after the nearby ice cream factory). Based on a former study (Thier 2006), fragments were chosen due to the occurrence of the legume *Piptadenia gonoacantha* (MART.) J. F. MACBR. The vegetation of two remnants (Maturano and David) can be classified as secondary forest in early to middle successional stages. The third (Sorvete) present a more advanced successional stage (middle to late) (Thier 2006).

Table 1: Location, elevation and extent of the three forest fragments.

Fragment	Location	Elev. [m]	Size [ha]
Sorvete	S 22°16.721; W 42°51.786	885	60.9
David	S 22°17.208; W 42°52.536	886	8.9
Maturano	S 22°16.369; W 42°50.366	890	36.7

According to the local community and own observations, the fragments are influenced by hunting (Sorvete, Maturano) and sparse selective logging (all). Maturano was partly affected by fire about 10 – 15 years before the study.

Data collection

In each fragment a 1 ha square plot with a 20 x 20 m grid was established. All 36 grid line intersections were considered as sample points for point centered quarter census. Following Cottam & Curtis (1956) and Mitchell (2005), the area around every point was imaginary divided into four quadrants. In all 144 quadrants, the nearest tree (diameter at breast height (dbh) > 5 cm) was determined, and the distance from the tree to the point and dbh of the tree was recorded. For trees with multiple trunks at breast height, the diameter of each trunk was recorded separately. Distance measurements were made to the centre of the trunk and the centre of the multistemmed clump respectively. If possible trees were identified during the field work. Voucher specimens were collected from the further individuals and identified so far as possible in the herbarium of the Botanical Garden Rio de Janeiro (RB). Some specimens could not be matched definitively to the taxa and thus, were given tentative names (e.g. Myrt spec. 5) and also treated as species in the data analyses.

Data Analysis

The Importance Value Index (IVI) was calculated for each tree species following Curtis & McIntosh (1951):

IVI = relative density + relative dominance + relative frequency

where:

relative density = number of individuals of a species/ number of all individuals *100%

relative dominance = total basal area of a species / total basal area *100%

relative frequency = frequency of a species / sum of frequencies of all species *100%

(as frequency measure were used the number of study points where each species occurred)

The IVI describes the ecological importance of a species according to its density, size and distribution. Similar to the IVI, an importance value for each family (Family Importance Value, FIV), based on density, dominance and diversity was calculated as suggested by Mori et al. (1983):

FIV = relative density + relative dominance + relative diversity

where:

relative density = number of individuals of a family / number of all individuals *100%

relative dominance = total basal area of a family / total basal area *100%

relative diversity = number of species of a family / total number of species *100%

Family classification is based on Stevens (2001 onwards). Unidentified species were included in the IVI calculations, but not in the FIV because of their unknown family relations.

The floristic α-diversity was calculated using the Simpson index (D) and the Shannon-Wiener index (H_s).

$$D = \sum_{i-1}^{S} \left(\frac{n_i [n_i - 1]}{N[N-1]} \right)$$

$$H_S = -\sum p_i \ln p_i \quad \text{with} \quad p_i = \frac{n_i}{N}$$

where:

n_i = number of individuals of the i-th species, N = total number of individuals and S = total number of species in the sample.

These Indices have low or moderate sensitivity to sample size and have been widely used (Magurran 2004). A low Simpson index value corresponds to a higher diversity, whereas a high value correlates to a lower diversity. Therefore, the Simpson diversity 1-D (cf. Krebs 1999) is used in the following. Species evenness (E) was calculated taking into account that H_s is a function of the total number of species and the species distribution (Magurran 2004).

$$E = \frac{H_S}{H_{\max}} \quad \text{with} \quad H_{\max} = \ln S$$

where:

S = total number of species in the sample and Hmax = maximum value of Hs

The similarity of the fragments with regard to species composition was assessed using Sørensen index (C_S) as a quantitative, and the estimated Chao's abundance-based Sørensen index corrected for unseen species (C_{SabdE}) as a qualitative coefficient. The latter is suitable for this survey because it takes unseen species into account and thus reduces the bias occurring especially in small sample sizes (Colwell 2005, Chao et al. 2005).

$$C_S = \frac{2j}{(a+b)}$$

where:

j= number of shared species, a = number of species in community 1, b = number of species in community 2

For formula of C_{SabdE} see Chao et al. (2005).

Diversity and similarity indices were calculated using EstimatS 7.5.0. Importance values were calculated using Microsoft Excel 2003.

Results and discussion

Species diversity

In total, 108 tree species belonging to at least 29 families were detected in all fragments (Appendix 2: Table 2). Nine species couldn't be identified not even to family level. With 54 respectively 52 species, Maturano and Sorvete are more diverse than David (35 species). Table 2 shows the species diversities of tree populations in these fragments.

Table 2: Diversity indices of the forest communities with number of detected species (S), Simpson diversity 1-D, Shannon-Wiener index (H_s), maximum value of H_s (H_{max}) and species evenness (E).

Fragment	*S*	1-*D*	H_S	H_{max}	*E*
Sorvete	52	0.91	3.23	3.95	0.82
David	35	0.88	2.70	3.56	0.76
Maturano	54	0.96	3.49	3.99	0.87

Although Maturano is similar to Sorvete regarding to the number of detected species, the diversity indices are higher in Maturano. This is caused by the smoother species distribution in this community illustrated by the higher species evenness. Despite of the low sample size (144 individuals) the detected α-diversity value in Maturano (Hs = 3.49) is not atypical for Mata Atlântica fragments (Silva & Soares 2003, Borem & Oliveira-Filho 2002). With the lowest diversity indices and the lowest evenness, David shows the least floristic diversity. With an area of only 8.9 ha, David represents by far the smallest fragment in this survey which may explain the low species diversity. It is well known that the diversity of species in forest fragments depends considerably from and is declining with its size (Collinge 1996, Hill & Curran 2003).

Family importance value

Figure 1 shows the 10 ecological most important families in the fragments.

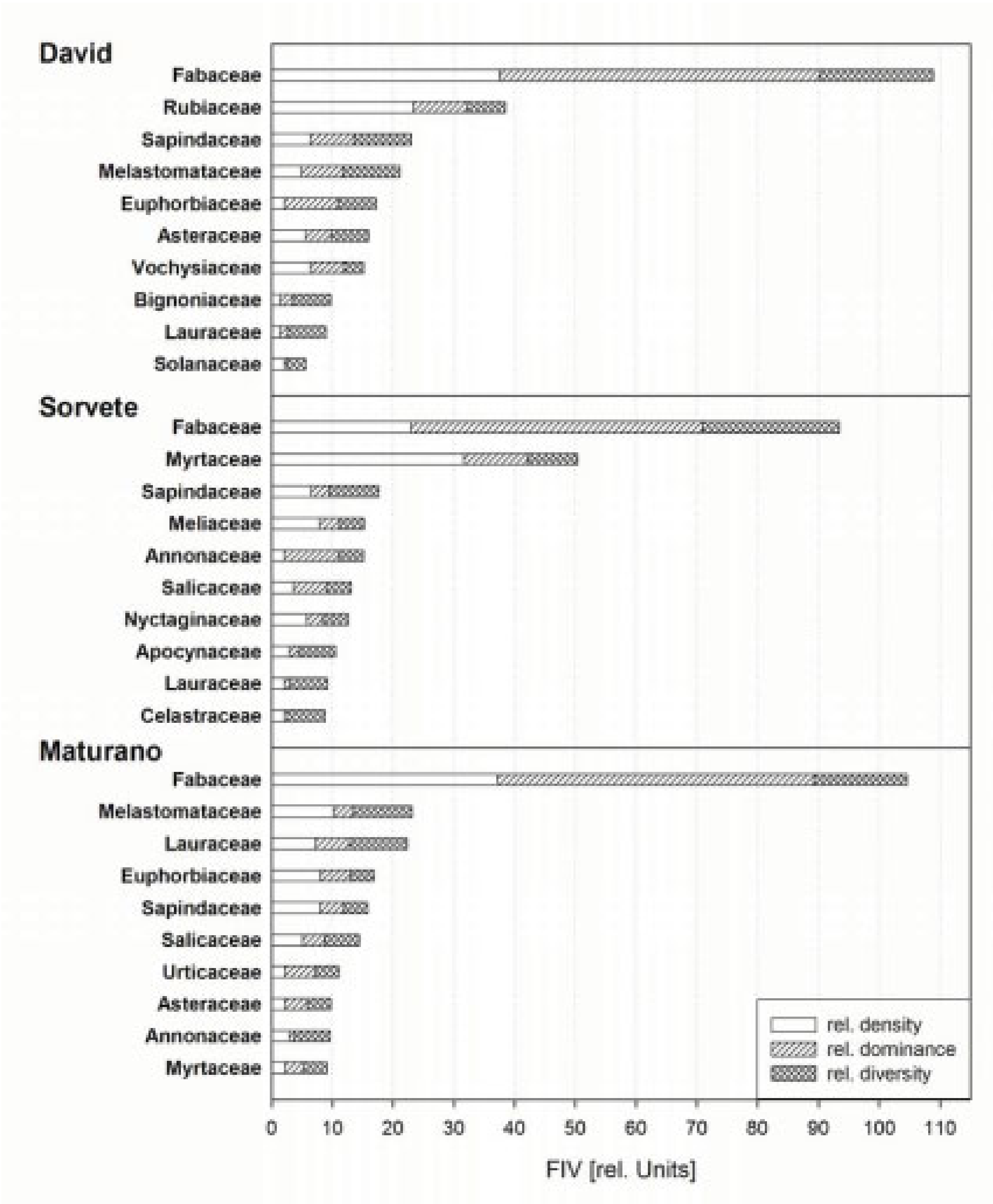

Figure 1: The 10 most important families in the three forest remnants.

Fabaceae seem to dominate the vegetation in all fragments. The FIV of this family is extraordinary high with 109 (36.3 % of the sum of all FIV) in David, 93 (31.1 %) in Sorvete and 105 in Maturano (43.9 %). In all fragments, Fabaceae represent the most dominant and the most diverse, in Maturano and David the most abundant family as well. The high importance of Leguminosae in forest remnants of the Mata Atlântica were detected in other studies as well (e.g. Stranghetti et al. 2003, Silva et al. 2004a). Gentry (1988) stated that Fabaceae is often the most diverse family in many Neotropical forests with one exception as Moraceae is becoming more diverse on very rich soils. Probably, the symbiosis with nodular root bacteria is a key factor for growing and surviving on poor soils typically for the study region.

Tabarelli et al. (1999) noticed that, besides Fabaceae, other families, especially Asteraceae, Euphorbiaceae and Solanaceae are getting more important with declining fragment sizes. This coincides with the finding of this study that Solanaceae is among the ten most important families in the smallest fragment David exclusively.

Lauraceae is another very diverse family in the investigated fragments (five species in Maturano, nine in total). Many studies reflect the importance of this family in costal rain forests of southeast Brazil (Vattimo 1959, Leitão-Filho 1987, Peixoto 1992, Kurtz & Araújo 2000). In coincidence, south American montane rainforests in general are assumed to be part of a diversity hotspot of Lauraceae (Vattimo 1959, Hueck 1966).

Myrtaceae is another extraordinary species rich and important family in the Mata Atlântica (Mori et al. 1983, Peixoto & Gentry 1990). However, in this study only in Sorvete, the most developed fragment, Myrtaceae show a high FIV (50.3). In contrast to other surveys in the Mata Atlântica (e.g. Wesenberg & Seele 2009), this high FIV is not caused by high diversity but by high density of just one species (Myrt spec. 5). It is suggested that Myrtaceae is strongly affected by habitat fragmentation due to its high diversity and the ensuing low density of its species.

Species importance value and floristic similarity

Figure 2 shows the 10 ecological most important species in the fragments.

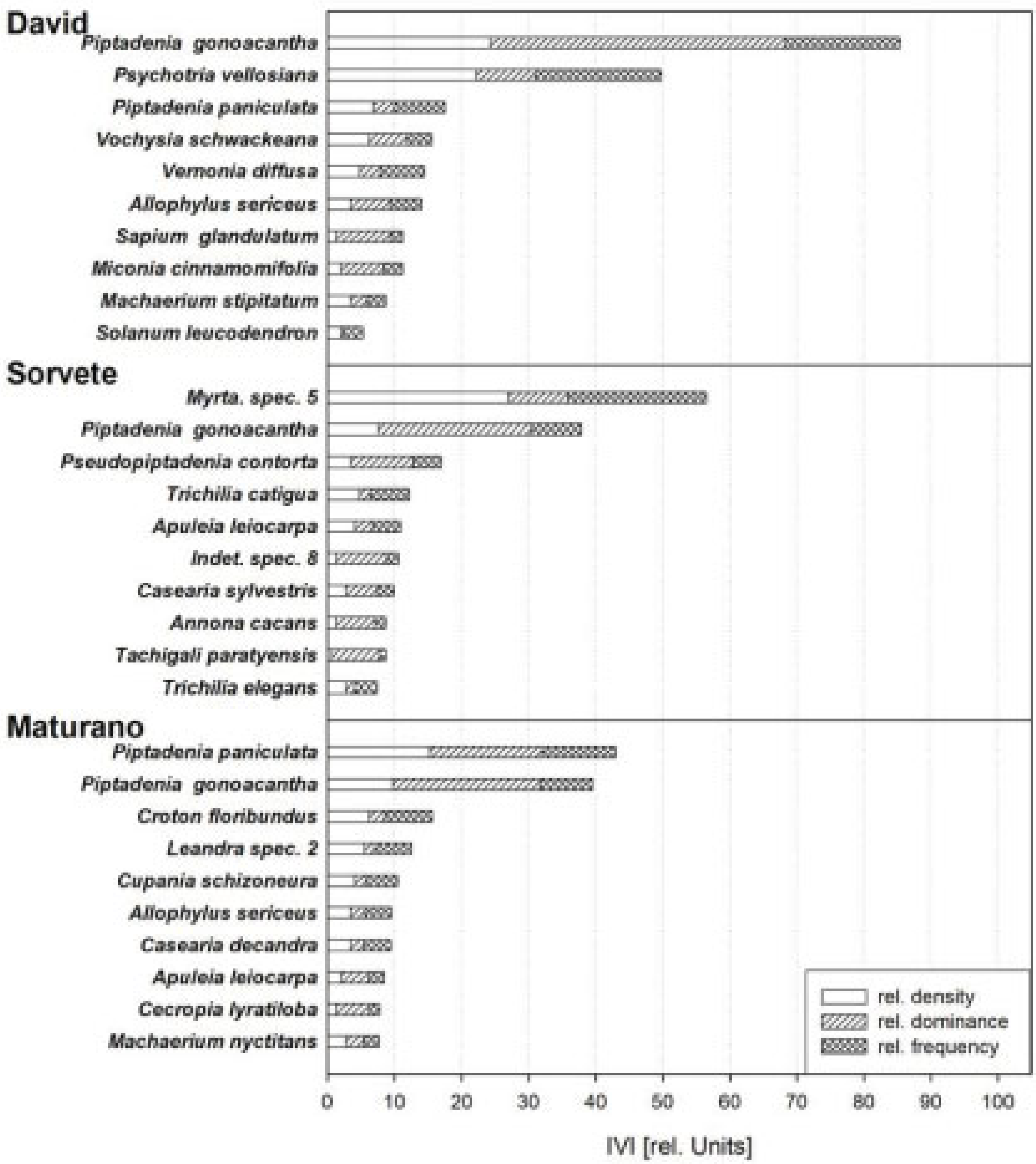

Figure 2: The 10 most important species in the three forest remnants.

The observed density distribution in all fragments reflects the well known phenomenon that, in tropical forests, few species are very frequent but the majority are rare (Hubbel 2005). In terms of IVI, the legume *Piptadenia gonoacantha* is one of the most important species in each fragment (IVI = 85.4 in David, 39.0 in

Maturano and 37.9 in Sorvete). No other species was found to be one of the ten most important species in all fragments. Although study sites were chosen due to the occurrence of this species, *P. gonoacantha* is considered to be one of the most common species in fragments of the Mata Atlântica (Aidar et al. 2001, Borem & Oliveira-Filho 2002, Silva et al. 2004b). Some areas in the study region are covered more or less totally by this species (own observations). *Piptadenia paniculata*, another legume, which is the most important species in Maturano (IVI = 43.0) and the second most important in David (IVI = 50.0), is also known as very common in this region. (Pardo, C., pers. comm.).

An unidentified Myrtaceae, which achieves the highest Importance Value Index in Sorvete (IVI = 56.6), was found neither in Maturano nor in David. Sorvete hosts generally 37 species exclusively found in this fragment. On the other hand, 32 species were found exclusively in Maturano, and 13 species exclusively in David. The fragments have very few species in common. Only seven species (*Allophylus sericeus, Apuleia leiocarpa, Cecropia glaziovi, Croton floribundus, Cupania schizoneura, Piptadenia gonoacantha* and *Psychotria vellosiana*) were detected in all fragments. David and Maturano share 18, David and Sorvete as well as Sorvete and Maturano 11 species (Fig. 3).

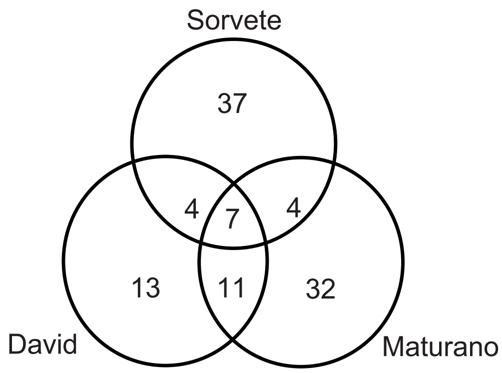

Figure 3: Number of detected shared species in the surveyed fragments.

The Sørensen-index as a qualitative index of similarity expresses the proportion of shared species (Table 3). Consequently, fragments have relative low similarity.

David and Maturano showed the highest (C_S = 0.40) and Sorvete and Maturano the lowest (C_S = 0.21) Sørensen index.

Table 3: Floristic similarity between the forest fragments expressed by Sørensen Index and Chao's abundance-based Sørensen index.

	Sorvete	***David***	***Maturano***
			Sørensen Index C_S
Sorvete	**---**	**0.25**	**0.21**
David	**0.33**	**---**	**0.40**
Maturano	**0.31**	**0.65**	**---**
	Chao's abundance-based Sørensen index C_{SabdE}		

Taking into account the density of species by means of Chao's abundance-based Sørensen index the fragments David and Maturano seemed to be more similar (C_{SabdE} = 0.65). This is caused mainly by the high abundant species *P. gonoacantha* und *P. paniculata* in both fragments (Fig. 2). *P. gonoacantha* is also common in Sorvete, but with lower density. Floristic dissimilarity between forest fragments of the Mata Atlântica has repeatedly been described in literature (Machado et al. 2004 Silva & Soares 2003). Machado et al. (2004) suspected that this is caused to a large part by the geographical heterogeneity of the landscape. Already 64 years ago, Velloso (1945) pointed out the extraordinary geographical diversity of this area. Furthermore, the dissimilarity might be explained through the ecological isolation of the fragments. It is known that fruit dispersers like birds rarely cross open landscapes (matrix) more than 100 m (Bierregaard & Dale 1996, Power 1996). However, since the floristic composition is changing with ongoing succession (Aidar et al. 2001, Ribas et al. 2003, Petrere Jr et al. 2004) the different stages of development of the investigated fragments might be the main reason for the detected dissimilarity.

Conclusion

On the one hand, the investigated fragments showed somewhat similar floristic patterns at least at family level. But on the other hand, substantial differences in the floristic composition resulting in low floristic similarity could be detected. Since the fragments of the presented survey are situated near to each other, the floristic dissimilarity might be explained by either abiotic differences, by different successional stages, or by both. These factors are, not only but also, depending on the fragment size itself. Furthermore the strong dissimilarities may indicate an elevated degree of ecological isolation of forest remnants on a relative small spatial scale. Thus, in order to support the development of effective and sustainable conservation concepts, studies on the floristic differentiation of forest remnants of the Mata Atlântica and their causes are of particular importance.

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Chapter 16

FLORISTIC DIFFERENTIATION AND CLASSIFICATION OF THE PTERIDOPHYTA IN THE UNDERSTOREY OF THE ATLANTIC RAIN FOREST IN THE EASTERN PART OF THE SERRA DOS ÓRGÃOS NATIONAL PARK, TERESÓPOLIS, RJ, BRAZIL.

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Abstract: In this study we analyzed the floristic differentiation of the pteridophyte community occurring in the understorey of the forest in the eastern part of the Serra dos Órgãos National Park, Teresópolis, federal state Rio de Janeiro, Brazil. The aims of this investigation were the description of the abundance structure of all occurring species of Pteridophyta, the classification of species combination (Cluster analysis, Two-Way Indicator Species Analysis and Correspondence Analyses) and the characterization of their dependence on the topographic and abiotic factors, respectively.

In the study area, including the 21 sample sites (400 m² each), a total of 17,041 fern individuals and 116 different species were recorded. This species belong to 19 families and 44 genera. The most abundant ferns were *Elaphoglossum vagans, Polybotrya speciosa, Polypodium pleopeltidis* and *Asplenium radicans var. uniseriale.*

The fern flora of 19 sample sites was classified into three different floristic groups. For each of these groups it was possible to identify typical species using the Indicator Species Analysis and to determine the dominant fern species using the abundance structure. Based on this analyses three different fern habitats could be distinguished within the study area. These were named after the most abundant fern species (*Elaphoglossum vagans, Asplenium radicans var. uniseriale, Polybotrya speciosa*).

In combination with the results of other running investigations about woody plants in the study area it may be possible to use the Pteridophyta as indicators for the different forest types.

Introduction

Investigations of species distribution in tropical rain forests are very difficult because of the high species diversity and are currently a field of intense research (Sollins 1998). The extent to which edaphic or topographic factors influence the distribution of species is considered as the key to understanding species diversity in tropical forests (Miyamoto et al. 2003). In recent years various studies dealt with the detection of diversity patterns within tropical forests and the analysis of their causes (e.g. Ruokolainen et al. 1997; Aiba & Kitayama 1999; Kessler 2001a, 2001b Tuomisto et al. 2002; Aldasoro et al. 2004; Bhattarai et al. 2004; Tuomisto & Ruokolainen 2005; Paciencia 2008).

The question, whether the environmental heterogeneity and the spatial structure cause the high diversity, arises repeatedly (Richard et al. 2000). According to this thesis the co-occurrence of several species with different ecological requirements is bound to a variation of environmental parameters, which needs to be adequately detected for each life-form. Frequently, just the detection is a serious problem in ecological studies. In the case of ferns, for example, generally the sporophyte generation is investigated, even though the successful establishment of the gametophyte generation is just as crucial for the spread of a species (Richard et al. 2000). The definition of a habitat is therefore always a subjective and simplified description of environmental variables, which do not necessarily match the environmental conditions that impact on a plant.

Several studies have revealed that the distribution of species in a tropical rain forest is not random, but correlates with different environmental variables. The occurrence of certain tree and palm species, for example, correlates with the topography and edaphic factors (Clark et al. 1998, Clark et al. 1999; Duque et al. 2002, Miyamoto et al. 2003, Phillips et al. 2003, Svenning 1999, Valencia et al. 2004). Furthermore it could be shown that herbaceous plants, due to their smaller size, are better indicators for abiotic differences on small spatial scales than trees (Poulsen 1996, Tuomisto et al. 2003a). For example, the distribution of undergrowth plants, as compared with the distribution of canopy trees, shows a stronger correlation with edaphic factors (Duque et al. 2002). In addition to these edaphic factors, Poulsen & Balslev (1991) and Costa (2004) verified the topography as a factor that influences the species composition of the herbaceous layer. This could also be shown in the group of ferns (Poulsen 1996; Poulsen & Tuomisto 1996), where the topography was interpreted as a measure for different soil and moisture conditions. Other studies have also shown a strong dependence of fern distribution on soil moisture (Karst et al. 2005) and air humidity or rainfall (Kessler 2001b). The occurrence of ferns in general shows a stronger correlation with topography, slope and edaphic factors than the distribution of other herbaceous species (Costa et al. 2005).

Within the BMBF funded project BLUMEN (Biodiversity and integrated land use management for economic and natural system stability in the Mata Atlântica of Rio de Janeiro) we studied the floristic differentiation of Pteridophyta along abiotic gradients in 21 sample sites. The aims of this investigation were (I) the analysis of the abundance structure of all occurring species of Pteridophyta; (II) their classification based on floristic similarity and (III) the analysis of the dependency of the floristic variability on topographic and other abiotic factors.

In this publication we present the characteristics of three different floristic groups of the flora of Pteridophyta. These groups have been detected using Cluster Analysis, Two Way Indicator Species Analysis and Correspondence Analysis

(Engelmann 2005). The analysis of the abundance structure of all occurring fern species was published yet (Engelmann et al. 2007).

Material and Methods

The investigation was carried out in a montane rain forest in the eastern part of the Serra dos Órgãos National Park (entrance Teresópolis). The study area was localized between 22°27’50’’- 22°26’53’’ S and 43°00’48’’- 42°59’17’’ W and covered an area of approximate 500 ha. The largest part of the study area is covered by Ombrophilous Dense Montane Forest (port.: Floresta Ombrófila Densa Montana, Velloso et al. 1991), whilst the highest parts are characterized as Ombrophilous Dense High-Montane Forest (port.: Floresta Ombrófila Densa Alta-Montana). For general information about geology, soils, climate and vegetation of the study area see for example Cronemberger & Viveiros de Castro (2007), Rizzini (1954, 1997), Engelmann (2005).

In this study area, the flora of the Pteridophyta was investigated along an altitudinal gradient between 1.100 m and 1.600 m. Whilst collection of ferns were carried out in the whole area, detailed studies on the abundance and diversity structure of the pteridophyte community were performed in 21 sample sites (400 m² each). These study sites were established following a random stratified sampling design (stratified regarding altitude). Within the sample sites all terrestrial fern individuals as well as all pteridophytic trunk epiphytes (individuals growing up to a height of two meters above ground) were registered, except for Hymenophyllaceae. All inventoried species were collected and herborized. The collected plants were subsequently identified as far as possible using taxonomic literature, consulting specialists and by comparisons with specimens of the herbarium of the Botanical Garden Rio de Janeiro. Voucher specimens were deposited in the herbaria of the Botanical Garden Rio de Janeiro (RB) and of the University of Leipzig (LZ). Furthermore, topographic (e.g. altitude, inclination, slope aspect) and other abiotic variables (light conditions, soil characteristics) were recorded for each sample site.

A floristic classification of the samples was performed based on their floristic similarity using Cluster analysis, Two Way Indicator Species Analysis and Correspondence Analysis. In order to analyze the different resulting floristic groups, a descriptive characterisation and differentiation of the formed groups of the fern flora was carried out. Only the fern species that occur with at least 3 individuals were included in the analysis. For each of the formed groups of the Pteridophyta-flora, an Important Value (IV) for each species was calculated. This equates to the sum of the Relative Abundance and the Relative Frequency of the species in that particular group.

In addition to the descriptive characterisation of the formed fern flora groups, an Indicator Species Analysis was performed. For each single group, the relative abundances and the relative frequencies of the found species were determined (Dufrene & Legendre 1997). In this way, an indicator value (in. va.) could be determined for each species in each group. A species acts as an indicator species for that group, in which it has the highest indicator value. The significance of the indicator value for a certain species was checked using the Monte Carlo permutation test with 1,000 iterations (McCune & Mefford 1999). By looking at the abundance values and the frequency values (steadiness) in and between groups, the ecological requirements regarding indicator species were met: An indicator species should constantly occur in one group and be limited with its distribution to this specific group (Leyer & Wesche 2008).

Results and Discussion

Overall, in this investigation 116 fern species could be identified within the study area (Engelmann et al. 2007). 74 of this species were found inside the 21 study sites. But as four of those species belong to the Hymenophyllaceae only 70 species were included in the further analyses. Based of the different abundance distribution of the fern species it was possible to assign 19 of the 21 study sites to three different floristic groups using various statistical methods (cluster analysis, Two Way Indicator Species Analysis, Correspondence Analysis) (Engelmann 2005, Engelmann et al. 2006). Each of these three floristic groups can clearly be characterized by one dominating fern species (Importance Value (IV) greater than 60%, figure 1) and one ore more indicator species (table 2 and table 3).

Out of the three different floristic groups of the Pteridophyta three different fern habitats could be identified within the study area. In the following, these habitats are characterized in detail regarding their pteridophytic flora (dominant species, indicator species etc.) and environmental variables.

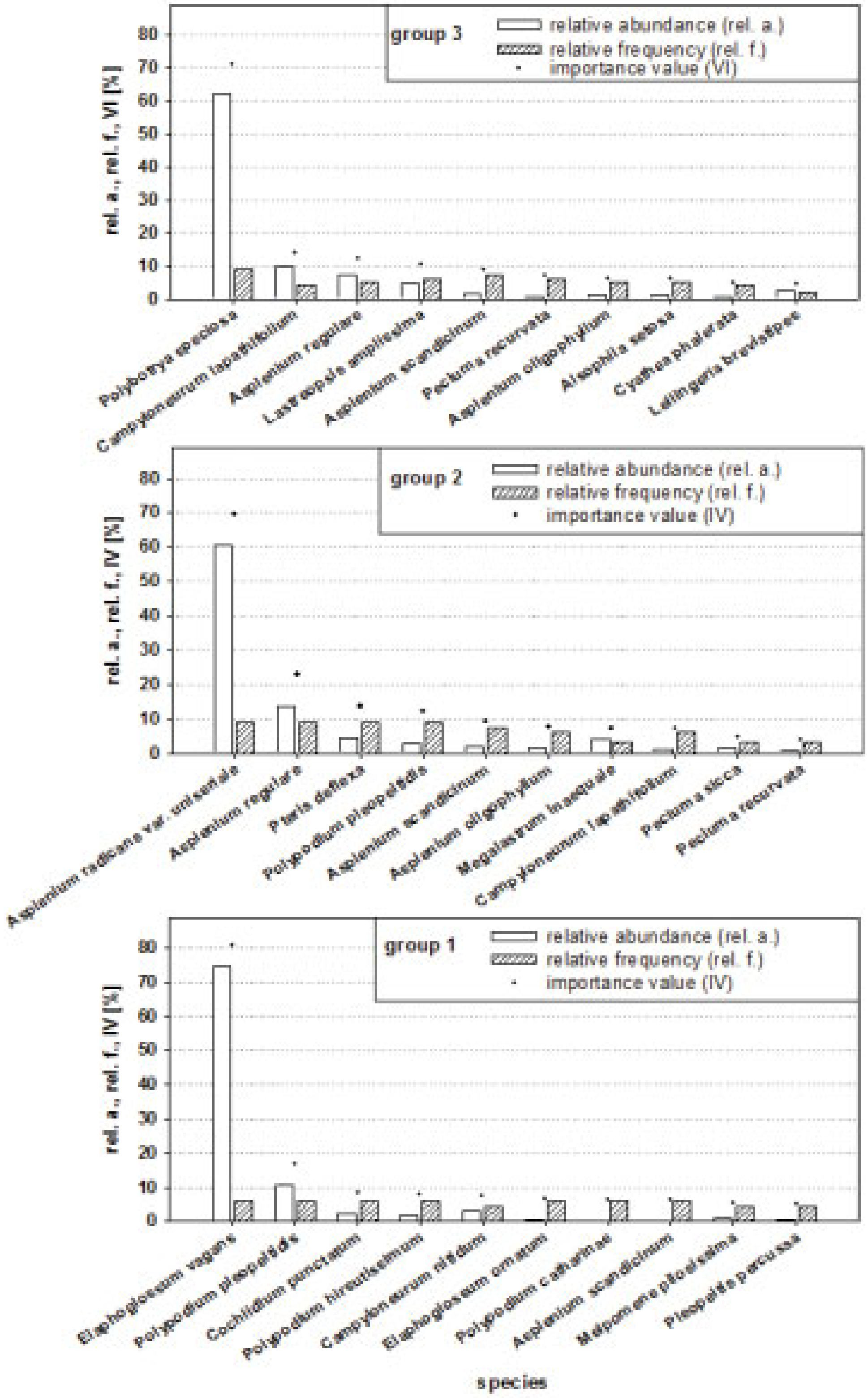

Figure 1: Relative abundance, relative frequency and importance value (IV) for the 10 species with the highest importance values in each group. The importance value equals the sum of the relative abundance and relative frequency. Group 1 includes four, Group 2 includes five and group 3 includes nine sample sites.

Group 1 – Elaphoglossum vagans

Group 1, represented by four different sample sites, is dominated by *Elaphoglossum vagans* with an Importance Value of IV = 80.5% (figure 3).

The *Elaphoglossum vagans – group* is defined by a total of 16 fern species (51.6% of all 31 species found in this group), which were detected exclusively in the plots of this group (figure 2). Since over the half of all ferns of this group are limited to this group only, the floristic delimitation of this group is stronger than in the other groups. Consequently, the number of species shared with the other groups is very low as well (figure 2).

Apart from floristic differences, the abiotic parameters differed between this and the other groups, too (Engelmann 2005). With an average height of 1.586 m a.s.l. the study sites belonging to this group are located significantly higher than those of other groups. The altitude a.s.l. influences several environmental parameters that change along the elevational gradient and affects the growth condition for plants. These include primarily temperature, potential evapotranspiration, length of the growing season, humidity, potential nutrient availability, ultraviolet radiation, and precipitation (Cavelier 1996; Bhattarai et al. 2004). It is well-known and has been observed in numerous studies that these environmental parameters influence the diversity, the abundance and the species composition of ferns along an elevational gradient (Kessler 2000a, Kessler 2001a, Kessler 2001b; Hemp 2002, Bhattarai et al. 2004).

The forest vegetation of the four study sites is significantly different to those of the remaining plots. At least two study sites are localized in the high-montane forest (port.: Floresta Ombrófila Densa Alta-Montana, Velloso et al. 1991). This forest is particularly characterized by lower tree heights of 5-10 m. Furthermore, many trees have xeromorphic properties, such as thin branches and trunks, a rough bark and often small, leathery and thick leaves. There is also an abundant occurrence of bromeliads and lichens in these plots. The other two sites are localized in a transition zone between montane and high-montane forest. Although the vegetation in this zone is physiognomically somewhat more similar to the montane forest, floristically it is much stronger related to high-montane forest. This was proved not only for the fern flora but also for the tree and the woody understorey vegetation (Engelmann 2005, Engelmann et al. 2006, Seele 2005, Seele et al. 2006, Wesenberg unpublished data).

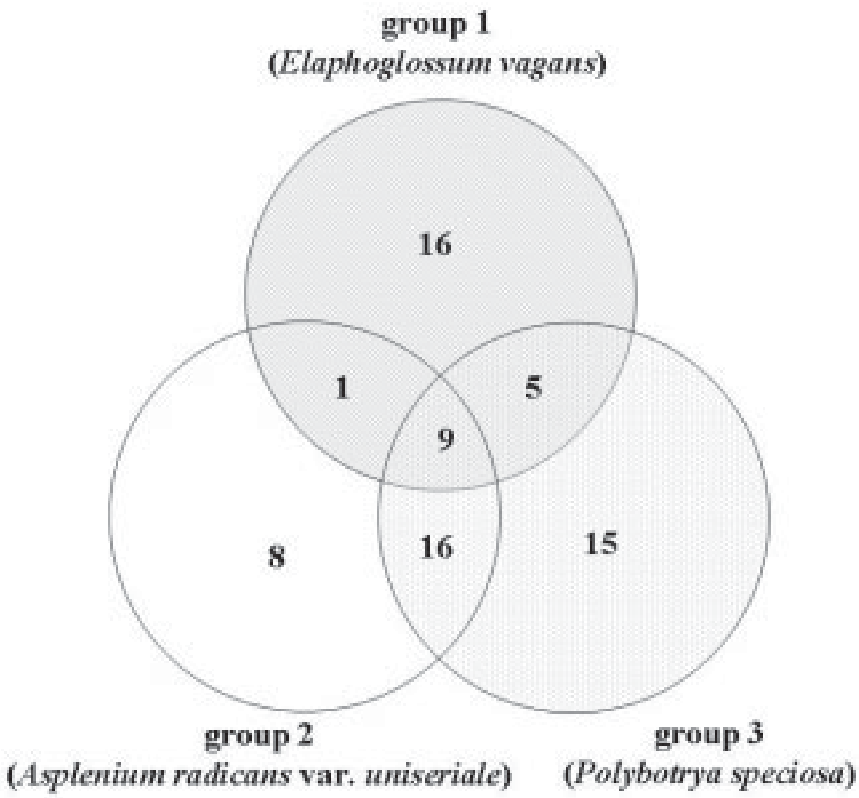

Figure 2: Schematic display of the distribution of the 70 ferns within the three groups. A total of 31 species occur in group 1, 34 species in group 2 and 45 species in group 3. The overlapping areas of the circles indicate the numbers of species, which can be found in two or all three groups. The numbers outside the overlapping areas show the numbers of species that occur in the respective groups only. The mentioned species are the main indicator species for the respective groups (table 2).

Group 2 – Asplenium radicans var. uniseriale

The dominant fern species in this group, represented by six different study sites, is *Asplenium radicans* var. *uniseriale* with an Importance Value of VI = 69.7% (figure 1). This group is floristically defined by only eight fern species (23.5% of all 34 species in this group) that solely occur in the plots of this group. The plots of the *Asplenium radicans* var. *uniseriale - group* are abiotically characterized by a concave horizontal curvature. The study areas of this group, as compared to the other groups, are located in depressions or small valleys.

Similar to the elevational gradient, the curvature of a study area influences several factors that in turn affect the growth of ferns. Habitats in depressions are clearly wetter than on hilltops (Poulsen 1996) and the thickness of the soil cover is dependent on the topography as well. It could be observed that the soil cover in shallow depressions is in part very voluminous or it is rinsed off the steep side slopes of gullies and accumulates in the bed of the valley. However, the soil cover, just as the light regime in a study area, is subject to strong temporal and often random changes (Poulsen 1996).

As could be observed elsewhere, the most dominant fern species in this group, *Asplenium radicans* var. *uniseriale*, is to be found especially at steep, rinsed off edges of gullies. The habitat advantage of this species could be explained by their capability to reproduce asexually. Especially in the completely or nearly humus free habitats, which are always rinsed off during heavy rain events, the vegetative establishment of seedlings is more successful than a generative propagation. Poulsen (1996) found fern species that are limited in their distribution to steep slope sections without humus or surface litter.

Group 3 – Polybotrya speciosa

With a total of nine study areas, the majority of the plots belong to this group. The dominant fern species is *Polybotrya speciosa* with an Importance Value of VI = 71.0% (figure 1). Overall, this group contains 45 different species of ferns and therefore it is the species richest group. Fifteen species (33.3% of all species in the group) are limited to this group only (figure 2). Due to many common species, there is a strong floristic similarity between this group and the *Asplenium radicans* var. *uniseriale – group*. After all, 16 fern species can be found in both groups. In contrast, only five fern species occur in both this and the *Elaphoglossum vagans - group*. Abiotically, the plots of the *Polybotrya speciosa – group* differ from the other groups only in the low altitude a.s.l.

Widespread species

There are nine fern species that occur in the entire study area and by association in all three groups (figure 2, 3). In the study area and also between the different groups, significant differences in the abiotic environmental parameters have been identified. This being the case, it can be assumed that the nine fern species occurring everywhere possess large ecological amplitudes. In this context it must be stated out that these nine species occurred exclusively epiphytically. Also Kessler (2001b) noted that the ecological distribution of epiphytic species is larger than that of terrestrial species. The reason for the considerable dispersal of epiphytic species can be found in their independency from various environmental variables, such as edaphic factors.

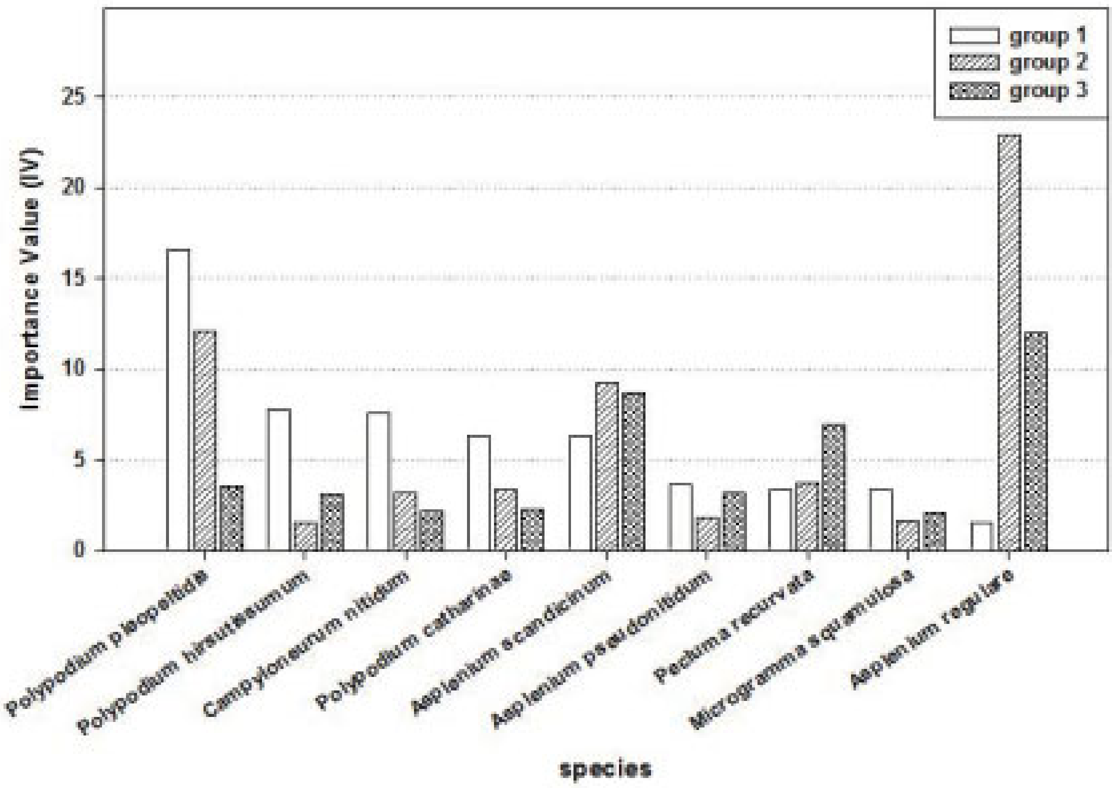

Figure 3: Importance values for each group of fern flora for the nine species that occur in all three groups. The importance value is the sum of the relative frequency and relative abundance.

Indicator species

By use of an Indicator Species Analysis, indicator species could be identified for all three main groups of fern flora (figure 2, table 1). These indicator species are characterized by a significant indicator value (table 1). Species such as *Elaphoglossum vagans*, *Asplenium radicans* var. *uniseriale* and *Elaphoglossum ornatum* with an indicator value at 100.0% occur only in the group that they indicate and are represented in all plots of this group.

Table 1: Results of the indicator species analysis for the three groups of the fern flora based on the 53 species that occur with at least 3 individuals in the plots. All significant ($p<0.05$) indicator species are written in bold.

** The individuals of this two species could not be clearly separated during the field work due to their morphological similarity.

species	maximum-group	real indicator value	theoretical indicator value	sd	p
Alsophila setosa	3	36.7	30.1	12.2	0.210
Asplenium harpeodes	3	11.1	15.8	5.4	1.000
Asplenium oligophyllum	2	31.7	36.9	14.0	0.541
Asplenium pseudonitidum	1	45.2	33.5	14.3	0.173
Asplenium radicans* var. *uniseriale	**2**	**100.0**	**28.4**	**12.8**	**0.001**
Asplenium radicans var. *cirrhatum*	3	11.1	15.7	5.2	1.000
Asplenium regulare / Asplenium raddianum **	**2**	**60.1**	**37.8**	**10.8**	**0.047**
Asplenium scandicinum	3	31.1	40.9	7.5	0.933
Arachniodes denticulata	1	25.0	16.3	5.4	0.237
Blechnum binervatum	3	11.1	15.7	5.2	1.000
Campyloneurum lapathifolium	3	41.1	38.5	14.7	0.381
Campyloneurum nitidum	**1**	**73.8**	**38.9**	**15.3**	**0.018**
Cochlidium punctatum	**1**	**98.9**	**31.6**	**13.7**	**0.001**
Ctenitis distans	2	16.7	15.7	5.2	0.533
cf. Ctenitis sp.	2	16.7	15.7	5.4	0.513
Cyathea dichromatolepis	3	20.6	22.4	11.3	0.508
Cyathea phahlerata	3	42.1	27.5	13.1	0.136
Diplazium ambiguum	2	10.0	18.4	9.0	1.000
Diplazium cristatum	2	16.7	15.7	5.2	0.533
Diplazium leptocarpon	3	11.1	15.7	5.2	1.000
Doryopeteris sagittifolia	3	11.1	15.7	5.3	1.000

species	maximum-group	real indicator value	theoretical indicator value	sd	p
Elaphoglossum edwallii	1	25,0	15,6	5,4	0,205
Elaphoglossum gayanum	**1**	**50.0**	**18.9**	**9.6**	**0.039**
Elaphoglossum macahense	1	25.0	16.3	5.4	0.237
Elaphoglossum ornotum	**1**	**100.0**	**24.7**	**11.8**	**0.002**
Elaphoglossum vagans	**1**	**100.0**	**26.7**	**12.4**	**0.002**
Elaphoglossum villosum	3	11.1	15.7	5.2	1.000
Huperzia biformis	**1**	**50.0**	**19.2**	**9.6**	**0.039**
Lastreopsis amplissima	3	66.1	37.8	15.1	0.070
Lellingeria apiculata	1	24.8	20.2	8.8	0.225
Lellingeria brevistipes	3	22.2	18.3	9.3	0.428
Lycopodium thyoides	**1**	**50.0**	**20.3**	**9.0**	**0.039**
Marattia laevis	3	18.1	22.6	11.0	0.648
Megalastrum inaequale	2	26.7	23.9	12.1	0.324
Melpomene pilosissima	**1**	**75.0**	**25.1**	**10.8**	**0.003**
Microgramma sqamulosa	1	46.0	27.6	13.1	0.099
Pecluma pectinatiformis	**1**	**50.9**	**25.8**	**12.0**	**0.040**
Pecluma recurvata	1	27.5	37.7	13.6	0.758
Pecluma sicca	2	27.0	27.7	12.8	0.366
Pleopeltis percussa	**1**	**75.0**	**21.7**	**11.1**	**0.007**
Polybotrya speciosa	**3**	**97.8**	**36.1**	**12.9**	**0.001**
Polypodium catharinae	**1**	**71.3**	**31.5**	**12.2**	**0.009**
Polypodium hirsutissimum	**1**	**98.6**	**36.1**	**14.5**	**0.003**
Polypodium longipetiolatum	1	42.9	20.4	11.5	0.066
Polypodium pleopeltitis	**1**	**95.1**	**66.2**	**14.6**	**0.044**
Pteris angustata	3	11.1	15.9	5.4	1.000

species	maximum-group	real indicator value	theoretical indicator value	sd	p
Pteris deflexa	**2**	**97.5**	**33.4**	**12.0**	**0.001**
Pteris splendens	3	14.8	21.9	11.4	0.739
Radiovittaria gardneriana	3	11.1	15.7	5.2	1.000
Rumohra adiantiformis	**1**	**50.0**	**18.5**	**9.8**	**0.039**
Terpsichore achilleifolia	3	22.2	18.6	9.2	0.496
Terpsichore gradate	1	25.0	15.7	5.5	0.220
Vittaria lineata	2	16.7	15.8	5.3	0.532

For group 1, a total of 13 indicator species could be determined (table 2). The four highly significant indicator species (p <0.01) of group 1 are *Elaphoglossum vagans* (IV = 100.0%), *Elaphoglossum ornatum* (in. va. = 100.0%), *Cochlidium punctatum* (in. va. = 98.9%), and *Polypodium hirsutissimum* (in. va. = 98.8%). For group 2, highly significant indicator species (p <0.01) are *Asplenium radicans* var. *uniseriale* (in. va. = 100.0%) and *Pteris deflexa* (in. va. = 97.5%). The only indicator species for group 3 is *Polybotrya speciosa* (in. va. = 97.8%, p <0.01).

Apart from the characterization of the three groups of fern flora through the dominant fern species, each group can be described with the help of indicator species. Also in studies on the fern flora in the Amazonian lowland rain forest such indicator species were used for the characterization of different types of fern flora (Costa 2004; Salovaara et al. 2004). In the investigation of Salovaara et al. (2004) all ferns with an indicator value greater than 30% were defined as indicator species. By contrast, the indicator species found in the present study show much higher indicator values (table 2). When considering only the species with a most significant indicator value (p <0.001), each group can be characterized by at least one fern species with an indicator value greater than 95%. Since the main indicator species of each group is the most dominant species for each group at the same time (figure 1 and table 2), an easy detection of a particular type of fern flora is possible without time consuming investigations.

*Table 2: Summary of the Indicator Species Analysis for the three groups of the fern flora. The species are arranged according to group affiliation and indicator value (in. va.). For each indicator value the significance value (p) is given (*** - p <0.001, ** - p <0.01, * - p <0.05).*

group 1		**group 2**		**group 3**	
species	**in. va. (%)**	**species**	**in. va. (%)**	**species**	**in. va. (%)**
Elaphoglossum vagans **	100.0	*Asplenium radicans* var. *uniseriale* ***	100.0	*Polybotrya speciosa* ***	97,8
Elaphoglossum ornatum **	100.0	*Pteris deflexa* ***	97.5		
Cochlidium punctatum ***	98.9	*Asplenium regulare* *	60.1		
Polypodium hirsutissimum **	98.6				
Polypodium pleopeltitis *	95.1				
Melpomene pilosissima **	75.0				
Campyloneurum nitidum *	73.8				
Polypodium catharinae **	71.3				
Pecluma pectinatiformis *	50.9				
Rumohra adiantiformis *	50.0				
Lycopodium thyoides *	50.0				
Huperzia biformis *	50.0				
Elaphoglossum gayanum *	50.0				

Conclusion and Outlook

The flora of the Pteridophyta in the study area shows a good floristic differentiation along abiotic gradients. Because of the observed habitat specialization and the broad ecological and geographical distribution, ferns work very well as indicator species. Therefore should be paid more attention to ferns in the future, because as biotic indicators they can provide a useful tool for the management of the National Park.

The special analyses of the dependence of the fern flora on abiotic factors and their correlation with data about woody species in the same study sites will be published elsewhere. Further research in the study area with a focus on a broader altitudinal gradient is in preparation and will contribute to a greater knowledge and understanding of the relevance of ferns for tropical montane rain forests.

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Chapter 17

MOBILE LINKS IN FRAGMENTED ECOSYSTEM: SEED AND BIRDS DISPERSAL APPROACH TOWARDS ATLANTIC FOREST RESTORATION AND CONSERVATION

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Abstract: Seed and birds were important mobile links to maintenance of connectivity because they were related to long distance plant dispersal. At the same time, seed input is a tool that can help to monitor forest restoration success and resilience. A quantitative approach was applied to compare seed rain, dispersal distances and bird communities in a pristine area and four fragments in an agricultural landscape. Dispersal syndromes were efficient indicators of degradation, and zoochory less than 60% indicated a high level of disturbance. Artificial perches were distance and source limited and distances less or higher than 100-200 m were no effective to promote zoochoric seed rain input and seedling establishment. Natural perches more than artificial ones were indicated in a "step-stone" model to restore fragments connectivity.

Introduction

Forest fragmentation is thought to be a major cause of biodiversity loss on the planet (Wilson 1994), and one of the most huge changes caused by humans in the environment. Changes in microclimate, structure and dynamic processes of the forest affect the whole community and the maintenance of populations in fragments. The distance among fragments, level of isolation, size and shape, surrounding matrix and the edge effect influence the biodiversity and their long-term survival (MMA 2003).

The landscape elements in the surrounded matrix of fragments determine the possibility of species dispersion and migration, and the connectivity can mitigate the effects of habitat losses by increasing the suitable habitat to those species (Holl 1998). For plant species, the connectivity restoration depends on the permeability of surrounded matrix and the capacity of maintain gene flux by pollen and seed dispersal in a fragmented landscape. Nowadays, seed dispersal has become a bottleneck for vegetation development, and restoration of connectivity is crucial, particularly for species having short-lived seed banks (Martine *et al*. 2004).

Seed rain is an important indicator of ecosystem resilience, being related to the capacity of recruitment of plant populations, which is directly influenced by the annual variation of fruit and seeds (Penhalber & Mantovani 1997). Fragmentation can alter the seed production through changes in light, soil moisture and nutrients. Biological changes caused by fragmentation also affects plant-animal interactions (Reis et al. 1999) with regard to pollination or increased inbreeding by decreasing the gene flow (Penhalber & Mantovani 1997), which subsequently can decrease the seed establishment, leading to loss of vigor in the next generations (Nascimento et al. 1999). After seed production, the plant-animal interactions are still working on reproductive cycle of plant populations through dispersal of seeds; therefore dynamics of tree populations can be studied through seed rain and dispersion.

The seed dispersal increases the reproductive success of plant species due to escape from vicinity of the parent plant (Murray 1986) where unfavorable conditions including high concentration of natural enemies such as parasites and seed predators, and competition with parental adults, reduce seedling establishment (Willson 1992). At the same time, seed dispersal can restrict the colonization of new areas, especially in fragmented landscapes where few animals are able to career out seeds from remaining forest (McClanahan & Wolfe 1993; Holl 1998 2000), caused by degraded surrounding areas that do not provide food, shelters or places to rest (Cubiña & Aide 2001).

Evaluation and monitoring seed dispersal in forest fragments are crucial to understand the dynamics of biodiversity maintenance in tropical forests, as demonstrated in many studies (Nascimento et al. 1999, Nunes et al. 2003, Gondim 2005, Müller 2005). The proportion of dispersal syndromes found in a particular area may indicate different stages of conservation. In tropical rainforest, for example, it is common that about two thirds of the canopy tree species produce fleshy fruits attractive to wildlife (Wheelwright 1988). Larger proportions of anemochory in such forest indicate environmental disturbance, due to changes in the community of dispersers, seed desiccation and increased input of wind (Penhalber and Mantovani 1997) caused by the edge effect on forest succession after disturbance (Uhl et al. 1991, Melo 1997, Wunderle Junior 1997, Da Silva et al. 1996, Souza 2000, Andrade & Andrade 2000, Sorreano 2002, Siqueira 2002, Batista & Souza 2004, Vieira 2004).

Provided that the probability of long-distance seed dispersal depends on characteristics of the landscape and structure of vegetation (Ozinga et al. 2004), techniques aimed to accelerate regeneration process may be based on increasing seed rain in the system. The attraction of dispersal agents, especially birds, by enhancing the structural complexity of vegetation with the use of artificial perches is one of these techniques that can accelerate the plant succession due to the increase in recruitment from seeds. Thus, studies focused on conservation and restoration of the Atlantic Forest might be designed aiming to answer questions about: (1) the role of seed dispersal as an indicator of environmental conditions, (2) how seed dispersal is influenced by structural complexity of vegetation and (3) whether there are effects of source distance on seed dispersal.

The role of seed dispersal as an indicator of environ-menttal conditions

Seed dispersal syndrome is a trait set that indicate how plants disperse their seeds (Pijl 1972) therefore, contribute to understand how gene flow is influenced by seed dispersion in natural population (Piña-Rodrigues *et al.* 2007). While bird dispersed seeds have the greatest potential for gene flow, in contrast dispersal by gravity reflects a short distance gene flow (Loveless & Hamrick 1986). Further, deforestation and disturbances also affect seed dispersion (Alvarez-Builla & Garcia-Barrios 1991) as a consequence of changes in natural conditions that improve the establishment of light demander pioneer and gap species and so, increasing at the same time the proportion of abiotic dispersion. As light is an important factor to control seedling growth in tropical forest (Lee *et al*. 1997), specially when associated to increasing of soil temperature (Drake 1998), gap colonizers and pioneer occupy the space of late successional species (Antônio & Meyerson 2000), affecting the relationship between biotic and abiotic syndromes.

Nowadays, successional studies attribute a significant correlation among the proportion of functional or ecological groups and guilds, species diversity and successional stages that depends on seed rain diversity (Jordano & Schupp 2000, Dungan *et al*. 2001, Clark & Poulsen 2001). One important aspect of these studies is the forest-edge relationship with a trend to reduce species dominance from inside to outside (CUBINA-AIDE 2001), with few species in the border, many of them dispersed by abiotic agents (Benites-Malvido 1998).

Also, dispersion syndromes reflect community changes. Canopy and sub-canopy species were different in relation to seed size and disperser agents (Schupp *et al.* 1989). Zoochory is dominant in canopy late successional species and small sized anemochoric seeds were more related to gap colonizers species and pioneers (Fenner 1985, Janzen 1988). Besides, seasonal environments (Barbosa *et al*. 2002), open areas, some life forms as lianas (Marques 2001) and, canopy emergent were frequently wind dispersed (Mantovani 1993) and are distributed in many ecosystems (Griz *et al*. 2002).

There are few studies in the area of Atlantic Rain Forest analyzing dispersal syndromes as a factor limiting natural regeneration after disturbance (Penhalber & Mantovani 1997, Souza 2002). In semideciduous tropical forests in Brazil, there was a dominance of zoochory in altitudinal forests (69%) and mesophyll (70%) while anemochory (26% and 22.5%) or autochory (5% and 7.5 %) were fewer representatives (Morellato & Leitão-Filho 1992). Further, in both vegetation type's anemochory is frequent in the emerging strata (60% of species) and between 32% and 37% (for altitude forests and mesophyll respectively) were zoochory. Below, in the canopy, the proportion of anemochory decreased (22% and 30%), increasing the proportion of zoochory (± 70%), while understory species 90% were zoochoric, 10% of autochory and there was an absence of wind dispersed species (Morellato & Leitão-Filho 1992). This increased distribution of animal dispersed species in the canopy and understory also was observed in semideciduous forests in Minas Gerais (Nunes et al. 2003). In the emergent layer, dispersal is facilitated by wind and the activity of animal dispersers was concentrated in the understory (Morellato & Leitão-Filho 1992, Nunes et al. 2003).

Wind dispersal is seen as a specialization, since many tropical families have predominantly animal dispersal and few species were adapted to be dispersed by wind (Snow 1970). An increase in the proportion of wind dispersed species in tropical fragmented landscapes shows environmental disturbance, due to changes that reduce animal dispersers' community and increase the input of wind caused by edges and gaps. Actually, in mature forest in the Amazon, UHL et al. (1991) observed only 11% of wind dispersed species, while in contrast, fragmented forests of southeastern Brazil presented a high percentage of anemochory (33%), which indicates dispersion by wind through the discontinuous canopy (Penhalber & Mantovani 1997). Also, in semideciduous forest, among the shade tolerant climax species, animal dispersal was significantly more frequent than wind dispersal which was frequent in light demanding pioneers (Nunes et al. 2003). So, diagnosis of the predominance of pioneer species and wind dispersal syndrome in disturbed environments suggests that the characterization of ecological groups and dispersal guilds in fragmented areas may be a very useful tool as indicator of landscape disturbance.

Searching for bioindicators: seed rain in a Mountain Atlantic Forest

Along three years, from 2002 until 2005 we studied phenology, seed rain and litterfall in five communities in a Montane Atlantic Forest. Our main objective was to study fragmentation in a landscape where historical use was known and there was a large research group working together, like social and economic researches, agronomist, biologist and others. Despite in Atlantic Forest there is a large literature about forest fragmentation however, as reported Vogt *et al*. (2009), in practice studies aiming identification of functional connectors were already an open issue. Moreover, few of them were concerned about connectivity and indicators to monitor forest recover and fragmentation. And, so our purpose was that, in a quantitative point of view, to generate data and available information in order to evaluate seed rain and birds as mobile links toward restoration of Atlantic Forest connectivity.

Site selection and methods- In a mountain ombrophilous Atlantic Forest the effect of fragmentation in a pristine and in a fragmented area was studied using seed rain as a biological indicator. The pristine area was the National Park of Serra dos Órgãos (PARNASO), a tropical mountain wet forest in Rio de Janeiro, Brazil (22º55´, 22º32´S and 42º 59´, 43º07´W) at 1250-1500 m (RADAMBRASIL 1993). Canopy is over 20±15 m with emergent trees up 35 m. The floristic composition includes 58 species from the richness families as Myrtaceae (20 species), Lauraceae (13 species), Melastomataceae (8), Leguminosae (6), Rubiaceae (6) and Euphorbiaceae (5). Arecaceae presented the highest relative abundance and it is represented almostly by *Euterpe edulis* (Matos *et al.* 2007). The high richness of Myrtaceae, Lauraceae and Melastomataceae indicate a late successional ecosystem in Atlantic Forest (Rizzini 1954, Lima & Guedes-Bruni 1997).

The studies were also conducted on four fragments located in the same watershed (22º25'-22°32'S and 42º59'- 43°07'W) and far-away 15-20 km in a straight line from PARNASO. Before deforestation, original vegetation type was ombrophilous montane Atlantic Forest with abundance of *Melanoxylon brauna*, *Dalbergia nigra* and *Paratecoma peroba* (ITT 2006). After intense agricultural use along more than hundred years, the remnants were classified according parameters of "Decreto 750" as a montane secondary forest (RADAMBRASIL 1983, ITT 2006) with presence of colonizers species such as *Cecropia glaziovi* Snethl, *Croton floribundus* Spreng, *Piptadenia gonoacantha* J.F. Macbr, *Solanum myosotis* Dun and *Vernonia* sp.

The four studied fragments were classified as isolated (> 1500 m from another remnant) and connected (≤ 150 m of distance from another fragment) and as small (< 10 ha) and large (> 20 ha). The larger were an isolated 64 ha fragment (F1) and a connected 23.2 ha (F2), while the smaller were a connected 9 ha (F3), and an isolated area with 3.2 ha (F4).

In order to study the seed rain, in the PARNASO, a total of 20 permanent plot of 20 x 25 m (1 ha) were established with a conic fabric seed trap (0.25 m²) placed in the center at 1.4 m above ground level. Besides, in each fragments a plot of 100 x 170 m (1.7 ha) was established in the same slope of the neighboring remnant. A line with four seed traps was installed in four distances from fragment edge, at 10 m, 35m, 65 m and 165m. Monthly, along one year (2004 to 2005) all seed rain was collected, weighted and classified in fruits, seeds and flowers. A general classification of life form (tree, shrub, herbaceous, liana and weed) and dispersion syndrome were used based on literature information (Van Der Pijl 1982, Mantovani & Martins 1988), propagule size and presence or absence of structures to assist dispersal. As zoochoric syndrome were included dispersion units with aril, fresh fruits, bright full colors and others attractive structures; as anemochoric were classified the seeds with presence of wings, hairs and planation structures, and finally as autochoric were included the explosive opening units, hard dehiscent fruits and others types not included in the above categories. Indeterminate propagule was just classified as "morphotypes" and seed rain was expressed as the number of seeds obtained in a time (n° seeds.month^{-1}) or total seed in an area unit (n° seeds.m^{-2}).

Results- In the PARNASO, the seed rain comprised 28,319 propagules.year^{-1} with 358± 1,512 seeds.species^{-1}.month^{-1} and mean of 2,359 seeds.month^{-1} (472 seeds.m^{-2}). This total was quite similar to Marques *et al*. (2003) in another area of PARNASO, with 29,100 propagules.ha^{-1} and 2,429 seeds.m^{-2}, however it was higher than seed rain observed in the fragmented area.

In the fragments, about 18,129 seeds or 116.3 seeds.m^{-2} were sampled, with only 57.3 seeds.m^{-2} in the smallest fragment and 220.6 seeds.m^{-2} in the largest. Others studies in secondary forest Atlantic in Brazil also obtained a higher seed rain than in the studied fragments, with 1,804.2 seeds.m^{-2} (Penhalber & Mantovani (1997), 591.3 seeds.m^{-2} (Siqueira 2002), and in Mexico with 710 seeds.m^{-2} (Guevara & Laborte 1993).

In the pristine area, about 93 species were recorded, and 7 morphotypes (5,9% of the total propagules) were identified only by families, 13 (35,1%) by genus and 73 (59%) at species level while MARQUES *et al*. (2003) recorded just 29 families and 60 species in the seed rain in a pristine area of PARNASO. In the total identified species (62%) found in the seed rain they belong to 21 families, 21 genus and 23 species. On the other hand, in the fragments were recorded 92 species from 25 families, however with dominance of colonizers species from Poaceae (33.7% of total propagules) and Asteraceae (21.4% of total propagules). Although these families were also found in the pristine area of PARNASO, they represent only 5.6% (Asteraceae) and 1.7% (Poaceae) of seed rain. Families with high density in PARNASO were Arecaceae (39.7% of total propagules), Melastomataceae (3.5%), Sapotaceae (3.1%), Myrtaceae (2.0%) and Malpighiaceae (1,9%) and Poaceae (1.7%), that together with Asteraceae and Poaceae represented 88.6% of seed rain. Families and seed densities in the PARNASO were quite similar to Marques *et al*. (2003) that pointed out Asteraceae, Malpighiaceae, Melastomataceae and Myrtaceae as the most representative families in the seed rain.

Species such as *Euterpe edulis*- Arecaceae (39.7%; n= 2,370 seeds.m^{-2}), *Miconia budlejoides* Triana - Melastomataceae (34.1%; n= 1,556 seeds.m^{-2}), *Micropolis crassipedicellatum*- Sapotaceae (3,1%.n= 180 seeds.m^{-2}), *Guadua tagoara* - Gramineae (1.7%; n= 86 seeds.m^{-2}), *Vochysia saldanhana*- Vochysiaceae (1.4%; n= 79 seeds.m^{-2}), and *Tetrapterys* sp.- Malpighiaceae (1.7%; n= 79 seeds.m^{-2}) were the most abundant with 80.2% of seed rain in PARNASO. Although the dominant *E. edulis* is an endemic and climax canopy species of Atlantic Forest, then again *M. budlejoides* is a common pioneer treelet from sub-canopy and understory that is found in many gaps of tropical forest (Loiselle *et al*. 1996, França & Sthmann 2004). Regardless the observed abundance of the pioneer treelet *M. budlejoides,* in the pristine area, the most common species life form was tree (53.8%; n= 239.72 seeds.m^{-2}) followed by shrubs (23.1%; n= 151.58 seeds.m^{-2}). Then again, herbaceous (15.4%; n= 35.65 seeds.m^{-2}) and weeds (7.7%; n= 7.45 seeds.m^{-2}) were the life form that less contributed to seed rain. Herbaceous species are well represented in secondary tropical forest and soil seed bank as light demanding pioneers' species (Gómez-Pompa & Vázquez-Yanes 1981, Gómez-Pompa *et al.* 1991) and their presence did not represent a disturbed area.

However, in the fragmented area the most common species were pioneers such as *Olyra taquara* (33.7%; n= 381 seeds.m^{-2}), *Mikania sp.* (21.4%; n= 242.8 seeds.m^{-2}), *Cecropia sp.* (15.8%; n= 178.6 seeds.m^{-2}) and *Miconia sp.* (12.6%; n=

146 seeds.m^{-2}) and although tree species were more common, gap colonizers abundance in the seed rain indicate the dominance of this ecological group in the area and conditions favoring their reproduction, and probably establishment.

The majority of species in the seed rain of pristine area was animal dispersed (69.2%) and the remaining syndromes were anemochory (19.2%) and autochory (11.5%), similar to Marques *et al.* (2003). Zoochory was well represented by bird dispersed species such as *E. edulis*-Arecaeae (Pizo & Simão 2001), *M. budlejoides* (Fleming 1993), *M. paniculata* –Melastomataceae, *Didimopanax longipetiolatum*-Begoniaceae and Myrtaceae. Zoochory was dominant among tree species (85.7%; n= 237.2 seeds.m^2), shrubs (66.7%; n= 151.5 seeds.m^2) and also the weed species *Meristachys sp.* and *G. tagoara*, otherwise anemochory occurred in 75% (n= 35.2 seeds.m^2) of herbaceous species.

Another circumstance was observed in the fragmented area, where 60.3% (n= 633 seeds.m^2) of total seed rain were wind dispersed while 37.7% animal dispersed and 2.1% were dispersed by gravity. The dominance of anemochory is caused by the large quantity of seeds produced by *Olyra taquara* and *Mikania* sp. Although based on species distribution, zoochory still dominant however with only 51.9% of the species in the seed rain dispersed by animals, anemochory represented by 35.4% and autochory just by 12.7%.

Dispersion by animals is usually common in wet tropical forests and woody species (Fenner 1985, Santos 2005). Although the present knowledge in Atlantic Forest is limited to isolated studies, there appears to be a tendency towards zoochory in the ombrophilous forests with a large majority of fleshy fruits, and a tendency towards anemochory in the semideciduous forests with predominately dry fruits (Ferraz *et al.* 2004). Furthermore, studies in Atlantic Forest indicated a presence of zoochory higher than 60% in conserved areas and less than 50% in disturbed areas (Table 1), whereas others tropical forest present about 70% of zoochory (Howe & Smallwood 1982).

Seed rain can be used to monitor restoration in degraded areas and the regeneration of tropical forests (Guevara & Gomez-Pompa 1972), and also effects of fragmentation since it is capable to be sensible to changes in ecological and reproductive processes. Sexual reproduction is considerably negatively affected by habitat fragmentation, regardless of the different ecological and life history traits and the different types of habitat (Aguilar et al. 2006). As a consequence, seed production decreases with the loss of pollinators and seed dispersers in the fragmented areas (Howe 1984, Cosson et al. 1999, Aizen & Feinsinger 1994) increasing the effects of habitat disturbance (Laurence *et al*. 1998). Gaps, discontinuous canopy and edge effects favor establishment of light demanding pioneer species in fragments increasing their density (Benito-Martinez 1998); simultaneously, anemochoric species were time consumer to arrive at the forest floor, thus they have a higher probability of being scattered more distant, carried by the wind (Horn et al. 2001).

In the PARNASO and studied fragment areas, seed rain clearly indicated the consequences of fragmentation. While zoochory still dominant in the pristine are (69.2%), in the fragment it drop down to 37.7%, and anemochory rise to 60.3%. In a quantitative approach the fragmentation effect was detected as a direct consequence of conditions favoring first successional species. At a simple point of view, the tautology is the conceptual base of applying seed rain as an useful indicator to evaluate disturbance effects, and so as fragmentation increase gaps and edge effects, thus changing soil, light, humidity and wind conditions that favor light demanding species establishment and reproduction, which were more commonly wind dispersed, and therefore affecting the proportion between syndromes in the seed rain. On the other hand, studies of vegetation composition, aimed at understanding the relations of similarity between communities or groups of species, the establishment of correlations and associations between patterns of spatial planning of vegetation and environmental factors (Matteuci & Colma 1982).

In the common sense, indicators are designed to assess the sustainability of the ecosystem (Riley 2001). So, ecological indicators are effective descriptors, used to assess the state of the environment and monitor trends over time (Dale & Beyeler 2001). Although, the establishment of indicators needs to attempt basic criteria such as relevance, representativeness, and appropriate scale, quality of data, measurability, relevance, support decisions and ambiguity, and at the same time they need to be sensible to ecological changes, low cost and easily understood, or predictable trend (Segip 1995).

The quantitative approach by means of seed rain as indicator was effective for our study case. Seed rain reflects not only the current state of forest however also its future, where continuous dominance of pioneers could improve without seed input. Despite this, an important issue to apply seed rain in order to evaluate disturbance effects is its scale and measurability. As seen in Table 1, there was a trend of values higher than 60% to zoochory in more conserved areas of Atlantic Forest, and regardless of the many different habitats and methods of trapping (conic or square traps) and plot size applied in those studies, the proportion among syndromes seems to be similar to the same forest type or habitat. On the other hand, in fragmented areas zoochory were close to 50-60%, and fall down to 30% in degraded areas. However in some conserved habitats inserted in fragments such as riparian forest it became closer to 60%. To verify this, future fragmentation studies on seed rain in Atlantic Forest should involve also a complete analyses of vegetation and ecological conditions such as soil, light, canopy cover that indicate also successional process.

Table 1: Seed rain in pristine, fragmented and secondary Atlantic Forest in Brazil.

	Forest (Local)	*Sampled area*	*Seed Rain*					***Author***
			Composition	*Quantity*	*Dispersal syndrome*			
					Zoochory	*Anemochory*	*Others*	
PRISTINE AREAS	Ombrophilous Atlantic Forest (mist) (Caçador- SC)	20 traps of 0.50 x 0.50 m	26 families; 37 genus; 44 species Seed rain: 19 species		68.4%	31.6%		Caldato *et al.* (1996)
	Montane Atlantic Forest (RJ)- Teresopolis	20 conic traps de 0.25 m^2	21 families 93 species	472 seeds. m^{-2}	68.2%	22.7%	9.1%	Freire (2006)
	Montane Atlantic Forest (RJ)- Teresopolis		29 families 63 species	2,429 seeds. m^{-2}	61.7%			Marques et al (2004)
FRAGMENTED AREAS AND SECODARY FORESTS	Fragments of riparian forests (MG)	30 traps of 1 m²	23 families, 38 genus, 50 species,	208 to 123 seeds. m^{-2}	61.9%	23.8%	14.3%	Araújo et al. (2004)
	Fragments de Floresta Atlantica Montana-	16 conic	34 species	99.6	58.8%	29.4%	11.8%	Gondim

Forest (Local)	*Sampled area*	*Seed Rain*					***Author***
		Composition	*Quantity*	*Dispersal syndrome*			
				Zoochory	*Anemochory*	*Others*	
RJ- Teresopolis	traps 8 ha		seeds /m²				(2005)
Fragments de Floresta Atlantica Montana- RJ- Teresopolis	16 conic traps 23 ha	49 species	103.4 seeds /m²	55.1%	34.7%	10.2%	Gondim (2005)

	Forest (Local)	*Sampled area*	*Seed Rain*					***Author***
			Composition	*Quantity*	*Dispersal syndrome*			
					Zoochory	*Anemochory*	*Others*	
FRAGMENTED AREAS AND SECODARY FORESTS	Fragments de Floresta Atlantica Montana-RJ-Teresopolis	16 conic traps 3.2 ha	44 species	57.3 seeds/m²	52.3%	29.5%	10.2%	Gondim (2005)
	Atlantic Forest- secondary semideciduous forest- (RJ)- Silva Jardim	12 conic traps -3 m² (675 m²)	44 species	7456 seeds /m²	50.8%	39%	10.2%	Araujo (2002)
	Fragments de Floresta Atlantica Montana-RJ-Teresopolis	16 conic traps 62 ha	31 species	220.6 seeds /m²	38.7%	51.6%	9.7%	Gondim (2005)
	Fragments of secondary semideciduous forest (RJ)- Seropédica	20 conic traps	77 species	2.295 seeds /m2	31%	25%	8%	Rudge (2007)
	Gallery Forest (SP)- Semideciduous forest	15 points of 25 x 25 x 4 cm		243±287 seeds. m^{-2}				Grombone-Garantini *et al.* (2002)

Searching for bioindicators: seed rain restoring connectivity

Evaluation and monitoring forest fragments through seed rain are essential to understanding the dynamics of maintenance of biodiversity in tropical forests and the improvement of techniques for restoration (Rudge 2008). Seed dispersal is a main factor limiting the enrichment of species in a degraded area, and may be a key issue for the success of restoration. Few animals' seeds are capable to be dispersed in the open areas around forest fragments (McClanahan & Wolfe 1993, Holl 1998 2000), because degraded surrounding areas do not provide food, shelters or places to rest (Cubiña & Aide 2001). Restoration techniques need to facilitate and accelerate regeneration process by increasing alien seed dispersal in the system. However, the probability of long-distance dispersal of a species will depend on landscape characteristics such as vegetation structure, presence of barriers and availability of dispersal vectors (Ozinga *et al*. 2004).

The attraction of dispersal agents, especially birds, by enhancing the structural complexity of vegetation with the use of artificial perches is one of these techniques that accelerate the process of plant succession due to the increase in recruitment from seed (Bechara *et al.* 2006, Bechara 2007). Thus, studies that aim answer questions about: (1) the role of seed dispersal as an indicator in restored areas, (2) the distance effects from seed source and (3) the effect of perches availability on seed dispersion in Atlantic Forest biome, are very useful and important for conservation and restoration projects.

Limitations on recruitment and colonization are particularly important in fragmented landscapes where remnants are small, the distances to seed sources are large and soil seed bank is scarce (McClanahan & Wolfe 1993). Clark *et al*. (1998) identified three mechanisms limiting seeds recruitment: (i) source limitation, which occurs when the recruitment is restricted by low seed availability in the population, (ii) dissemination limitation, which occurs when recruitment is restricted by a failure in seed dispersal to potential recruitment sites, (iii) establishment limitation, when the recruitment is limited by biotic or abiotic inappropriate conditions. Nevertheless, studies have identified that seed dispersal is one of the major factors constraining species recruitment (Cubiña & Aide 2001, Terborgh *et al*. 2002, Shiels & Walker 2003). Based on dissemination limitation as the principal contributor to recruitment limitation in forest communities, Schupp *et al.* (2002) defined three processes causing restrictions on recruitment of forest species by dissemination limitation: (i) quantitatively restricted seed dispersal, (ii) distance-restricted seed dispersal, and (iii) spatially contagious seed dispersal. According to the author, seed soil supply reach higher densities in habitats chosen by animal dispersers, as beneath natural perches, along travel routes, reproductive and nest places, and under or between fruit trees.

Distance-restricted seed dispersal is a direct consequence of fragmentation in Atlantic Forest. Despite barriers to seed dispersal exists in nature, the fragmentation of habitats has increased dramatically the number of barriers, causing isolation of many native species (Noss 1991). The degree of isolation can limit the growth and maintenance of floristic and genetic diversity in forest restoration and conservation. The floristic diversity of reforested areas is increased with the arrival of propagules from primary or secondary forest remnants (Ingle 2003, Souza & Batista 2004), or even isolated trees (Guevara *et al*. 1986, Mcclanahan & Wolfe 1987, Harvey *et al*. 1998, Holl *et al*. 2000) in its neighborhood. In Atlantic Forest many restoration efforts are failing to return ecological functions and resilience because of constraints in seed dispersal. Distance from seed source and loss of dispersal animals were pointed out as the main cause of lacking restoration (Souza 2000, Gondim 2005).

Although the sites of deposition and the routes may influence animal seed dispersion pattern, its establishment is affected not only by the final substrate however also by the adjacent landscape (Nathan & Muller-Landau 2000). The height of vegetation nearby to parent plant is the possibility of birds' displacement by providing many points of resting. Also, frugivorous birds rarely move into degraded areas due to lack of natural perching (Aide & Cavelier 1994), low abundance of fruit (Silva et al. 1996) and due to extreme weather conditions and greater risk of predation in open areas (Estrada *et al*. 1997).

McDonnell & Stiles (1983) found in abandoned fields, that the structural complexity of vegetation allowed birds to move in open areas of the landscape, establishing a movement of seeds between forest remnants. According to the authors, as areas of intensive use were abandoned, there was initially colonization by herbaceous species. The trees and shrubs that were established after increasing the structural complexity of vegetation were like recruitment foci for seeds dispersed by birds. Therefore, the increasing of structural complexity is a main factor in subsequent enrichment of biodiversity due to the importance of heterogeneity of habitat for animals and seed dispersers and to allow microclimatic heterogeneity for seed germination (Parrota *et al*. 1997). McDonnell & Stiles (1983), and McClanahan & Wolfe (1987), suggested the use of artificial perches to increase seed supply in open areas. According to the authors, artificial perches create "artificial island" enhancing seed deposition abundance and diversity of bird-dispersed plants.

Although many studies were conducted in order to evaluate perches as a nucleation technique to restore degraded areas (Guedes *et al.* 1997, Reis 2003, Bechara *et al.* 2006, Mikich & Possette 2007), few of them were established in tropical areas (Melo 1997, Holl 1998, Zanini & Ganadi 2005 e Bechara 2006). Besides, some questions about the efficiency of perches to connect fragments in degraded landscape, the distance from seed source expected to perches' use and the effect of environmental matrix in the effectiveness of perches as a nucleation technique remain uncertain.

In order to study nucleation techniques in an Atlantic Forest fragmented landscape, the aim of our study was to evaluate the efficiency of artificial perches to the input of propagules based on the following questions: a) how seed rain changes with distance from a seed source? b) Does the use of artificial perches promote intake of seeds and species establishment?

Study case: lowland Atlantic Forest, Rio de Janeiro (RJ)

The study area was located in the boundaries of Tinguá Biological Reserve (TBR) in the central-western region of Rio de Janeiro State, Brazil, in the Guandu river watershed (22º44'38"S; 43º42'27"W). This conservation unit is connected to the central corridor of Atlantic Forest also integrated by the National Park of Teresópolis (PARNASO). The studied region is a fragmented landscape with urban areas in the west, pasture and forest remnants in the east side surrounded by sand mines and degraded areas with herbaceous and pastures species. Mean annual precipitation of 1200 mm with a dry period from June to August ($\leq$ 50 mm.month^{-1}) and a wet season from December to March ($\geq$ 300 mm.month^{-1}). Mean monthly temperatures range from 20.4 (dry) to 24.5ºC in the wet season (Penna 2006).

The natural vegetation in the TBR is classified as montane and lower montane ombrophilous dense Atlantic Forest (Veloso *et al.* 1991, Rizzini 1997) dominated by species of Rubiaceae, Leguminosae, Myrtaceae and Lauraceae (Rodrigues 1996, BRAZ *et al.* 2004). In the studied region intense agricultural and industrial activity since 1616 (Penna 2006) changed natural vegetation that nowadays can be classified as a tropical lowland ombrophilous secondary Atlantic Forest, with moderate diversity (H′= 3.37 bits), and dominance of Areacaeae, Myrtaceae, Erythroxylaceae and Celastraceae (Rudge 2008).

Study sites- In the region three experimental conditions were selected: (i) a 9.4 ha forest fragment, (ii) the surrounded area around the fragment, and (iii) a natural perch (NP). A floristic vegetation survey in forest remnant included 33 families and 62 species, and the common ones were *Astrocaryum aculeatissimum* (Schott) Burret. (Arecaceae), *Eugenia* sp. (Myrtaceae), *Psychotria* sp. (Rubiaceae), *Erythroxylum pulchrum* A. St.-Hil. (Erythroxylaceae) and *Maytenus* sp. (Celastraceae). Together these species represent 132 individuals and 24.9% of total sampled population. Fragment´s surrounded area was composed by an abandoned pasture and a small patch (< 1 ha) about 100 m from fragment´s edge. Abandoned pastures presented dominance of weed and herbaceous species such as *Brachiaria decumbens* L., *Chromolaena maximiliani* (Schrad) R. M. King & H. Rob, *Eupatorium laevigatum* Lam. and *Sidastrum micranthum* (St. Hil.) Fryxell.) with sparse shrubs (< 2 m) of *Ludwigia octovalvis* (Jacq.) P. H. Raven., *Jatropha curcas* L. and *Solanum palinacanthum* Dun. The patch was covered by weed and shrubs species, with only three arboreal individuals (*Galesia integrifolia*, *Casearia sylvestris* and *Trema micrantha*) and intense natural regeneration of *Albizia polycephala*, *Casearia* sp., *Cecropia pachystachya*, *Erytroxylum pulchrum*, *Tabernaemontana laeta*, *Trichilia* sp, *Solanum* sp, *G. integrifolia C. sylvestris*, *T. micrantha* and *Guarea guidonea* (Rudge 2007). The natural perch (NP) was an isolated tree of *Ficus gomelleira* Kunth & Bouche, about 10 m height and 80 m far away from the forest remnant.

Seed rain - Inside the fragment was established a plot line far away 20 m from the forest edge. Also, outside of the forest fragment, in the surrounded matrix, five linear plots (20 x 1 m) were established at 20 200, and 300 m far from the forest´s edge. Close to the natural perch (NP), a plot (20 x 1 m) was established 20 m from the individual tree and 100 m far from fragment in the same arrangement of the others plots. In each plot, except that one inside the fragment, were established three perches at least 10 m from each other. In the two external perches, near to the plot edge, were placed one conic fabric trap, and two others traps at least 5 m from the external perches. The two perches with traps served as control for seed rain. Inside fragment´s plot, four seed traps were established 10 m from each one.

The perches were made with bamboos 4.8 m height with two centered artificial branches, the first one 3 m above the ground, with two perpendicular sticks of 1 m and the second one, at 3.5 m height, with the two perpendicular sticks measuring 0.5 m. Monthly from November 2006 to October 2007, seed rain was collected. Seeds were counted, weighted and identified using literature and comparisons with seed herbariums. Each diaspore was categorized by dispersal syndrome, life form (weed, shrubs, tree, and liana) and successional group (pioneer, secondary and climax).

Data Analyses- Biodiversity was evaluated by using ecological indices as Margaleff (D), richness (S= number of species.m^{-2}.$year^{-1}$), Shannon diversity (H´), Pielou´s evenness (J) and abundance (N= number of individuals.m^{-2}.$year^{-1}$) (Magurran 1991). Similarity in seed rain among studied sites was evaluated by cluster analyses (MacCune & Mefford 1997). Distance from seed source, presence/absence of perches and dispersion syndromes among areas were evaluated by regression analyses, *t*- test, Chi-square, Kolmogorov-Smirnov (K-S) and Kruskall Wallis (KW).

Results- A total of 6,369 diaspores (2,295 seeds.m^{-2}.$year^{-1}$) were collected in the 20 seed traps from 77 morphotypes, 38% (29) identified at the species level, 8% (6) at the genus level and 8% (6) only by family, representing 54% of total seed rain partially or fully identified. Inside the fragment was the higher density of seeds of shrub species, trees and vines (Table 2), with higher seeds density than other areas of more conserved Atlantic Forest (Holl 1998, Penhalber and Mantovani 1997) and fragments (Gondim 2005).

Table 2: Number of species and seed abundance in seed rain sampled at different distance from fragment edge in an Atlantic Forest, Rio de Janeiro, Brazil. NP= Natural Perch represented by a plot 20 m adjacent to Ficus gameleira isolated tree and 100 m far way from fragment edge. Nº= number. November 2006 to October 2007.

Study site	Distance (m) from fragment edge	Number of species (trees, shrubs and vines)	Abundance (nº of seeds. m^{-2})
Fragment (inside)	20 m	53	3.265
Degraded area surrounding fragment (outside)	20 m	16	540
	100 m (NP)	16	1.014
	200 m	19	650
	300 m	9	391

Although at 20 m from fragment edge, the number of species (n= 16) and relative abundance (n= 317 seeds.m^{-2}.$year^{-1}$) were significantly higher than those obtained at 300 m (n= 9 species and 85 seeds.m^{-2}.$year^{-1}$), its heterogeneous distribution of diaspores resulted is low evenness (J = 0.4611) and diversity (H' = 0.555 nats.ind^{-1}) when compared to the farthest part of fragment (J '= 0.9129 and H '= 0.871 nats.ind^{-1}) (Table 3). Even if the plots at 200 m and 300 m also were significantly different in seed abundance, none distance from seed source were statistically significant in richness (χ^2= 2.59; p> 0.05). Differences in seed rain abundance and the same richness has direct implications on the restoration of connectivity among fragments since this indicates an input of seeds in quantity, however not in quality which is reflected in an expected increase in the number of species.

As indicated in the studies in the Atlantic Forest area of PARNASO, the diversity indices for seed rain ranged from 2.18 nats.ind^{-1} (Freire 2007) to 3.06 nats.ind^{-1} (Marques et al. 2003). Moreover, the studied forest fragments in the same region had rates ranging from 0.3374 nats.ind^{-1} (degraded fragments) to 0.9562nats.ind^{-1} (conserved areas) (Gondim 2005). In the case of undisturbed areas studied by Caldato et al. (1996), diversity index ranged from 1.65 to 1.86 nats.ind^{-1}. Based on this results, the indices of diversity for seed rain in our studied fragment was low, close to those obtained by Gondim (2005) in degraded sites, which may indicate that the effects of degradation is also reflected in the perches´ seed rain.

Table 3: Diversity, richness and evenness index applied to seed rain in Five different distance from a fragment edge, in a lowland Atlantic Forest, in Rio de Janeiro- Brazil. S= number of species, N= relative abundance. d (Margalef)= species richness, J' (Pielou)= evenness e H' (Shannon-Wiener)= diversity. (-20) = plot inside the fragment, 20 m far from the edge. November 2006 to October 2007.

Local	Distance from fragment´s edge (m)	S	N	d	J'	H'(log10)
Inside fragment	(-20)	53	3,335	6.41	0.5801	1.0000
Outside fragment (surrounding área)	20	16	317	2.605	0.4611	0.5552
	100	16	762	2.261	0.7502	0.9034
	200	19	699	2.748	0.6925	0.8855
	300	9	85	1.801	0.9129	0.8712

The highest number of species (31%) were animal dispersed (n= 24), 25% were wind-dispersed (n= 19) and only 8% were autochoric (n= 6). The same pattern was observed to total number of seeds, 30% were zoochoric (n= 1,913 or 720 seeds.m^{-2}.year^{-1}), 21% anemochoric (n= 1,368 or 515 seeds.m^{-2}.year^{-1}) and 43% were autochoric (n= 2,770 or 804 seeds.m^{-2}.year^{-1}). The density of seeds obtained to dispersal syndromes was significantly different among distances (χ^2 = 1,274, p <0.001). Zoochoric species were most frequent in all distances, however especially at 20 m from fragment´s edge (n= 10; 272 seeds.m^{-2}.year^{-1}) and 200 m (n= 14; 463 seeds.m^{-2}.year^{-1}) and at the plot close to the natural perch and distant 100 m from fragment´s edge (n= 11; 536 seeds.m^{-2}.year^{-1}) (Table 4). Inside the fragment, 28% of species in the seed rain were zoochoric, 26% wind dispersed and only 2% were autochoric.

Table 4: Number of species and number of seeds.m^{-2} dispersed from November 2006 to October 2007 in the seed rain at five different distances from fragments edge, in a lowland Atlantic Forest, in Rio de Janeiro, Brazil. (-20) = plot inside the fragment 20m far from the edge.

Dispersion syndromes	Distance from the edge (m)									
	Interior (20 m)		20		100		200		300	
	species	Seed /m^2	species	Seed /m^2	species	Seed /m^2	species	Seed /m^2	species	Seed /m^2
Zoochory	16	1.432	10	272	11	536	14	463	6	44
Anemochory	15	1.464	3	90	3	7	2	4,6	4	86
Autochory	1	19	2	3955	3	23	2	120	2	390
Total	57	3.265	20	391	30	5.296	25	650	28	540

There were 794 animal dispersed seed (630 seeds.m^{-2}.year^{-1}) under the perches and only 12 seeds (10 seeds.m^{-2}.year^{-1}) below traps without perches. This corroborates the significantly effect of perches (χ^2=464.48; p< 0.01) as sources of animal dispersed seeds. Despite presence of perches significantly increased simultaneously the number of propagules and the animal dispersed seeds (χ^2= 35.05; p< 0,001), there was a reduction on seed abundance 300 m away from fragment´s edge (Figure 1). Increasing in animal dispersed seeds was observed in the perches close to the natural perches and 100 m far from fragment (1,005 seeds.m^{-2}.year^{-1}) and in the plot 200 m far from fragment´s edge (816 seeds.m^{-2}.year^{-1}); then again, seed input by animals was statistically different between 20 m plot (272 seeds.m^{-2}.year^{-1}) and 300 m (44 seeds.m^{-2}.year^{-1}) (t = - 0.97; p= 0.1766) and so, we can suppose that perches 300 m far from seed source were not so efficient as that one's 20 to 100 m away from the fragment´s edge. However, at 20 m the diversity lower than that obtained to the perches at 100 and 200 m far from the fragment (Table 3) reinforce the possibility that there is an "optimal distance" for the perches effects in the seed rain.

This results support the hypothesis that the efficiency of perches depends on distance from the seed source. As in the perches 100 m away from the fragment was obtained an increasing in animal dispersal we can suppose that this result could be cumulative and simultaneously influenced by the fragment seed rain (100 m away) and also by the natural perch, only 20 m distant from this plot. The same could be inferred to the 200 m plot, which is at the same time 120 m far away from the natural perch. A interesting question is why perches close to fragment (20 m) and only 60 m away from the natural perches were significantly different from others distances in terms of diversity and seed abundance (Tables 3 and 4). Those results indicated that in our studies the perches only 20 m far from a seed source were not so efficient to attract seed dispersers as another at 100-200m. Although need to be tested, seems that the natural perch was an attractive to animals and could be more effective than the artificial perches to increase the diversity of animal dispersed species as observed in the plots 100 and 200 m away from the seed source.

Many authors indicated the efficiency of artificial perches as a nucleation technique capable to attract dispersers and increase bird dispersed seeds (Reis *et al.* 2003, Bechara 2006, Bechara *et al.* 2007, Regensburger *et al.* 2008). Despite this, our results were not contradictories as we have distinct approaches. In our study we noted that all the identified species were autochthones, originated in the surrounded fragments and patches and concentrated 100-200 m far from the main fragment´s edge. The authors then again have studied ≥1 ha patches, with artificial perches not 100-200 m far from a restoration area, and so our results match.

Our study indicated that artificial perches could not be a nucleation technique that can be applied to all situations. There was a seed source limitation, because seed rain depends on fragment´s quality, and there was distance-restricted seed dispersal. Artificial perches were a useful tool 100-200 m away from fragment source though cost-benefit was high when considered land use to agricultural purpose. If we assume artificial and natural perches as a "step-stone" towards fragments connectivity we can lay down the seed source limitation, and perhaps distance-restricted dispersal, restoring connectivity not in a local assessment, however in a landscape point of view. And so, in order to restore connectivity among fragments, artificial and natural perches could be combined to increase animal dispersed diaspores in the seed rain. As in agricultural landscape the restoration implies in a reduction of cultivate land, despite its legal and ecological need, on the other hand nucleation techniques with the use of small groups of forest species and artificial perches can be proposed and collaborate to pasture activities with shadow for the cattle and a secure place to seed dispersers.

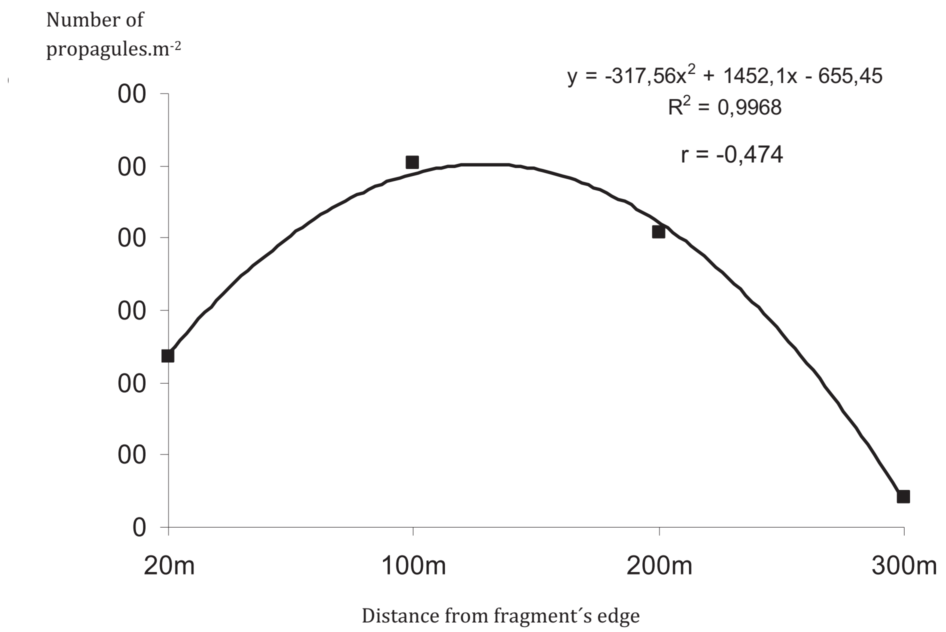


Figure 3: Correlation coefficient (r), and regression equation ($p<0.01$) to distance from fragment´s edge and number f zoochoric seeds.m^{-2} sampled in the seed rain in artificial perches in a degraded area, in lowland Atlantic Forest, in Rio de Janeiro, Brazil. November 2006 to October 2007.

Study case: Montane Atlantic Forest in Teresópolis, RJ

The second studied area was an advanced successional forest remnant inserted in a transition zone of "capoeira" and pasture in the region of Teresópolis, Rio de Janeiro, at 22º25'- 22º32'S and 42º59'- 43º07'W, in the watershed of rio Preto. This area is an abandoned pasture of *Brachiaria decumbens* in a secondary succession with establishment of "capoeira", a vegetation type that combine herbaceous, shrubs and small tress. The herbaceous layer was composed mainly by Poaceae (*Brachiaria decumbens* and *Melinis minutuflora*), Asteraceae (*Baccharis trimera*, *Eclipta alba* and *Blainville* sp), Leguminosae (*Aeschynomene denticulata*) and Cyperaceae (*Cyperus rotundus*). The shrub layer was about 3.5 m high, with a predominance of Asteraceae (*Baccharis* sp and *Vernonia* sp), and few individuals of species such as Melastomataceae (*Tibouchina* sp.), Sapotaceae, Solonaceae (*Solanun* sp), Myrcinaceae (*Rapanea ferruginea*) Verbenaceae (*Lantana camara*), Myrtaceae (*Psidium cattleiano*), Leguminosae (*Senna multijuga*) and Tiliaceae (*Triunfeta bartramia*). In this site a floristic inventory showed a dominance of Asteraceae, from genus *Baccharis* and *Vernonia* with relative frequency (rf) of

32.1%, and few individuals of *Tibouchina* sp.- Melastomataceae (rf= 0.13%), *Solanun* sp.- Solanaceae (0.13%), *Rapanea ferruginea*- Myrcinaceae (rf = 0.13%), *Lantana camara*- Verbenaceae (rf = 4.17%), *Psidium cattleiano*- Myrtaceae (rf = 2.67%), *Senna multijuga*- Leguminosae (rf = 0.67%) and the Tiliaceae, *Triunfeta bartramia* (rf = 7.20%) (Gomes & Piña-Rodrigues 2005). The tree layer was characterized by the presence of individuals about 9 m height and dominance of Leguminosae (rf = 17.96%). The most frequently species were *Lanchocarpus* sp. (rf = 6%), *Erythroxylum pulcrum*, *Schinus terebinthifolia* with 0.8% of relative frequency for both, *Tabebuia* sp. (rf= 0.3% and *Machaerium hirtum* (rf = 0.3%).

Seed rain- Perches with 4.8 m were established with two artificial centered branches at 3.0 m and 3.5 m from the ground and 1.0 and 0.5 m of length, respectively and a natural branch in the top. In the "capoeira" zone, parallel to the remnant edge, were placed four plots of 50 x 1 m (50 m²) at 10, 25, 150 and 250 m far away from the fragment. At each plot were distributed five perches about 10 m away from each other. Above the external perches were placed two conic fabric trap (0.25 m²) about 1.3 m from the ground level and two traps were established without perches, as control. Above each perch were established four subplots of 0.25 x 0.25, in which a germination box (0.25 m²) with sterilized vermiculite was placed in two replications to study seed germination. In the others two subplots the weed was removed and they were considered as control. Weekly along 30 days the seed rain was sampled, weighted, counted and indentified. The boxes were removed to the nursery and replaced by a new one. Seedlings were counted and identified and compared to specimens in the herbarium.

Data analyses- The number of seeds and seedlings obtained with and without perches in the different distances were compared applying Kolmogorov-Smirnoff test. Correlation among seed abundance (S) and distance from fragment´s edge were determined by Spearman Coefficient and a regression analysis was applied to study the distance and seed and seedling abundance relationship.

Results- Along 30 days were collected 15,274 (3,818 seeds.m²) in seed traps, and 66% (n = 10,065; 2,516 seeds.m²) were sampled below the perches and 34% (n = 5,209; 1,302 seeds.m²) in the traps without perches (control). The presence of perches increased significantly the seed rain in the traps and contributed to attract animal seed dispersers. Also, the number of morphotypes obtained at different distances from the edge reinforce the effect of perches' presence and the number of species, was more than expected for the chance (z= 0, 13, p <0.01), mainly because the seed rain at 250 m far from fragment´s edge (Figure 2). Close to the fragment (10 to 25 m) there was no effect of the perches in the seed rain and increasing was only observed in more distant perches (250 m). As the study area was a heterogeneous landscape with presence of shrubs, treelets and trees, we cannot exclude the probable effect of these natural perches to dispersers. Although, in the floristic survey was observed that 21 adult trees (height ≤ 9 m) were 10 m around to the first plot at 10 m far from the fragment´s edge, 31 at 25 m, 6 individuals at 150 m and 16 plants at 250m. As the adult plants were considered as "natural perches" and were distributed in higher density close to the perches near to the fragment, we can suppose that: (a) independent of the presence of natural perches, there was "an optimal distance" for the artificial perch effect in the seed rain, as was also observed in our study in the lowland Atlantic Forest, or (b) on the other hand, natural perches were preferred by dispersers than artificial ones.

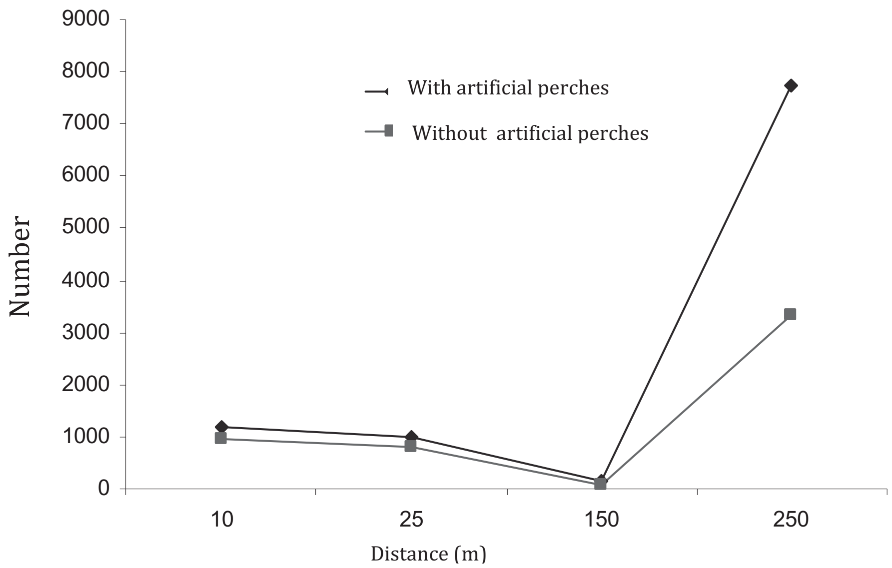


Figure 4: Number of botanic morphotypes (seeds) sampled in different distances from a fragment edge in a degraded area in Montane Atlantic Forest, Teresópolis, RJ.

Despite the abundance increase on seed rain in the fastest perches, there was an inverse effect on seed establishment. Seedlings of 513 individuals from 44 species were obtained from seed rain germination. There was a significant difference in total seed germinated for the presence of perches ($z = 0.16$, $p = 0.0044$), with a tendency to greater differentiation in the distance of 25 m from the edge (Figure 3).

Distance from the fragment was negatively correlated ($r = -0.90$) to the number of seedlings found under the perches. At 150 m from the edge there was a sharp reduction of the influence of the fragment in the input of germinable seeds. The distance effect on the viable seed rain, though is only significative ($R^2 = 0.89$; $p < 0.05$) in the control (traps without perches) and not in the perched ones ($R^2 = 0.51$; $p > 0.05$) what means that there were others effects than just presence of perches influencing viable seed rain in different distances from seed source. One hypothesis could be the heterogeneous landscape with a concentration of natural perches close to the fragments that, although did not influenced seed rain abundance, increased the contribution of viable seed rain into the fragment´s surrounded area.

Similar to the lowland study area, our result reinforce the limited effect of artificial perches in restore connectivity and increase of seed rain. There was a seed source distance effect (150-200 m) that ensure seed dispersal. Perches close to the fragment (<150 m far way) were not efficient as demonstrated in this study and in the lowland area (<100 m). On the other hand it seems that to natural perches this limit was not so defined and need more researches. As landscape complexities improve seed dispersal among natural patches, it is determinant to restoration processes (Parrota *et al.* 1997).

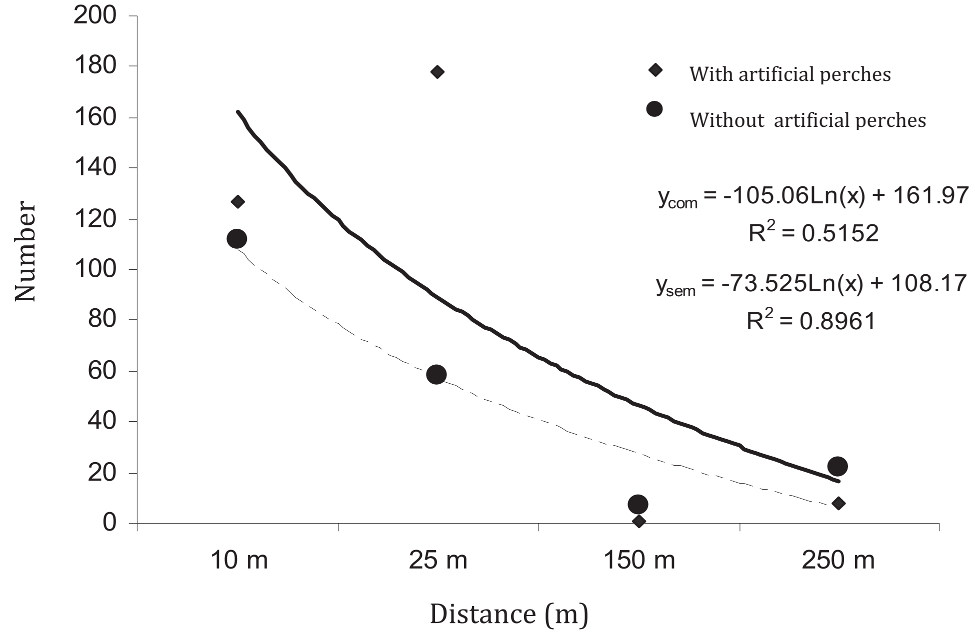


Figure 5: Number of seedlings obtained in germination boxes under artificial perches and controls (without artificial perches) in different distances from a fragment edge in a degraded area in Montane Atlantic Forest, Teresópolis, RJ. Results of regression analyses (R^2; $p< 0.01$). Y_{com}= with artificial perches; Y_{sem}= control (without artificial perches).

The seed rain heterogeneity is not a simply function of distance from an adult plant as observed in many studies (Terborgh *et al.* 2002, Schupp *et al*. 2002, Ozinga *et al.* 2004); however it is also driven by animal behavior (Stiles & White 1986, Schupp *et al*. 2002) and vegetation structure (McDonnell & Stiles 1983, McClanahan & Wolfe 1987, McClanahan & Wolfe 1993). Based on this we consider that natural perches, even isolated trees could be more effective to produce an environmental heterogeneity in fragmented landscape. Artificial perches, in our study case, although increased quantitative seed rain, did not influenced viable seed rain. On the other hand, natural vegetation could be not only a place to seed displacement, however also a place to viable seed establishment.

This support the hypothesis that the pattern of animal seed dispersal does not follow a smooth decay curve from the mother plant, although it is characterized by distinct peaks representing the increased number of seeds deposited under the recruitment foci (McDonnell & Stiles 1983). The distance from propagules source and availability of animal dispersers need to be considered in the natural regeneration (Holl 1999). In the long term, the decline of specific vectors of dispersion like frugivorous birds will also result in the decline of regional guild of species that depend on these dispersal agents (Ozinga *et al*. 2004).

In order to improve perches efficiency, we propose that in fragmented landscape we can introduce groups, lines or isolated trees almost 100-200m far from each other; and while tree species were growing we can combine them with artificial perches in a step-stone model that can increase complexity of surrounded area in order to promote safe sites to animals and seed associated to agricultural activities.

Studied cases reported here discussed only quantitative effects of artificial and natural perches in seed rain. Sometimes is very difficult in field studies to exclude all factors influencing our results and our montane study area is a real example. Statistical tools could be effective to minimize some environmental effects and analyze covariance of some of them. And so, even in this case, bias will persist. The best approach is to identify these biases, to control effects (when possible) and formulate new hypothesis, methods and continue the research. That is what we are trying to do.

Conclusion

A quantitative approach about seed rain to evaluate restoration and degradation in a Montane Atlantic Forest was valuable to compare studied fragments. In PARNASO seed rain was dominated by zoochory (69.2%) while in the fragments anemochory (>60.3%) was dominant. Seed rain reflected not only the current vegetation dominated by pioneers, but the future potential quality of the fragments trending to maintain degradation process due to low intake of later successional species, in general zoochoric. Seed source and distance effect influenced the quality of seed rain in the surrounded area of two Atlantic Forest remnants. Although artificial perches were capable to promote an intake of zoochoric seeds, there was, in both areas, an “optimal distance” of perches effectiveness to seed dispersal between 100 and 200m, which increase at the same time seed quantity and diversity. Natural perches where significantly a “safe site” to viable seed establishment when compared to artificial perches. In order to restore connectivity in Atlantic Forest fragmented landscape we propose a combination in time and space of artificial and natural perches in a step stone model.

The role of birds as an indicator of environmental conditions

Bird communities and the effects of forest fragmentation

The Atlantic Forest is one of the most fragmented, altered and threatened biomes of the world. From over 1.3 million of square kilometers spread throughout seventeen Brazilian states, today it is estimated from 7 to 16% remains (Galindo-Leal & Câmara 2003, SOS Mata Atlântica 2004, Ribeiroa et al. 2009). Regardless such devastation, the Atlantic Forest still harbors significant elements of Brazilian biological diversity, with highest levels of endemisms and threatened species. Due to all these characteristics, it is considered by as one of the international hotspots for biological conservation (Myers et. al. 2000, Galindo-Leal & Câmara 2003). In the state of Rio de Janeiro, the destruction and fragmentation of the forest, the hunting and capture for cage are the main threats to the avifauna. Currently there are about 82 threatened bird species in that state, from which 24.39% (n=20) as probably extinct and 56.10% (n=46) as vulnerable (Alves *et al* 2000).

Studies on local biodiversity are of extreme importance, since the speed and continuity of the degradation process are related to the losses of the fauna and flora, mainly because these jeopardized environments have all of their structure modified, resulting in patterns very distinct from the previously found.

The aim of this study was to evaluate the bird fauna composition in and in a surrounded area of Serra dos Órgãos National Park (from now PARNASO) in Teresópolis (RJ), in order to answer the following questions: (a) how parameters of that communities, like structure, abundance and diversity differ when comparing a continuous forest and small fragments? (b) Which are the main elements that may change? (c) How the fragmentation and isolation affect the ecological integrity of these communities?

Study site and methods- The region of Teresópolis has high incidence of deforestation and degradation, as part of the so called "green belt of Rio de Janeiro", supplying a relevant fraction of the agricultural products to that city. A pristine area in PARNASO and four forest fragments were compared along two years from December 2003 to August 2005. The fragments were the same ones studied to seed rain and perches. Based on their size, they were identified as F1, F2, F3 and F4 (4, 9, 23 and 64 ha).

Two sites were established in PARNASO, from now called point 1 and point 2. For captures, 36-mm 12x3-mm mist nets were used in already existing trails from August 2003 to June 2005. Mist nets remained open all day long, and captured birds were identified with metallic rings supplied by CEMAVE/IBAMA and morphological data (weight, sizes and ecological information) were registered. Taxonomic nomenclature follows Sick (1997).

The smallest fragment (F1) was located at 22º 17' 56" S and 42º 52' 29" W. Despite its size, it has been protected from cattle, fire and human direct actions by management practices in the surrounded area. Located at 22º 17' 17" S, 42º 52' 28" W, the F2 fragment was less than 800 m far from F3. Both were surrounded and separated by pasturelands. There was a stream between the edge and its interior that was regularly used by cattle. The F3 had the more intensive human interference, with wood extraction, fire and cattle trail in some places. Far from the others fragments, however in the same slope and watershed, F4 (22º 16' 35" S and 42º 51' 49" W) was the most conserved. In the surrounded area the main activity were horticulture and pasture.

Bird sampling was conducted by point counts and mist nets (Vielliard & Silva 1990, Bierregaard 1990). From August 2003 to May 2004 field surveys were irregular in F1, F2 and F3 and in the last year F4 was included in the sample effort. Initially two net lines were established, except the small F1 (4 ha) which had only one.

Morphometric data as wing length, tail and total length were measured with a metallic rule and bill culmen, width and height, and tarsus with a digital caliper. Masses were obtained using dynamometers (pesolas®). Species ecological characteristics, as trophic guild, endemism, habitat and nesting were attributed based on data from literature (Willis 1979, Sick 1997, Pacheco & Bauer 2000, Piratelli & Pereira 2002, Donatelli et al. 2004).

Data analysis – Here we only analyze data from mist nets. Each capture was transformed in relative capture (%) and sample effort was calculated based on net hour. Species richness was estimated by the Margalef index (d). Shannon-Wiener diversity index (H') was applied to estimate species' diversity; homogeneity and evenness (J') were also calculated, and all these analyses were done using the package Primer 5.0 for Windows (Clarke & Gorley 2001).

. The similarity of species composition among sites (pristine area and fragments) was compared by cluster analysis using presence/absence Sorensen index as a measure of similarity. Clusters were constructed by the unweighted pair-group method using the arithmetic averages (UPGMA). This analysis was conducted with the help of the package PCOrd 4.0 (McCune & Mefford 1997).

Results

1. PARNASO

In PARNASO 186 individuals and 60 recaptures from 45 species and 17 families were done in more than 1900 net-hour (Table 5). A total of 42 species (93%) were considered as dependent on forests and only three (7%) as facultative forest species. Nineteen species were classified as endemic of Atlantic Forest (Appendix 2: Table 3)

*Table 5**:** Bird captures in two sites in PARNASO (Serra dos Órgãos National Park; 22°24'36''S and 42°58'48''W), in Teresópolis, state of Rio de Janeiro, Brazil. August 2003 to June 2005.*

Sites	Net-hours	Number of Species	Number of captures	Number of recaptures
Point 1	983	35	86	20
Point 2	922	33	100	40
Total	**1905**	**45**	**186**	**60**

The most frequent species were *Chiroxiphia caudata* (n=20), *Turdus albicollis* (n=14), *Trichothraupis melanops* (n=13), *Lepidocolaptes fuscus* (n=12), *Mionectes rufiventris* (n=11) e *Scansor Sclerurus* (n=10). *Turdus rufiventris*, *Mionectes rufiventris* and *Sittasomus griseicapilus* had 80% of their captures in point 2.

The analysis of feeding guilds showed a predominance of insectivorous in both sites, and for the whole data. Insectivorous species were represented by 23 species (51%), followed by 10 omnivores (22%), five frugivorous (11%), four nectarivores (9%) and three carnivores (7%). It is assumed that there is a predominance of insectivores followed by omnivores in forest patches, a fact already reported by other authors (eg. Motta Jr. 1990, Anjos 1998)(Table 6).

Table 6: Relative frequency (%) of trophic guilds in two sites in PARNASO - 10,600 ha (Serra dos Órgãos National Park; 22º24'36"S and 42º58'48"W), in Teresópolis, state of Rio de Janeiro, Brazil. August 2003 until June 2005.

Guild	Point 1 Relative frequency (%)	Point 2 Relative frequency (%)	Total of species and %
Insectivorous	48	55	23 (51.1%)
Omnivores	23	21	10 (22.2%)
Frugivorous	11	12	5 (11.1%)
Nectarivorous	9	9	4 (8.9%)
Carnivorous	6	3	3 (6.7%)

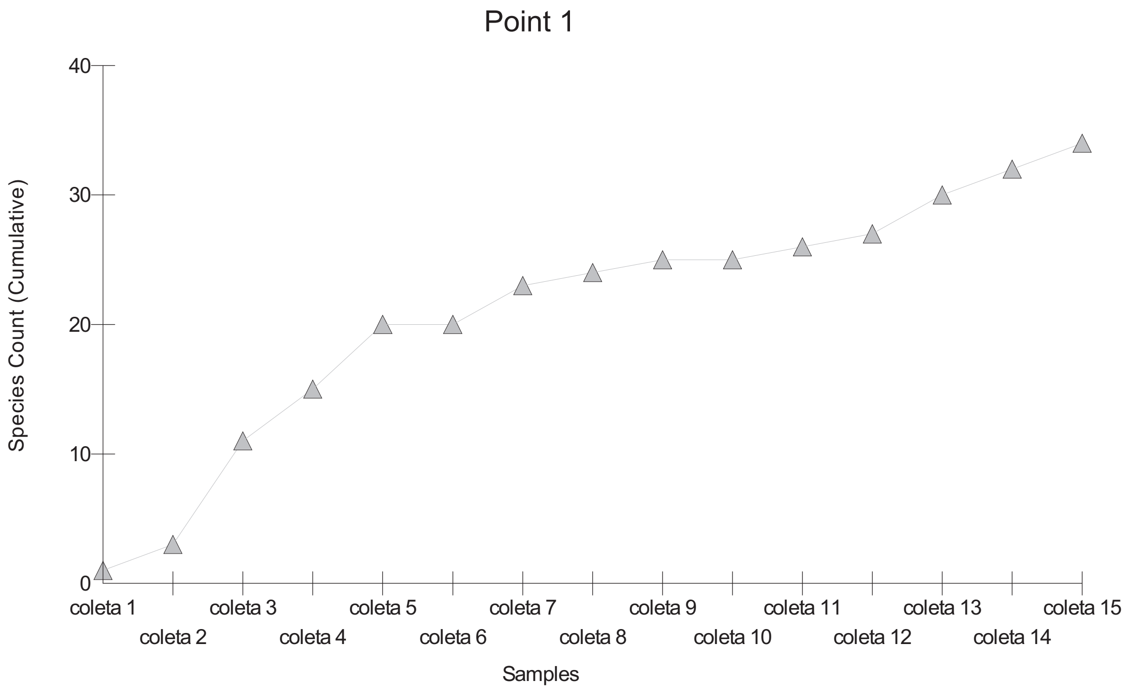
In relation to reproduction, species that nest over vegetation predominated in both sites. Species that burrow into tree trunks and arboreal termite nests and those that nest in galleries dug in the ground are more vulnerable to the effects of fragmentation. Cavities in trees are naturally scarce resources (Sick 1997) and the problem gets worse with the fragmentation, because the wind down many dead trees that could offer these cavities (Antunes 2005). As a total for PARNASO, 29 species

(65%) may nest on vegetation, six (13%) occupy pre-existing cavities in tree trunks, four (9%) excavate trunks termite nests, four (9%) burrow galleries in the ground and two (4%) nest on the ground.

Both sites were very similar in all of their ecological descriptors (Table 7). On the other hand, the accumulative curve of new species not yet tends the stabilization neither for Point 1 nor for Point 2, suggesting the necessity of continuity of the studies for a more complete evaluation of the sampled area (Table 7).

Table 7: Characteristics of birds communities in two sites in PARNASO- 10,600 ha (Serra dos Órgãos National Park; 22°24'36"S and 42°58'48"W), in Teresópolis, state of Rio de Janeiro, Brazil. August 2003 until June 2005. S= species number; n = number of individuals; d= species richness, as calculated by Margalef index: d=[S-1]/logS), J´= evenness; ,H´= Shannon diversity index.

Site	S	N	D	J'	H'
Point 1-Rancho Frio	35	86	7.633	0.909	3.231
Point 2- Pedra do Sino	33	100	6.949	0.912	3.189



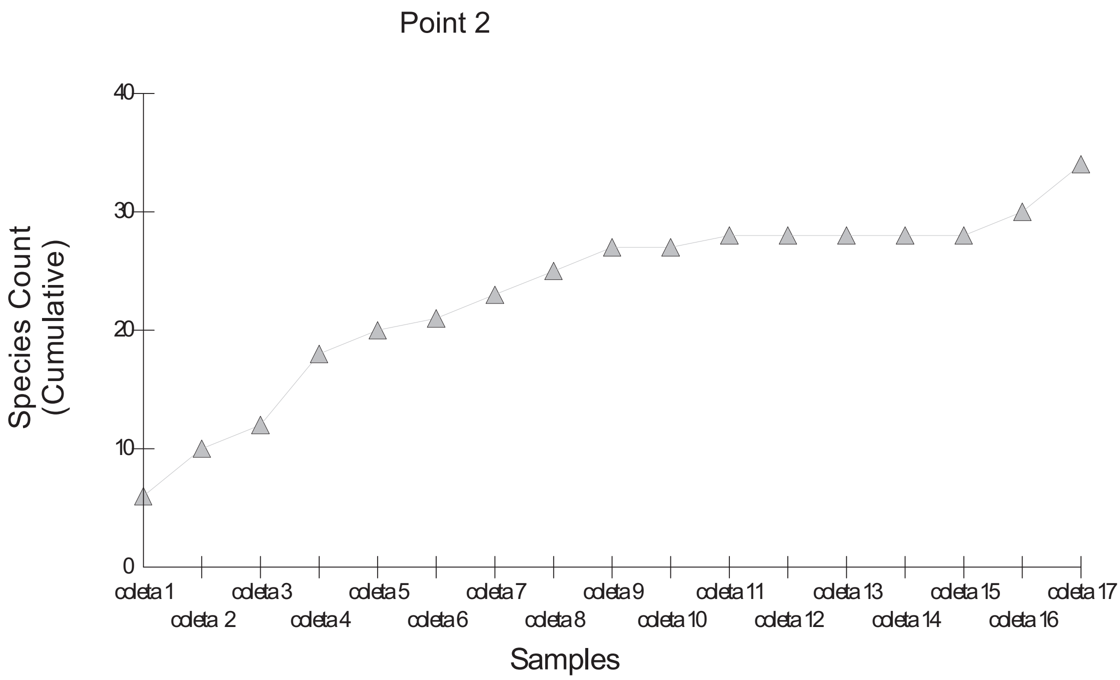


Figure 6: Cumulative curve of bird species captured in two sites in (Serra dos Órgãos National Park; 22º24’36”S and 42º58’48”W), in Teresópolis, state of Rio de Janeiro, Brazil. August 2003 until June 2005.

2. FRAGMENTS

After 3529 net-hours in two years, we had 399 captures and 84 recaptures in the four fragments (Table 8), and these sampled 45 species from 15 families. The accumulative curve of new species showed a trend to stabilize, suggesting that the sample effort was relatively satisfactory (Figure 2).

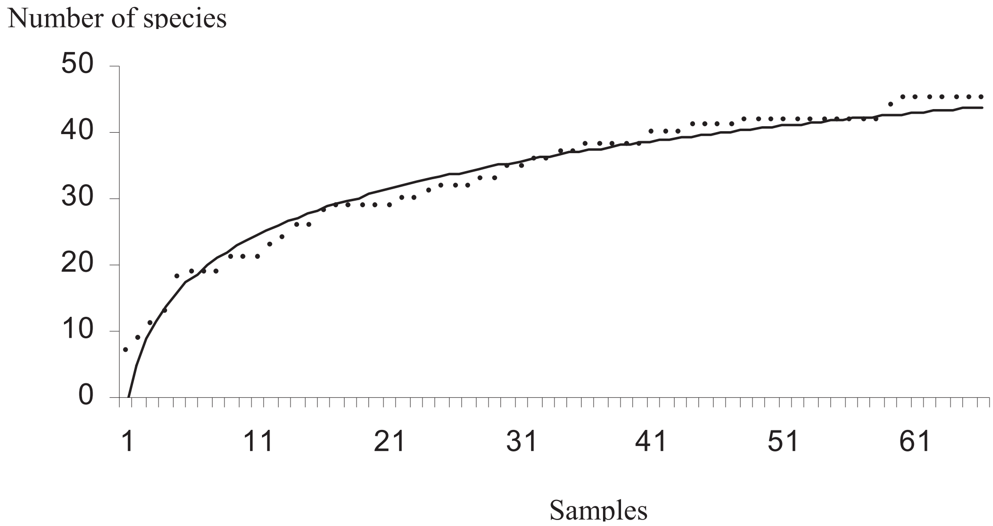


Figure 7: Accumulative curve of new species, with logarithmic trend line, for capture efforts in four forest fragments in the region of Teresópolis, RJ.

Table 8: Total of species, captures, recaptures and species/net-hours in four fragments of Atlantic Forest in Teresópolis, Rio de Janeiro, Brazil. Data from August 2003 to August 2005.

Fragments	**Area (ha)**	**Net-hour**	**Species (n)**	**Captures (n)**	**Recaptures (n)**	**Total**	**(species/net-hour)**
F1	4	873	15	44	5	49	0.0056
F2	9	927	23	84	47	131	0.1413
F3	23	857	31	100	16	116	0.1353
F4	63	872	30	87	16	103	0.1181
Total	-	3529	45	315	84	399	0.1131

Forty species were classified as typically forest species (88.9%), including the ones that use the edges, while five (11.1%) were considered as facultative forest species. Endemic species of Atlantic forest have represented 37.7% (n= 17) and were more abundant in F3 (n= 13) and F4 (n= 11) and were quite similar in F1 (n= 6) and F2 (n= 7).

The nine more captured species were *Turdus rufiventris* (n=43), *Pyriglena leucoptera* (n=36), *Tricothraupis melanops* (n=22), *Tachyphonus coronatus* (n=21), *Conopophaga lineata* (n=21), *Chiroxiphia caudata* (n=17), *Lepidocolaptes fuscus* (n=16), *Turdus leucomelas* (n=13) and *Leptotila rufaxilla* (n=11). The generalist and omnivorous *Turdus rufiventris* was the dominant species, with 43 captures in the four fragments, particularly in F3 (n= 16) and F2 (n= 14). The understory insectivore *Pyriglena leucoptera* although the second more frequent species in the captures, with a total of 36 individuals, was clearly concentrated in F3 (n= 15) and F4 (n= 11). Accordng to the dendrogram of cluster analysis, the fragment F3 was the most distinguishable, and F1 and F2 the most similar (Fig. 8).

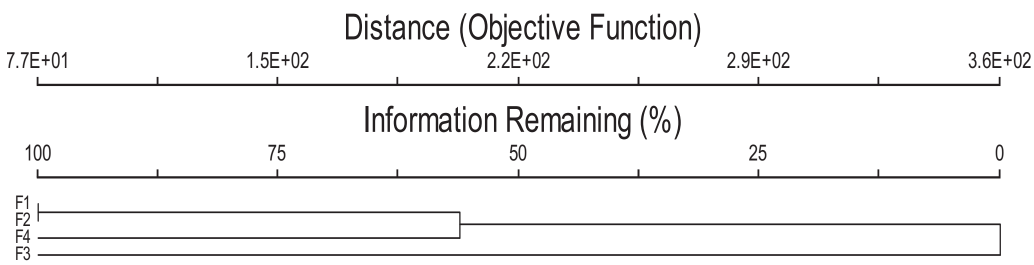


Figure 8: Dendrogram showing cluster analysis for the four studied fragments in relation to capture rates in Teresópolis, RJ.

A total of 84 individuals from 22 species were recaptured during the sampling efforts. *Tachyphonus coronatus* was the most recaptured species (n = 13), followed by *Lepidocolaptes fuscus* (n = 11), *Chiroxiphia caudata* (n = 9), *Thamnophilus caerulescens* (n = 7), *Turdus ruufiventris*, *Conopophaga lineata* and *Turdus albicollis* (n=5 each one).

Only one individual (*Lathrotriccus euleri*) was recaptured in a fragment different from where it was banded. This record of movement occurred between the fragments F2 and F3, which were very close to each other (150 meters). Movements within the fragments were recorded when the net lines alternated edge and interior; eight occurrences in the F2 and two in the F3 and F4.

The Shannon's diversity index has indicated F4 as having the highest diversity (H'= 3.117), followed by F3 (H' = 2.972), F2 (H '= 2.885) and F1 (H' = 2.544). All these indexes are below those of PARNASO (see Table 3). The Homogeneity Index (J ') had values close to 1 for all fragments, which indicates uniformity in the composition of species and the absence of dominance (Table 9).

Table 9: Number of species and individuals, species richness, indices of Homogeneity and Diversity in four fragments in the region of Teresópolis, RIO DE JANEIRO.

	S	**n**	**d**	**J´**	**H´**
F1	15	44	3.700	0.939	2.544
F2	23	84	4.965	0.920	2.885
F3	31	100	6.514	0.865	2.972
F4	30	87	6.493	0.916	3.117

S = number of species, n = number of individuals, d= species richness according to the Margalef index: d=[S-1]/logS), J´= homogeneity index ,H´= Shannon's index of diversity.

A positive and significant correlation between fragments' size and species diversity (R = 0.9681, p = 0.81) was verified (Figure 7). The Sorensen's Index of Similarity has showed that the fragments F3 and F4 (83.05) and F2 and F3 (79.57) would be the most similar concerning bird fauna composition. No indicator species was detected after running the Indicator Species Analysis.

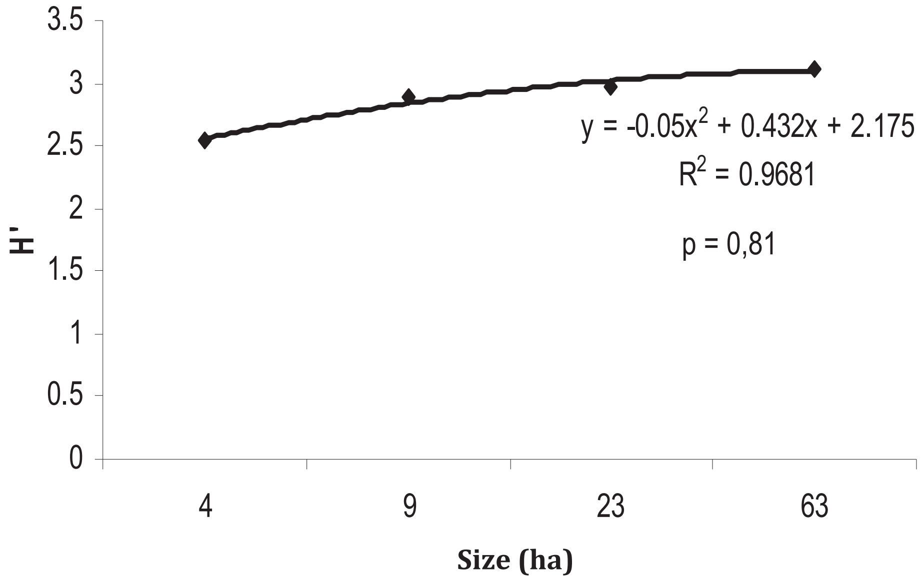


Figure 9: Second-order polynomial regression relating Index of Diversity (H') and size of four forest fragments in the region of Teresópolis, RIO DE JANEIRO.

Insectivorous species have predominated in all fragments, but mainly the most generalist ones (the understory insectivorous), followed by the omnivores. In all cases, the representativeness of frugivorous was very low (Table 10). Although not as a conclusive approach, we can observe a trend in occurrence of some more specialized groups, both in fragment F4 (the largest) and the PARNASO (Figures 5 and 6). These groups, as the carnivores, ground and trunk-twig insectivores and canopy frugivorous, may also have been underestimated by mist nets, but can indicate a trend that may be related to the ecological integrity of more continuous forest areas.

Table 10: Trophic guilds of bird species sampled in four forest fragments in the region of Teresópolis (RJ).

Trophic Guilds	**F1**	**F2**	**F3**	**F4**	**PARNASO**
DIURNAL CARNIVORES	0	0	0	0	3 (6.7%)
NECTARIVOROUS	0	1 (4.3%)	0	1 (3.3%)	4 (8.9%)
Canopy frugivorous	0	0	0	0	3
Egde frugivorous	1	1	2	0	0
Ground frugivorous	1	1	2	2	2
Understory frugivorous	0	0	0	0	1
TOTAL OF FRUGIVOROUS	2 (13.3%)	2 (8.7%)	4 (12.9%)	2 (6.7%)	6 (13.3%)
Bamboo-tangles insectivorous	1	1	3	2	1
Canopy insectivorous	1	0	1	1	3
Egde insectivorous	0	0	1	0	0
Ground insectivorous	0	0	0	0	3
Trunk-twig insectivorous	1	3	3	6	4
Understory insectivorous	5	9	10	11	14
TOTAL OF INSECTIVOROUS	8 (53.3%)	13 (56.5%)	18 (58.1%)	20 (66.7%)	25 (55.6%)
Edge omnivores	3	4	5	3	4
Understory omnivores	2	3	4	4	3
TOTAL OF OMNIVORES	5 (33.3%)	7 (30.4%)	9 (29.0%)	7 (23.3%)	7 (15.6%)
Total of species	**15**	**23**	**31**	**30**	**45**

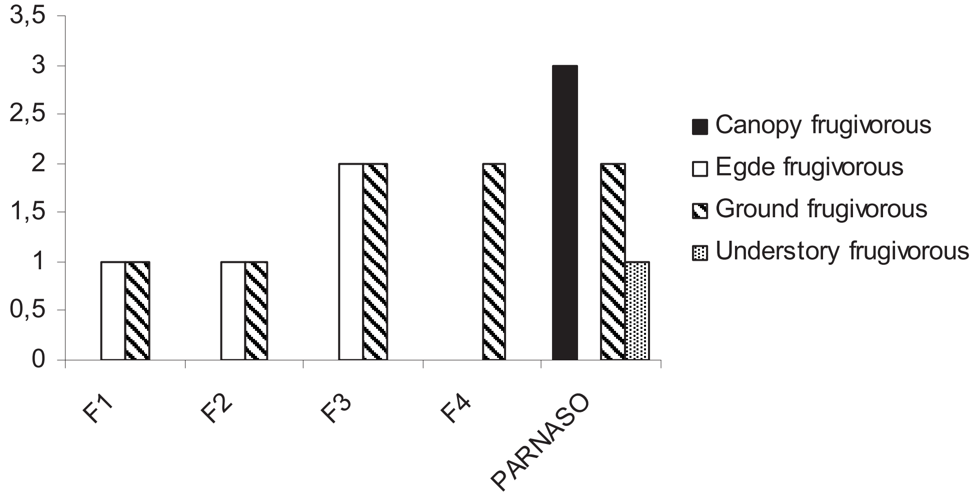


Figure 10: Frugivorous birds in four forest fragments and in the Serra dos Órgãos National Park, Teresópolis (RJ),

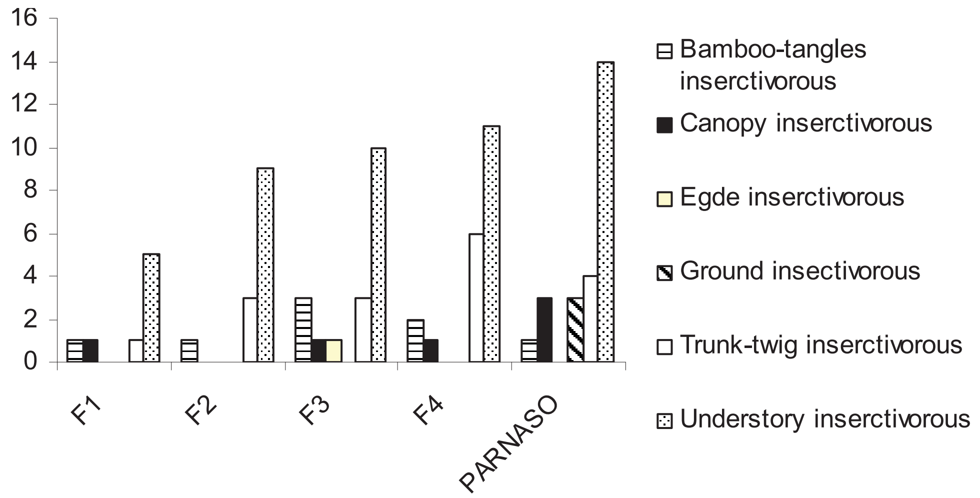


Figure 11: Insectivorous birds in four forest fragments and in the Serra dos Órgãos National Park, Teresópolis (RJ).

In relation to nesting, there was a predominance of species that nest on the vegetation, and presence of birds that excavate galleries in the soil for nesting was observed only in fragment F2. Comparing to PARNASO (Table 11), almost the same proportion was observed, but including more species that burrow galleries in the soil. This could be a bias of the methodology; mist nets may to sample these kinds of birds with the same efficiency than others, due to their habits.

Table 11: Bird species according to their assumed substrate for nesting in four forest fragments and in PARNASO, in the region of Teresópolis, RJ. (V: species that nest on the vegetation, TE: species that burrow in the trunks of trees and arboreal termite nests, TO: species that occupy pre-existing cavities in tree trunks, but are unable to dig them, S: species that nest on the ground and G: species that burrow galleries in the soil. According SICK (1997).

	F1	**F2**	**F3**	**F4**	PARNASO
V	10 (66,7%)	14 (60,9%)	24 (77,4%)	19 (63,3%)	29 (64.4%)
TE	1 (6,7%)	1 (4,3%)	1 (3,2%)	7 (23,3%)	4 (8.9%)
TO	1 (6,7%)	3 (13,1%)	3 (9,7%)	2 (6,7%)	6 (13.3%)
S	3 (20,0%)	3 (13,1%)	3 (9,7%)	2 (6,7%)	2 (4.4%)
G	0	2 (8,7%)	0	0	4 (8.9%)

Discussion

Our results show that the analysis here proposed can be valuables tools for characterization of bird communities and for understanding the effects of forest fragmentation on these communities.

Former studies have shown that for many Passerine birds the distance between fragments is a crucial factor for their dispersal (Anjos & Boçon 1999, Anjos 2001). It is already very known that the fragment size, as well as the surround area, is very important in determinating bird communities structure (Gascon et al. 1999, Laurance et al. 2000, Stouffer et al. 2006). Thus, the more fragmented and isolated an area, the less complex a bird community would be. This can be notice by many ways, as the structure of trophic guilds, the way the birds nests and the presence of rare/specialized/endemic species.

The predominance of generalist insectiovorous and omnivores confirms Willis (1979), who stressed that birds in these guilds are the most resilient in degraded areas. Expressive representation of insectivores are also common in smaller fragments (ANJOS 1998), mainly the generalist ones, which capture insects on the vegetation. In this sense, it is notorious the absence or reduced number of more specialized feeding guilds in the fragments, as trunk-twig insectivores and large frugivorous, which can be found in PARNASO.

The lack of specialized frugivorous in the fragments may reflect in seed dispersal, which is much reduced and less efficient. In this sense, the regeneration of open pasturelands will be influenced, thought good potential seed dispersals may not live there anymore, and the more generalist small passerines may not cross open areas. Here we link these data to the need of strategies to “stimulate” birds going to open areas, as the artificial perches.

Piratelli et al. (2008) have published a paper discussing the role of some passerine birds as bioindicators of forest fragmentation, and they concluded that some species were not by chance associated to the PARNASO, and indeed, these species could be assigned as bioindicators for more continuous and preserved areas.

The presence of birds that use galleries dug in the ground to nest only in one fragment (F4) can be explained by the presence of a water course in this fragment. This led us to the assumption that habitat heterogeneity is very important for sustain such specialized birds. The evaluation of data on structure of habitat, topography, impact of light and phytophisiognomy of the studied areas may contribute to understanding the results, considering that huge human changes were and keep been made in these areas.

The fragments serve as a source of energy to the surrounding population, mainly in the form of wood for firewood and small buildings. It is also relevant to note that activities of captures for cage occurs in those areas, with special emphasis on F2 and F3, which may reflect in the absence of some songbirds, for example.

Conclusions

Bird communities in fragmented areas have some common problems that, once detected, can be used to indicate levels of environmental degradation. Among these problems, we can mention the loss of specialized trophic groups as the large canopy frugivorous and predators, trunk-twig and ground insectivores. Species that need more specific substrates for nesting, such as those that burrow galleries in the soil and / or use cavities in tree trunks to nest are also very affect to the degradation of their habitats.

In the particular case of frugivorous, the loss of these elements reflects the reduction of seed dispersal and plants communities impoverishing, contributing to an increasing isolation of forest remnants. Isolated, the populations of the resilient species tend to a rapid reduction and to local extinction. Alternatives such as artificial perches discussed here, as well as the addition of trunks of dead trees, can help restore areas in an advanced state of degradation.

The data here shown may not only reflect a local situation, but a recurring problem for the Atlantic: degradation and fragmentation. Predatory activities must be fought and, at the same time, rural communities need to rethink the way natural resources have been exploited. It is urge and necessary a strict enforcement by the authorities, but at the same time offering alternatives for sustainable use of forests.

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CHAPTER 18

AGROBIODIVERSITY ASSESSMENT IN THE ATLANTIC RAINFOREST OF BRAZIL

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Abstract: In the municipality of Teresópolis Rio de Janeiro, the genetic resources of plants in a dynamic, ecological and economic complex were evaluated and the agro-biodiversity in seven farming systems within 7 agro-ecosystems and 2 natural systems was assessed. The use and management of biodiversity and indicators of agricultural crop genetic resources were evaluated. The ecological farming systems, agroforestry, Silvopastoral systems, and perennial cultivations present the best indices and help to reduce the pressure on the fragments and deforested areas. Also, they play an important role as bio-corridors and buffering reserves and they also introduces a modest biodiversity level in these depredated areas of the Atlantic Forest.

Key words: *Agrobiodiversity, biodiversity, farming systems, Atlantic Forest.*

Introduction

The current world food crisis is making us reanalyze the way that we should continue to develop the agriculture at world levels and we meet again the importance of agro-biodiversity to develop sustainable agricultural production systems. There is a need to suitably express the enormous importance of agro-biodiversity for the food security of future generations, for the sustainability and stability of the agricultural ecosystems of the world, and as a source of original material for breeding and innovations. Its conservation and sustainable utilization must be formulated as a political priority in all important areas of politics (Hammer 2003).

The objective of this paper was to evaluate genetic resources of plants in a dynamic, ecological and economic complex and to assess agro-biodiversity in seven farming systems within agro-ecosystems and natural systems. We assume as hypotheses that agricultural systems can reduce the pressure on forest fragments and deforested areas, improve the cycle of water, influence the dispersion of fauna and flora, offer better resources and habitat for the survival of plants and animals, and also play an important role as bio-corridors and buffering reserves.

Methods

The study was conducted in the mountain region of Rio de Janeiro in the municipality of Teresópolis (latitude -22°24´43.2 and a longitude of 42°67´), an altitude of 871 meters above sea level. A total of 108 production units were evaluated. In natural and agricultural systems, only plant diversity was evaluated, i.e. crops and plants, herbaceous cover, bush vegetation, and tree species inside the farming systems. The evaluated farming systems in Teresópolis were: (i) Leaf vegetables systems, (ii) Fruit vegetable systems, (iii) Mixed Fruit and Leaf Vegetable Systems, (iv) Citrus Production systems, (v) Ecological Production systems, (vi) Cattle Production systems and (vii) Silvopastoral system. The use and management of biodiversity and indicators of agricultural crop genetic resources were evaluated.

Use and management of biodiversity

During two years, 16 case studies were carried out and 164 structured surveys were carried out as a main tool to characterize the production systems and management of resources. In addition, 28 informal interviews were conducted.

Indicator of agricultural crop genetic resources

The *Shannon Diversity Index (H')*. H' has two properties that have made it a popular measure of species diversity: (i) H' = 0 if and only if there is one species in the sample, and (ii) H' is maximum only when all S species are represented by the same number of individuals, that is, a perfectly even distribution of abundances. (Merman 2004, Magurran 1988, Eiden 1994). The *Simpson* is a *dominance index*, which is suited for inter-varietal diversity combining the number of varieties planted with their relative importance (Meng *et al.* 1998). The *H'* and Evenness (*E)* indices, which are generally referred as *alpha diversity*, indicate richness and evenness of species within a locality, but they do not indicate the identity of the species and where they occur. Consequently, variation in composition of species among the different farms and systems was determined by computing *Beta diversity*. *Beta diversity (â)* is expressed in terms of a similarity index between different habitats in the same geographical area.

Findings

Biodiversity in farming systems: The clearly dominant system is raising cattle with 74% of the total agricultural surface of the basin. The horticultural systems are the second most important (24%), of which the leaf-vegetables systems are most important with 14%. The Silvopastoral system occupies only 2% and the ecological and organic cultivations less than 0.4% (Figure 1).

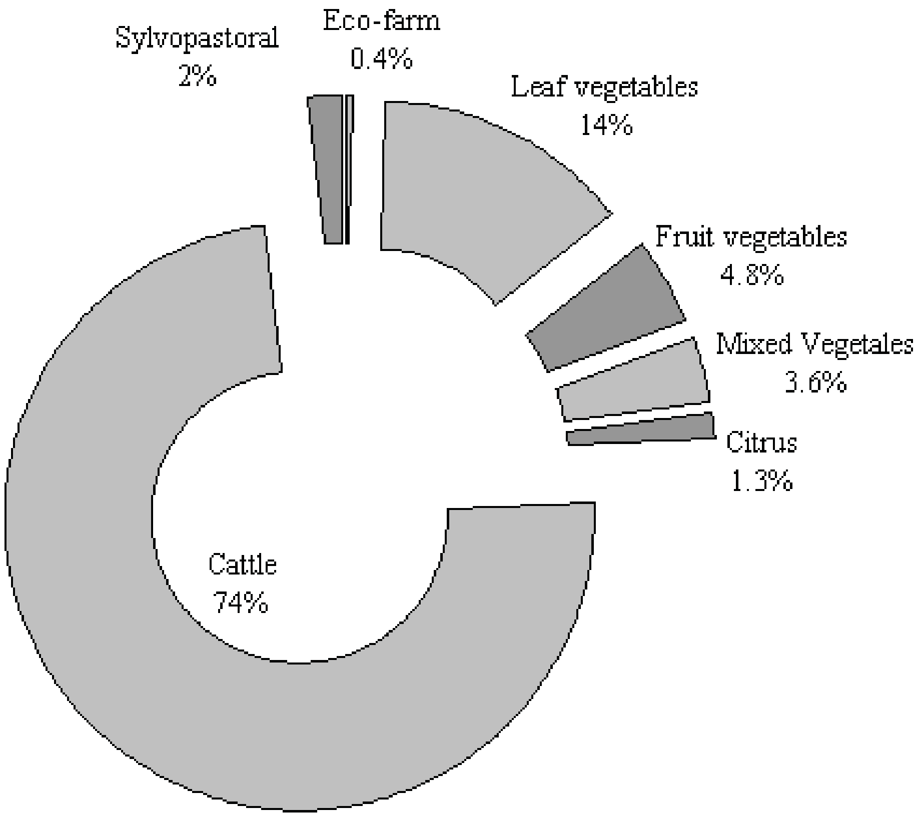

Figure 1: Relative importance of farming systems

Cattle or livestock grazing is one of the most widespread land uses in Brazil. In Teresópolis, raising cattle has greatest impact on regional biodiversity. Approximately 74% of land (1,327 ha) is currently under pasture and in many areas pasture land is still expanding slowly. The gradual transformation of forest into pasture and agricultural land has had profound ecological impacts in the region, changing the species composition of communities, disrupting ecosystem functions (including nutrient cycling and succession), altering habitat structure, aiding the spread of exotic species, isolating and fragmenting natural habitats, and changing the physical characteristics of both terrestrial and hydrological systems. Similar transformation processes have been reported by Fleischner (1994), Noss (1994), Gomez-Pompa et al. (1993), CCAD (1998). These changes, in turn, have often resulted in the reduction of both local and regional biodiversity.

Table 1: Diversity, richness, dominance and evenness indices compared across different farming systems in Teresópolis

	Diversity (H′)	**Richness** (R_{ch})	**Dominance** (1-D)	**Evenness** (E)
Ecological systems	3.19	96	0.93	0.70
Leaf vegetables	2.18	19	0.86	0.74
Fruit vegetables	2.01	19	0.81	0.68
Mixed vegetables	2.22	21	0.86	0.73
Citrus	0.1	8	0.03	0.05
Cattle	0.01	8	0.00	0.00
Silvopastoral	0.08	34	0.01	0.03

H′=-(sum Pi*lnPi); Rch=N°sp; D=1-(sum Pi^2); E=H′/lnS

A complete list of the species is enclosed in Appendix 2: Table 5

The lowest dominance indices correspond to cattle systems (0.00) and to citrus (0.01). It means that a few species dominate, in this case, *Brachiaria decumbens* and *Melinis minutiflor.* Both systems are also characterized by lowest richness, with only 8 species mostly herbaceous (Table 1).

The implementation of cattle systems is the cause for the fragmentation of landscapes, not only altering their functions but also the behaviour and dynamics of animal and plant populations inside the fragments (Birregard *et al*. 2001). Fragmentation also causes decrease of biomass production, especially at the fragment edge (Laurence *et al*. 1997). For the development of tropical ecosystems, cattle systems are ranked as the major driving force for the next 100 years (Sala *et al*. 2000). Smaller patches contain relatively more edges than larger patches. Abrupt forest edges also affect most ecological variables and indicators of forest dynamics, such as species distribution, tree mortality and regeneration, biomass loss, and community composition of trees. According to some recent estimates of the edge effects of fragments, only the largest forest fragments (>50000 ha) are immune from detectable ecological effects of isolation (Curran *et al*. 1999).

The Silvopastoral system maintains low indices of diversity, still dominated by grasses. The great difference with the cattle systems is the richness of species, being increased fourfold. The most important Silvopastoral species are the following (i) pastos: *Melinis minutiflor and Brachiaria decumbens.* Timber: *Lonchocarpus sp, Tibuchina sp, Piptadenia gonoacantha, Cróton floribundus, Machaerium sp*. All species from Silvopastoral systems are listed in Appendix 2: Table 5.

Thirty four timber species were identified in Silvopastoral systems. Thus indicates that in these systems, a significant portion of the original biodiversity can be maintained within pastures, if they are designed and managed appropriately (Greenberg 1997; Harvey 1999). Pezo & Ibrahim (1998) listed additional positive effects for maintaining and conserving biodiversity, e.g. producing timber, forage and fruits, providing shade for cattle, and promoting soil conservation and nutrient recycling.

Silvopastoral systems provide structures, habitats and resources that may enable the persistence of some plant and animal species within the fragmented landscape, thereby partially mitigating the negative impacts of deforestation and habitat fragmentation. Marten (1986) additionally says that in these systems the arboreal species are used for construction materials, firewood, tools, medicine, livestock feed, and human food. Besides providing useful products, the trees in these systems minimize nutrient leaching and soil erosion and restore key nutrients by pumping them from the lower soil strata.

The management of natural regeneration timber species in Silvopastoral systems represents a low cost alternative for the producer. These systems can be applied especially for farmers with small long term investment capacity. *Lonchocarpus sp, Tibuchina sp, Piptadenia gonoacantha, Cróton floribundus, and Machaerium sp*. are all species that possess good characteristics for the implementation of systems in the study region. Diverse other native species also possess positive characteristics for Silvopastoral systems and they should be evaluated in future. It is important to highlight that pasture fires are considered as an extremely noxious practice for the propagation of tree species.

Exotic species should be broadly investigated for their implementation such as the case of eucalyptus (Andrade 2001). Carvalho (2001) recommends *Acacia mangium, A. auriculiformis* and *Mimosa artemisiana* for use in sylvopatoral systems. The latter three species would also have the capacity to synthesize atmospheric nitrogen.

The leaf vegetables lettuce, cabbage, broccoli, spinach, and watercress and the fruit-vegetables chayote, paprika, and tomato are the base of the economy and occupy circa 40% of the agricultural area. On average, the farmers manage 4 species per hectare (minimum average) with up to 12 species per hectare (maximum average). Plots with as much as 18 cultivated species per hectare were also observed.

Of 15 cultivated families, *Brassicaceae, Solanaceae, Fabaceae, Asteraceae, Fabaceae,* and *Cucurbitaceae* are the most important ones with more than 60 species and 140 varieties of vegetables. This crop diversity is represented by high diversity index (H´=2.18, 2.01, 2.22) for leaf vegetables, fruit-vegetables and mixed vegetables, respectively. It represents a good value for agricultural systems. For the three variants of vegetable systems, dominance is not high (1-D= 0.86, 0.81, 0.86) and the species are equitably distributed. There is a relatively good quantity of species (R_{ch}= 19), in spite of weed control, and most of these species are located on the edge of small plots (Table 1; Appendix 2: Table 5).

The ecological systems present the best indices of diversity. No one crop is dominant, rather, the crops are equally distributed in number and area (1-D=0.93; E=0.7; Table 1). The system houses a very high quantity of species (96). Finally, the Shannon diversity index (3.6) clearly indicates that this system combines a high number of cultivated and not cultivated species.

The most important species in the ecological systems are: (i) vegetables and annual crops; (ii) trees: *Acnistus arborescens* (marianera) is a plant with great potential for agroforestry systems. It is very fast growing, has easy reproduction and good biomass production, and is a good tutor for other cultivations such as chayote. Finally, it produces good quantity of fruits for human consumption and for birds. *Ricinus comunis* is another very fast growing plant, it is important for the recuperation of fertility in fallow plots and contributes with a good quantity of organic matter to fertility restoration of the systems. Their great quantity of terpenes is also used for obtaining bio-energy. Other important species in the region, which can be found in ecological farms and agroforestry systems, are *Vernonia polianthes, Piptadenia gonoacantha, Lonchocarpus sp, , Luehea divaricata;* (iii) herbaceous: *Cyperus rotundus L* (tiririca), *Melinis minutiflora, Artemisia vulgaris* (Losna), *Eleusine indica* (pê de galinha), *Siegesbeckia orientalis* (botao de ouro), *Amaranthus deflexus* (carurú), *Digitaria horizontalis* (mulambo), *Aristolochia clematitis* (papo de peru) all considered weeds. Some other plants can be found in ecological farms and in recovery areas, such as *Baccharis sp., Vernonia polianthes, Psidium cattleiano, Aeschynomene denticulate, Triunfeta sp., Lantana camara, Cecropia sp., Tibuchina sp.,* and *Euphorbia heterophylla.*

In ecological systems, biodiversity offers ecosystems services beyond the mere production of food, fibre, fuel, and income, by stabilising yield or income in case of incidences of disease and pests or when market prices are fluctuating (Wiersum 1982). This ecosystem service also helps in recycling nutrients (Alesandria *et al*. 2002), controlling local microclimate, regulating local hydrological processes, regulating abundant undesirable organisms, and finally, detoxifying noxious chemicals. Reijntjes *et al*. (1992) states that the main strategy in ecological systems is to exploit the complementarities and synergism that result from various combinations of crops, trees and animals in spatial and temporal arrangements.

The richness and stability in ecological systems make them important sites for in situ conservation within eco-zones and also offer better positive possibilities through the presence of numerous niches in which agro-diversity can survive. Trinh *et al.* (2003), Michon *et al*. (1983), Fernandes (1986) concluded in a similar way after having studied agro-diversity in home gardens. In concordance with Mac (2001), it was found that managing numerous species in ecological systems could provide usable frameworks for maximizing their benefit to biodiversity.

Polycultures and agroforest patterns are characteristic of these systems. The high species richness of all biotic components of traditional and ecological agro-ecosystems is comparable with that of many natural ecosystems (Altieri 1999).

One way to reintroduce biodiversity into large-scale monocultures is by establishing crop diversity by enriching available field margins and hedgerows which may then serve as biological corridors allowing the movement and distribution of useful animals and insects.

There is wide acceptance of the importance of field margins as reservoirs of the natural enemies of crop pests. Many studies have demonstrated increased abundance of natural enemies and more effective biological control where crops are bordered by wild vegetation. These habitats may be important as over wintering sites for natural enemies and may provide increased resources such as alternative host, pollen and nectar for parasitism and predators from flowering plants (Landis 1994, Altieri 1999).

Analyzing biodiversity within this context is an extremely complex task, but one which lies at the heart of all discussions concerning its sustainable use. This complexity arises because of the multitude of different ways and the range of different scales, both in time and space, in which any given resource can be viewed (Serageldin and Steer 1994). In terms of human uses and needs, biodiversity can be looked on as part of the entire capital stock on which development is based. This stock can be divided into the following: natural capital, living and non-living environmental assets, including biodiversity; fabricated capital, machines, buildings, infrastructure, human capital, human resources, and social capital, the social framework (Groombridge 1996).

In fallow land or forest areas in regeneration, plant diversity and density of individuals and species are influenced by the intensity and frequency of management operations. Vegetation of wild fallows that were not managed was clearly dominated by individuals of C*ecropia spp* (embaúbas), *Lonchocarpus sp* (timbó), *Vernonia polianthes* (Assa peixe), *Tibuchina sp, Piptadenia gonoacantha* (Pau Jacaré), *Croton floribundus* (sange de drago), *Aeschynomene denticulate* (angiquinho), and other early colonizing pioneer species.

The fallow land on agricultural areas include mostly herbaceous and shrub species such as *Vernonia polianthes* (assa peixe), *Acnistus arborescens* (marianera). This enriched area normally contains forest species, bananas and varieties of citrus. In these areas more species were found than in the natural fallow areas, in agreement with Anderson (1992) and Pinedo-Vazquez (2000). The latter authors say that despite the assumption that human intervention in fallows lowers the species richness, it is still possible that fallow land may contain higher levels of plant diversity.

Despite differences in forest use and in management practiced by farmers, forests in all sites showed high diversity of Shannon's Index (average H' = 2.59). These results were very similar to those reported for forest areas in other regions of Brazil as e.g. in the estuarine floodplains of neotropical forest (Anderson 1992).

In agricultural areas reconverting to secondary forest (about three years of age), the most important families and species were Leguminosae (Papilonoideae) (*Lonchocarpus sp*), Euphorbiaceae (*Croton floribundus*), Anacardiaceae (*Schinus* *terebinthifolius*), and Sapotaceae. In the bush stratum, the most important families and species are Asteraceae (*Baccharis sp, Vernonia polianthes*), Myrtaceae (*Psidium cattleiano*), Melastomataceae (Tibuchina sp).

The ecologically most important families of the woody understory vegetation are Myrtaceae, Lauraceae, Rubiaceae, Melastomataceae, Arecaceae, Nyctaginaceae (BLUMEN 2006).

Interactions among the land use systems: *Fragment-agriculture.* In fact, the interaction of the agriculture with the fragments is very low. Certainly, the farming systems will influence the composition of species in the edges, but fragments are hardly used for extraction purposes by farmers. The environmental impact of the agricultural (horticultural) land on the fragment is rather low, since this land use system is usually located below the fragment. Thus, erosion and water quality impacts are rather inflicted on land use systems downstream within the river basins, than on forest fragments. Not-quantified nutrients that come from the fragments are deposited on horticultural land, a benefit yet to be quantified.

Specific cultivations such as chayote and tomato are examples of direct impact of farming activities on fragments, requiring stakes and posts to serve as tutors in the cultivation. The total area of these cultivations is low, as well as the numbers of farmers extracting these materials. The requirements of extraction are about 620 posts of 2.3 m per hectare of chayote. For one hectare of tomato, 10500 stakes of bamboo of 1.8 m, and 260 stakes of 2.3 m are extracted.

Fragment - raising cattle. Although at a very low rate, deforestation for pasture land is still going on. The dynamics of land use change could not be analyzed, and so it can not be said, what kind of land is being lost, whether valuable old structured forests or recently re-established fragments with *Capoeira* (re-emerging bush land during fallow) characteristics.

A serious impact of beef cattle and horses was observed by accesses to water sources in the forest, where animals go to drink, ruminate and rest in the shade, and graze or browse from what plants can offer there. Doing so, animal faeces contaminate the water sources, which are often used as drinking water in the households below.

Raising cattle– agriculture. The agricultural systems and cattle have very little interaction. The manure is not used in agriculture; it remains in the pasture areas. The agriculture residuals are kept in the cultivation field for organic matter incorporation. Sugarcane and *Capim gigante (Penisetum purpureum)*, as stated before, are the only cultivated forage crops requiring arable land and thus, are directly competing with alternative cropping systems.

Horticulture production requires large amounts of organic matter, which is obtained by truckload from other regions, even neighbouring states such as São Paulo and Minas Gerais.

Organic matter is certainly an economically highly significant matter. More interaction among animal husbandry and horticulture systems is assumed to be required for overall agricultural productivity and profitability improvement. Ecologically, it would be highly welcome to substitute long-distance transports of manure with local supply.

Settlements – fragments. For house construction and tools, the farmers usually use the wood of the fragments. They also extract some medicinal plants and occasionally eat some animals.

Environmental perception of farmers: e environmental perception of farmers was assessed in individual interviews and a workshop was held with the farmers from the study area.

*Farmers' observations of landscapes***.** 81% of the interviewees stated that during the last 30 - 50 years the landscape has changed a lot. Major changes observed were urbanization – construction of many new houses. Forest used to be more dominant in relation to pasture and agriculture (50 years ago). The practice of burning bush land is nowadays more widespread than5-10 years ago. Orchards with citrus have emerged only recently.

Farmers' observations of forest fragments. In the past, large and "beautiful" tree species were found in the forests, many of them with great economic value, some of them being scarce and having already disappeared from the fragments as for example: Brauna, Cambota, Garapa, Ipê, Cedar, Maçaranduba, Jacaranda, Peroba, Oricana, candeia, Cinzero, and some others that the farmers were not able to specify.

Conservation attitude. 92% of the interviewees answered that they preserve their fragments. They prevent hunting and deforestation because they are aware that they need the forest to preserve water sources. Reforestation practices are absent. Main reasons for applying conservation measures are: water source, legislation, and emotional value of forest. 72% of the farmers do not know that agriculture could contaminate and cause damage to the environment and only 13% know that inappropriate agriculture practices can cause damage. The remaining percentage did not answer. One out of each 150 productive units has organic production, 33% have heard about organic agriculture and agro-forestry and are inclined to change but they lack the required know-how. 48% do not want to change the production to organic agriculture, considering such efforts as not necessary. The remaining producers consider such a change not possible because of adverse physical conditions and difficulties.

Fragment value to farmers. The most important value of the fragments is as water source (96 % of the interviewees agreed). The second most important use is the wood extraction for construction timber of low quality. The third use is medicinal plants extraction, although 37% state not knowing the medicinal plants from the forest.

Conclusions

From the biodiversity point of view, ecological farming systems, agroforestry- and Silvopastoral systems, and perennial cultivations help to reduce the pressure on the fragments and deforested areas. It improves the cycle of water, and it has also positive influence on the dispersion of fauna and flora. They offer better resources and habitat for the survival of plants and animals than the cattle and horticultural systems. Also, they play important roles as bio-corridors and buffering reserves. Those systems also introduces a modest biodiversity level in these depredated areas of the Atlantic forest, where at the present, a single grass (*Brachiaria decumbens*) dominates more than 35% of the surface.

Also, the diversity and structure of ecological, agroforestry, and Silvopastoral systems contribute additional benefits to the local population, microclimate, and flow of nutrients, dissipate the dynamics of plagues and diseases, and decrease the effects of fluctuating prices of the market.

The agricultural subsystems, cattle and forest, are not very interrelated to each other, giving place mainly to trade-offs rather than providing synergies. The cattle systems do not contribute from any point of view with the conservation of biodiversity. To the contrary, it is the most degenerative practice that threatens biodiversity in the region. It is the main cause for forest fragmentation, also presents bigger soil erosion, and breaks the dispersion of flora and fauna.

In general, farmers appreciate biodiversity positively, but they have no exact knowledge of their benefits. At the moment, the forest fragments represent for the farmers mainly their water source, and are considered very less important as wood source or supply of other by-products such as fruits or medicines.

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PART V

Conclusions

CHAPTER 19

CONCLUSIONS:

BIODIVERSITY AND LAND USE SYSTEMS IN THE FRAGMENTED MATA ATLÂNTICA OF RIO DE JANEIRO

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Challenges for natural resources conservation and sustainable development in the Mata Atlântica of Rio de Janeiro

Land use intensification and climate change are emerging as the greatest threats to biodiversity; we are already seeing the negative impacts of changes in temperature, precipitation and extreme events. Among the ecosystems that are most vulnerable to the negative impacts of land use intensification is the Mata Atlântica.

Biodiversity loss and natural resources degradation in the Mata Atlântica of Rio de Janeiro will continue and will probably accelerate if proper and prompt measures are not taken to break the increased pressure upon the forest fragments, soil and water resources through the intensification of land use systems.

Integration of forest fragments, water and soil protection measures into sectoral policies could be the best solution implementable in a short time. As biodiversity and agricultural good practices are cross cutting issues, the assessment approaches and protection policies need to incorporate wide perspectives. Thus, it would be necessary to integrate assessment and responses at the administrative, sectoral and geographical levels.

The effects on biodiversity and good agricultural practices of the implementation of existing measures need to be analyzed and monitored. Ideally such results should be communicated on a regular basis through a reporting mechanism based on a national monitoring and assessment framework.

Such assessments would also help identify what else may be necessary but is not covered by existing legislation. Showing the gaps in policy terms will help to increase the awareness of importance of biodiversity protection in sectoral policies and possibly lead to the development of a policy framework, which will recognize the central role of land use and biodiversity in Rio de Janeiro state and in the Mata Atlântica Region.

In the near future, the sustainable use of land will be a great challenge, comparable and closely interrelated with the global concerns about changes in climate and biodiversity. This would require that the necessary actions are taken in order to meet today the diverse and potentially conflicting demands on the land resource, without compromising its sustainability.

Sustainable land management is a challenge for the Mata Atlântica. The control of land degradation can be most easily justified in terms of global benefits; these benefits include conservation of biodiversity, control of climate change and progress towards the Millennium Development Goals for human development and poverty alleviation.

The current activities of the Rio Conventions such as the Convention on Biological Diversity are developing revised strategic plans and will soon be assessing progress towards the achievement of the 2010 biodiversity target. The United Nations Framework Convention on Climate Change is in the midst of implementing the Bali Action Plan and is looking towards Copenhagen as an opportunity to negotiate a post-2012 agreement. The United Nations Convention to Combat Desertification has begun to implement its own 10 year strategic plan.

Enhancing the resilience and adaptive capacity requires coordinated efforts to address the drivers of loss including: Restoring or rehabilitating degraded habitats and ecosystem services; promoting the conservation and sustainable use of forest fragments; preserving and enhancing the protective ecosystem services that buffer communities from extreme events; and promoting more sustainable agricultural systems. In addition to preserving and reducing land degradation, maintaining and enhancing the natural adaptive capacity of species should be included in the priorized activities. It could increase the resilience and reduce the vulnerability of ecosystems and people in the face of the adverse effects of global changes.

Finding a balance between activities related to global change, biodiversity conservation, sustainable land use management, and activities to reduce land degradation and desertification does, however, require careful planning. Ecosystem approaches and interdisciplinary analyses are some ways in which the objectives of the different Environmental Conventions can be aligned for the benefit of sustainable development.

Interdisciplinary analysis for land use and biodiversity conservation

The UNESCO remarked that the concept of sustainability represents a fundamental challenge at the theoretical and methodological levels, reorientation within the social sciences themselves is required, implying: Firstly, to give more attention to now vital issues such as land use, the social use of natural resources like water or wood, production and consumption patterns, the loss of biodiversity, etc.; Secondly, to improve and intensify interdisciplinary cooperation among the various social science disciplines. This is necessary to achieve a more integrated and comprehensive understanding of development processes, as well as the relationships between individuals and the environment in their social, political, economic, psychological and cultural aspects. With regard to this, the historical boundaries between the disciplines must be re-examined and methodologies of interdisciplinary research are to be developed; thirdly, to expand the problem oriented cooperation between the social and the natural sciences on issues and questions of sustainability. Of crucial importance here is that natural and social sciences cooperate on an equal basis, starting from the phase of defining the problems under study.

'Synergy' in global environmental discourse means the combined interaction of different topics together towards a common goal – in this case the conservation of the environment and the protection of the services provided by renewable natural resources, the inter-linkages provide greater effectiveness than the sum of the parts.

The problem of integrating different disciplines is not so much a problem of methodology or IT. Large and interdisciplinary cluster projects require an efficient knowledge management to deal with human capital. Integrated models assume the sharing of knowledge and this may lead to the abandonment of a knowledge advantage in favour of the overall project, which principally is an unnatural process.

A move towards more sustainable land use systems, agriculture production and resources conservation in the tropics requires land uses to be integrated into complex but often fragile ecosystems, so that their interactions are mutually reinforcing. Land use options applied by humans should not only seek to exploit resources, but complement each other in optimizing nutrient flow, conserving biodiversity and meeting the range of community needs. The spatial and temporal integration of land use systems is fundamental to sustainable agriculture and the conservation of natural resources. The spatial arrangement of various land use systems affects biophysical factors as well as socioeconomic factors within the agro-ecosystem. In addition to the difficulties of determining an appropriate mix of land uses within a region, a country or a specific site, sustainability also requires the temporal arrangement of land uses and their integration over time.

Landscape and soil degradation in the municipality of Teresópolis

Deforestation processes in the municipality of Teresópolis started in the early 19th century with the establishment of the first *fazendas* in the mountain region. The clearing of the natural vegetation cover led to high erosion rates on the steep slopes and accumulation of colluvial sediments in the foothills and floodplains. Until the mid-20th century land use types and intensity were strongly related to road infrastructure and market access, land ownership, motivation of the farmer and traditions of the European settlers.

With the construction of the National Highway BR-116 in 1959, providing a direct road connection between Teresópolis and Rio de Janeiro, and the asphalt coating of the Interstate Highway RJ-130 Teresópolis – Nova Friburgo in 1974, market access was essentially improved. As a consequence, vegetable gardening in the hinterland of Teresópolis became more attractive, because from then on products could profitably be sold in the markets of Rio de Janeiro. Former fazendas, such as the Fazenda Conceição in the Córrego Sujo valley, were split into smaller units. These so called "micrositios" with an average size of 3-4 ha were cultivated by small farmers. In many valleys a typical land use pattern evolved: intensive vegetable gardening in the floodplains and intramontane basins and pastures and some permanent crops on the steeper slopes and hilltops. Forest fragments of different sizes and shapes remained mainly on south-facing slopes, very steep slopes (>30%), and in source areas.

Rill and gully erosion are mainly found on pastures as a result of overgrazing. Some gullies cut deep into former drainage channels along fences. A few gullies are already stabilized and overgrown with bushes or trees. Some of them likely developed under different environmental and land use conditions. The spatial distribution of gullies reflects primarily the relief feature's slope inclination and length as well as historical development and land use intensity. Thus gullies are concentrated on steep slopes on overgrazed pastures, particularity along main roads. By contrast, the impact of soil properties and local climatic conditions is relatively low. As agricultural activities in the municipality of Teresópolis started just two centuries ago, the extent of damage is much lower than in the wider parts of the coastal ranges of Rio de Janeiro State, which have been intensively used for many centuries (Nehren 2008).

Apart from visible erosion, soil analyses shed light on further landscape and soil degradation processes. For instance, a high content of charcoal pieces in loose colluvial foothill sediments of the investigated forest fragments prove former cultivation. In some cases even fire horizons of some decimetres were found. Various catenas show that the topsoils of the (recently or formerly) cultivated hilltops and higher slopes are eroded and only a thin soil layer of a few decimetres with a high content of saprolite material is left. The eroded material is deposited on the foothills as colluvial layers (Nehren 2008).

Even though most degradation processes are directly related to agricultural land use practices, (sub)urbanization processes and tourism also cause great damage. Apart from deforestation and soil erosion in the cities and suburbs, these processes also take place in rural areas. In the municipality of Teresópolis numerous tourism facilities and secondary residences were built on hills along the main roads and in accessible side valleys. These new developments have a massive impact on vegetation, soil and water resources. Landslides are also related to building activities. They often occur after heavy rainfall events along roads and in hillside settlements, mainly in favelas.

Currently, rural land use dynamics are mainly characterized by an expansion of irrigated vegetable cultivation due to the high demand for vegetables in Rio de Janeiro. Eucalyptus plantations are also becoming more important. In some less developed valleys floodplains are drained to increase the area available for irrigation agriculture. In intensively used valleys most of the floodplains are already used for vegetable production. Here, new fields are cleared on steep slopes mainly on former pastures or bush fallow (capoeira). In the Corrego Sujo valley an (illegal) clearing of forest land for vegetable gardening was observed only in two cases, both limited to relatively small edges of forest fragments (between 2002 and 2005). Further deforestation zones were visible in the suburbs of Teresópolis, rural settlements, and tourism facilities adjoining to forest areas. On the other hand, some areas of advanced successional forest indicate natural reforestation processes. All in all the present dynamics of deforestation and reforestation in the municipality of Teresópolis are relatively low.

These findings correspond with satellite observations (LANDSAT 7) showing that the forest cover in the municipality of Teresópolis (32% of the total land cover) has not changed in the periods 2000-2005 and 2005-2008 (SOS Mata Atlântica/INPE 2008, 2009). However, with the scale of 1:50,000 only forest patches of at least 3 ha can be identified, so that land cover changes at a small scale are not considered. Moreover, the satellite data do not provide information about the quality of forest fragments. Hence, neither the qualitative degradation of (remaining) fragments nor the proportional loss of old, precious fragments is recorded.

As a result, we can state that the stage of landscape degradation in the municipality of Teresópolis is relatively low compared to many other landscapes in the triangle of Rio de Janeiro, São Paulo and Belo Horizonte. The main reason is the high relief energy with very steep slopes towards the Atlantic side involving difficult accessibility and therefore late development as well as difficult or impossible agricultural land use. Nevertheless, in the hinterland of Teresópolis deforestation and soil degradation have reached serious levels within a short period of time. Although LANDSAT images show no major forest loss between 2000 and 2008, the remaining forest patches are under high pressure due to a massive change of the environmental conditions.

The cultivation of vegetables on steep slopes in particular causes high erosion rates. As many former pastures are transformed into cropland, interrill and sheet erosion become predominant over linear types. In addition, the widespread burning of grasses and shrubs (legal if not higher than 3 m) and building activities are responsible for severe soil losses. Due to an often thin soil cover on the upper and middle slopes, the risk of losing agricultural land is very high, even if preventive measures, such as terracing and contour ploughing, are taken. This in turn puts more pressure on the remaining forest fragments as a resource for new agricultural land. In this context, further investigations in the field of quantitative soil erosion modelling for different land use systems are necessary. From the agricultural side, practical guides for erosion control need to be developed.

Another important aspect of land use intensification is its impact on the water balance. Some effects, such as an increased runoff through reduced infiltration, leading to more intense flood events has already been proved for small watersheds in the municipality of Cachoeiras de Macacu in the lower ranges of the Serra dos Órgãos (Rominger 2008, Doose 2009). Moreover, bank erosion along streams and the loss of highly productive alluvial soils going along with it are already visible. Less obvious are the consequences for groundwater resources. Here, land use changes and the increasing water demand for irrigation may probably lead to seasonal water scarcity even in a region with rich water resources. Therefore, in the new research project DINARIO more attention will be given to hydrological models including land use changes and local climatic effects.

Finally, the regional effects of climate change must be considered. For Southeast Brazil current scenarios show a moderate temperature rise of 1 to 3 °C (optimistic scenario) or 2-4 (pessimistic scenario) until 2100 (Marengo 2007). Furthermore, the region may become slightly drier and extreme weather events may become more intense and more frequent (Marengo et al. 2007). This will probably aggravate water scarcity problems in agricultural landscapes and even result in water stress for rainforest vegetation in dry periods, particularly for isolated forest fragments in the drier hinterland. At the same time increasing erosive rainfalls in the wet season will cause higher erosion rates and a further degradation of soil resources.

Vegetation variability on different scales

The high biodiversity and endemism rates found in the Atlantic Forest can be explained at least partly by historical vegetation dynamics and the related speciation processes as well as by the latitudinal, altitudinal and continentality gradients and the resulting environmental diversity. On large spatial scales the differentiation and variability of vegetation along these gradients is well known. By contrast, the small-scale floristic differentiation is poorly studied for most of the vegetation formations recognized and classified within the Mata Atlântica.

All our investigations on floristic and structural vegetation characteristics carried out in the municipality of Teresópolis indicate variable vegetation patterns and dynamics at regional and local scales, which may be based on a variety of at least partially interacting causes. Different spatiotemporal within-canopy dynamics of relatively small forest fragments in the rural area of Teresópolis and the larger continuous forest of the Serra do Órgãos National Park results from differently expressed seasonality of microclimatic conditions within the forests. These conditions are influenced partly by the mesoclimatic variability within the region but as well by forest size and its floristic composition. On the other hand forest size and floristic composition as well as phytodiversity are also strongly coupled to each other. Different sized forest fragments have been shown to present different floristic and diversity patterns, even though they are spatially very close together. This might be explained partially by either abiotic differences, by different disturbance and successional dynamics, or by the interaction of these factors, which in turn are influenced also by the fragment size itself.

Also within the well preserved, continuous forest of the Serra do Órgãos National Park a comparable high variability of vegetation patterns observable on a relatively small, local spatial scale. Furthermore, this variability is strongly expressed in different vegetation strata and floristic groups. As the high habitat heterogeneity may be the most important differentiating factor within the investigated area, this indicates a different sensitivity of different vegetation components to spatial habitat heterogeneity on a mesoscale. In this context we suggest the stronger inclusion of understorey vegetation in future floristic-structural surveys. This would not only provide much more complete knowledge concerning phytodiversity and vegetation patterns, but probably also facilitate the detection and evaluation of possible indicator species. Because of their observed habitat specialization, some Pteridophytes in particular should be very suitable indicator species, which may provide a useful tool for the management of the National Park.

A profound knowledge of the actual variability of species and structural diversity and dynamics is widely accepted to be a basic precondition for the planning and execution of effective and sustainable conservation activities and the modelling of development scenarios. In this context, even the few results of floristic and structural vegetation variability presented in this book demonstrate the necessity of research approaches which focus on the detection and analysis of species and structural diversity patterns and dynamics, as well as their causes on different spatial and temporal scales and different organismic and structural organizational levels. We need more long-term studies involving a great variety of biological, environmental, spatial and land use-related aspects and their interrelationships, which will allow the detection of reliable patterns and cause-effect-relationships. This in turn will allow the derivation and examination of models, rapid assessment approaches and indicators as powerful instruments and tools for conservation and monitoring practice as well as for landscape development planning.

Fragmentation and connectivity

Despite their rarity, long-term studies in the Atlantic Forest are crucial for conservation and restoration efforts. Seasonal processes such as phenology, seed production and dispersal, seedling establishment and litterfall are complex processes that may reflect habitat fragmentation. Edge effects causing abiotic changes reduce safe sites for late successional regeneration and increase conditions for local impoverishment of plant assemblages. Besides regional effects, global conditions such as climatic change, agricultural activities, deforestation, and fire interfere in the maintenance of forest connectivity, breaking important links that sustain the plant-animal relationship. Seeds and birds are mobile links crucial for plant long-dispersal and their movement and migration patterns are restricted, particularly in the fragmented montane landscape of the Atlantic Forest. Our three years' phenological studies have pointed out that maximum monthly temperature decreased litterfall. At the same time, seed production was reduced in the larger (64 ha) and increased in the smaller fragment (23.2 ha). This effect, if continuous and influenced by global warming, is likely to induce a process of “exhaustion” mainly in the small fragment, caused by annual increase of tree reproduction and reduction of nutrient uptake from litterfall. Vegetation surveys done by the D. Sattler and J. Wesemberg research groups confirm the degradation of studied fragments, dominated by *Piptadenia gonoacantha*, an autochoric invasive species. Accordingly, our studies indicate an increase of this pioneer species in seed rain and seed banks in all studied areas, except in the National Park Serra dos Orgaos where zoochoric seed dispersal (>60%) dominated, whereas in the forest fragments anemochory and autochory were dominant (>30%). This may be an evidence of the dominance of generalist birds, such as the omnivorous *Turdus rufiventris* in all fragmented areas and the preference of the insectivorous *Pyriglena leucoptera* for the larger remnants (23.2 and 64 ha). Fragment size influences bird diversity (rS= 0.97): the larger ones, despite a higher bird diversity than the smallest (4 and 8 ha) showed lower distributions, suggesting that some species, mainly granivorous, concentrate a larger number of individuals.. Birds that disperse seeds have a relative importance in the fragments (51% of total). However, 44.1% were omnivorous, 4.4% frugivorous and 2.5% granivorous, which leads us to conclude that forest-specialized bird species are not representative in those fragments. The complexity of microhabitats in the fragments, such the presence of streams, nidification substrata (trunks, remnant trees), small rivers and less human interference also may influence bird communities, and probably due to this fragment F3 (23.3 ha) had similar abundance and composition of bird species as the larger F4 (64 ha). To improve bird among the studied fragments, the use of artificial perches seemed to be a partial solution. There was an "optimal distance " to seed dispersal in the studied areas, between 100 and 200 m away from the forest edge. At the same time, the number of viable seeds was not influenced by the presence of artificial perches, and we propose the great potential of natural perches to improve bird movement among forest fragments. We suggest that connectivity can be restored in these landscapes using a combination, in time and space, of natural and artificial perches. In agricultural areas groups of or isolated trees (± 100-200 m) could be introduced, and while these are growing, artificial perches can be introduced to encourage animal dispersal movements.

Here we studied a particular landscape, and as a future framework we propose some questions and bias identified in our research for further investigation: such as for instance, how natural perches improve seedling establishment and how the complexity of fragments and the surrounding areas can be used for supporting seed and bird movements. This is particularly important for birds, considering that, for many species, agricultural areas may be additional foraging habitats. These investigations may help the restoration and conservation of forest remnant connectivity in a human- dominated landscape in the Atlantic Forest.

Contribution of agricultural systems to biodiversity conservation

It seems contradictory to say that agricultural systems can influence biodiversity, at times even positively, although they are mainly responsible for imbalances in natural systems, and hence, for loss of biodiversity. We assumed that present natural systems are deteriorated, and we analyzed issues such as management and conservation activities of genetic resources. From our starting point of view of a deteriorated current state of natural systems, we conclude that agricultural systems can have a great influence on the management and conservation of biodiversity.

Ecological farming systems, agroforestry and silvopastoral systems, as well as perennial crops help reduce the pressure from forest fragments and deforested areas. They improve the water cycle, and they also positively influence the dispersal of fauna and flora. They offer better resources and habitats for the survival of plants and animals than cattle and horticultural systems. Also, they play an important role as bio-corridors and as buffers and also introduce a modest biodiversity level in these degraded areas of the Atlantic forest, where currently a single grass species dominates approximately one third of the surface.

In ecological systems, the spatial and temporal combinations of crops, trees and animals constitute the main strategy for equal distribution of crops in number and area. These systems include a wide range and combination of cultivated and uncultivated species (around a hundred) in the mountainous region of Rio de Janeiro. . The richness and stability in ecological systems make them important sites for *in situ* conservation and provide a usable framework for maximizing their benefit to biodiversity.

Forests and cattle present strong trade-offs, threatening the conservation of biodiversity. Cattle are the main cause for forest fragmentation in the Atlantic

Forest, disrupting the dispersion of flora and fauna, and also leading to higher rates of soil erosion.

The silvopastoral system maintains low indices of diversity and is widely dominated by grasses. However it differs from cattle systems in richness of species, their number being increased fourfold. Significant portions of the original biodiversity can be maintained within pastures. In Côrrego Sujo thirty-four timber species were identified in silvopastoral systems, providing structures, habitats and resources that may enable the persistence of some plant and animal species within the fragmented landscape, thereby partially mitigating the negative impacts of deforestation and habitat fragmentation. Other additional positive effects are the production of timber, forage and fruits, providing shade for cattle, and promoting soil conservation and nutrient recycling. The management of natural regeneration timber species in silvopastoral systems and its implementation represents a low-cost alternative for the producer. These systems can be beneficial, especially for farmers with low long-term investment capacity.

Ecological and silvopastoral systems contribute additional benefits to the local population, microclimate, and flow of nutrients, whilst dissipating the dynamics of plagues and diseases, and decreasing the effects of fluctuating market prices. The vegetable system has a good crop diversity index, and a good quantity of species is equitably distributed. Eight out of more than fifty commercial crops constitute the economic base and occupy circa 40% of the agricultural area. The farmers manage on average 6 species per hectare, but the trend is towards fewer species.

Forest areas in regeneration present high plant diversity and density of individuals. If fallow land is left idle then vegetation is dominated by a few individuals with rapid development. All studied forest fragments showed high diversity, despite different management and use.

Biodiversity can be considered as part of the entire capital stock on which development is based, in spite of farmers not appreciating biodiversity positively. However, they have no exact knowledge of the benefits from biodiversity. At the moment for the farmers, forest fragments are primarily water, and only secondarily as a source of wood or other by-products like fruits or medicines.

The agricultural and natural mosaic in the landscape

Production conditions in the mountainous region of Rio de Janeiro are very favourable for agriculture, especially for vegetable production systems and some fruits like citrus. These good conditions are determined by physical factors of climate and water availability. Additionally the region is very close to a big market with a favourable demand for agricultural products. Manpower is cheap and abundant, whereas soil is said to be available at a fair price. These good production characteristics are threatened by deforestation to the point that even unsuitable soils are considered for cultivation. Further, the intensive production systems themselves impair the quality of water resources. In many areas erosion threatens the sustainability of the production systems.

The landscape is dominated by forest fragments (36.2%), grasses (31.1%) and forest regeneration (18.8%). The cropped area is only 2.6% (1793 ha) of the total available land. Of these 1793 ha under agricultural production, 74% (1327 ha) are devoted to cattle production, 24% to horticultural systems, and the rest (2%) are silvopastoral systems.

Cattle raising is the biggest agricultural system in surface terms; unfortunately, it also causes the most fragmentation: not only altering the ecological functions of the forest but also the behaviour and the dynamics of animal and plant populations inside the remaining forest fragments.

Extensive forest areas have been replaced by grasses, leaving small forest fragments not larger than 16 ha on average. Hence, isolation of these fragments is constantly growing, as are the edge effects.. This landscape tends to change little by little, pastures being replaced by horticulture in places with steeper slopes (the most prevalent), by fallow to a lesser extent or by regeneration forest.

Agriculture as consumer and producer of energy and Carbon

The main primary agricultural production in Teresópolis is not a good energy producer. Its energy conversion from natural resources into biomass is small. Hence, agriculture around Teresópolis can not save great quantities of energy, neither directly nor through efficient use of energy. The cattle system, which occupies the largest area in the landscape, is the most inefficient one in terms of energy, requiring 461 Joules of inputs to produce one Joule in meat form. It has a poor capacity to accumulate biomass in the system (energy). Horticultural systems, generally combined with a small forest, can store energy up to 1.03E11 Joules ha^{-1} yr^{-1}. But some agricultural systems like ecological and silvopastoral systems produce great quantities of energy and at the same time can save large amounts of energy through its efficient use. Ecological systems have a great capacity for storing energy (1.80E11 Joules ha^{-1} yr^{-1}). Silvopastoral systems, in contrast to cattle raising, have a better capacity to store biomass, with a positive difference of 2.6E10 to 5.56E10 Joules ha^{-1} yr^{-1}.

An important alternative in this region is the development of carbon projects, as an ecological measure to preserve and increase the forest area and income. It has been demonstrated that natural systems have a good potential for sequestering carbon: the mature forest of the "Serra dos Orgãos" National Park (Atlantic Forest) can store 272 Mg C ha^{-1} , while the secondary forest fragments can store 87.3 Mg C ha^{-1}. Total dry phytomass in Côrrego Sujo (53 km^2) amounts to a stock of 386,844 tons. The same area will produce annually 20,478 tons dry matter, representing 2.28E14 Joules. The forest fragments and the forest areas in regeneration accumulate more than 92% of the biomass in the system. Horticulture can end up producing more phytomass (27.8 Mg C ha^{-1}) than neighbouring natural systems were it not that 93% of it is exported from the system. Hence, this situation disables these systems for carbon sequestration. Secondary forests and forest fallows are the most important forms of C recovery in Teresópolis. The pastoral system stores and produces less C and energy and, because this system is the principal factor for fragmentation, it also causes the decrease of biomass production at the fragment edges.

Environmental impacts, quality of inputs, and sustainnability

The environmental impact caused by the agricultural systems in Côrrego Sujo is moderate as the system makes high use of renewable resources. Ecological sustainability is moderate to good. The basin as a system contributes positively to the economy; it gives more emergy than that it takes from the economic system in the form of materials and services. However, this fact also represents a loss of capital.

The material and services increase the environmental load indirectly because great quantities of non-renewable sources were used to manufacture them.

Positive economic indices were recorded for all crops except cattle. The most positive impact was achieved through the substitution of cattle production by ecological systems. The revenues are multiplied 4 to 12 times, the negative ecological impact is considerably decreased (0.3 to 0.8 million \$US in Côrrego Sujo, for erosion), and the stock of carbon and biomass is significantly increased. Vegetable systems tend to give the greatest economic productivity per hectare per annum. The vegetable systems demonstrate an increase of yield per area to which high inputs like fertilizers and services, did contribute. Dependence on these inputs reduces the fraction of renewable energy and increases environmental degradation, making these systems less sustainable relative to systems that are more dependent on renewable energies. Finally, they also contribute less to the economy of the region, because of their low use of renewable resources.

The ecological system presents the largest value of sustainability in ecological terms, and possesses the capacity to save a great quantity of biomass in the system, because it uses more natural renewable resources and fewer resources from the economy, which eventually guarantees its sustainability. Ecological systems ensure the survival of the producer on a long-term basis and the preservation of biodiversity. The cattle system on the hillside loses the biggest quantity of soil, representing five-fold that of the ecological system and twice that of the other systems.

Cattle production is the main consumer of natural resources altogether. Cattle systems cause greater environmental damage and they have the smallest yield per hectare in economic and energy terms. Erosion is the most important factor in terms of the use of non-renewable resources. Runoff was identified as the most important process leading to pollution of the superficial water. Based on emergy synthesis which allocates a value to soil based on the environmental work required to produce it (rather than a value based on surveys or derived pricing techniques), the loss of organic matter through soil erosion for the whole Côrrego Sujo basin represents a value in economic terms of between 1.7 and 4.9 million US dollars per year.

To increase the sustainability of agricultural systems it is necessary to reduce their dependence on external inputs. In Teresópolis the AS showed great invested quantities of energy in irrigation, fertilizer application and fuel. Among the studied systems, the least sustainable one is cattle, followed by citrus and silvopastoral systems. The horticultural systems also cause environmental damage but they offer the biggest economic revenues. The most sustainable systems are the ecological ones. The implementation of silvopastoral systems in the study region is not only a cheap, simple alternative, but by the same token it also possesses a high positive ecological impact.

From the economic point of view timber production through eucalyptus plantations could be optimal for small- to medium-sized agro-business units. From the technical point of view this alternative is possible and could create medium-term profits through a guaranteed market in Rio de Janeiro. But from the ecological point of view it is debatable if the reforestation of marginal areas with exotic species such as eucalyptus is sustainable.

Resilience in natural and agricultural systems

Resilience relates to the continuity of an ecosystem and its ability to endure changes, disturbances, stresses as well as to its capacity to rebuild itself to equilibrium level, at which it is capable of achieving its ecosystem functions, and providing goods and services.

Reduction of eco-volume (fragmentation and perturbation of forest ecosystems) represents a negative impact on ecosystem functionality, resulting in ecosystems not being able to provide goods and services for human well-being as well as for wildlife. Increasing eco-volume, i.e. increasing the horizontal and vertical connectivity, is important to the long-term health of ecosystems. The grass, vegetable, and fruit systems in Teresópolis lose a great deal of eco-volume. In contrast, sylvopastoral and ecological systems present low losses.

An alternative method of measuring resilience considers the actual V_{bio} as a function of the potential eco-volume. This method makes it possible to measure resilience and its evolution in time very easily. This method allows the comparison of natural and agricultural systems using the same units. It also enables the integration of other variables such as biodiversity, energy flow and carbon accumulation. To obtain a better scenario of the ecosystem's capacity to return to its original climax equilibrium state. It has been shown that there does exist a high positive correlation between resilience index, biomass, energy efficiency and biodiversity.

Through the evaluation of resiliency it can be concluded that the dominant agricultural systems in Teresópolis and, more particularly, in the water basin of Côrrego Sujo (cattle and vegetable) have a reduced resiliency index, whilst the less important systems (Ecological and Silvopastoral) achieve the greatest resilience.

Challenges for natural resources conservation and sustainable development in the Mata Atlântica of RJ.

Biodiversity loss and natural resources degradation in the Mata Atlântica of Rio de Janeiro will continue and will probably accelerate if proper and prompt measures are not taken to de-couple the progress of economic sectors and their pressures on the forest fragments and water-soil resources through the intensification of agricultural systems.

Integration of forest-fragments, water and soil protection measures into sectoral policies could be best solution in a short time. As biodiversity and agricultural good practices are a cross-cutting issue, the assessment approaches and protection policies need to incorporate a wide perspective. This means that it would be necessary to integrate assessment and responses at the administrative (from national to local level), sectoral (economic sectors and other environmental issues) and geographical levels (landscapes, urban, rural, mountain and coastal areas).

The effects on biodiversity and good agricultural practices of the implementation of existing measures need to be analyzed and monitored. Ideally such results should be communicated on a regular basis through, for example, a soil reporting mechanism based on a national soil monitoring and assessment framework. This would require a closer collaboration among administrations in order to improve access to data and data comparability, and to avoid duplication.

Such assessments would also help identify what else may be necessary but is not covered by existing legislation. Showing the gaps in policy terms will help to increase the awareness of importance of biodiversity protection in sectoral policies and possibly lead to the development of a policy framework which will recognize the central role of land use and biodiversity in Rio de Janeiro state and in the Mata Atlântica Region.

In the decades to come, the sustainable use of land will be a great challenge, comparable and closely interrelated with the global concerns about changes in climate and biodiversity. This would require that the necessary actions are taken in order to meet today the diverse and potentially conflicting demands on the land resource, without compromising its use and availability to future generations.

Sustainable land management is a challenge for the Mata Atlântica. The control of land degradation can be most easily justified in terms of global benefits; these benefits include conservation of biodiversity, control of climate change and progress towards the Millennium Development Goals for human development and poverty alleviation.

Sustainability should be understand more than ecological and biophysical integrity, declining quality of natural resources place us into a 'vicious cycle' of degradation and poverty. Sustainable development is not only about reversing the cycle, but also placing us into a 'virtuous cycle' of improvement.

Conservation implications

- Atlantic Forest remnants are vanishing, biological reserves have a tendency to be in short supply, and conservation of biodiversity will largely depend on proper management of the landscape dominated by anthropogenic matrix. Bio-corridor restoration can be easily coupled with other important measures for species and environmental conservation.

- Forest fragments and agricultural systems should be managed so as to minimize edge effects and improve connectivity. The Brazilian federal Forest Code states that each property should maintain a proportion of land covered by native habitats from 20% to 80%, by ensuring compliance of this Code, Brazil could achieve a great conservation goal.

- Mature and large forest fragments should be conserved. The reduction in the average age of forest fragments in an agricultural matrix landscape is a great threat and enormous efforts should be allocated to protect mature and old-growth forests and avoiding the creation of large tracts of homogeneous monocultures.

- Environmentally friendly agricultural practices should be supported in order to reduce the pressure on the fragments and to introduce and conserve modest biodiversity quantities. For example, extensive cattle systems should be changed into silvopastoral systems or agroforestry systems. The intensive agricultural production systems in the hill cultivated areas should be avoided or, in these areas, terrace-systems should be implemented and promoted. It was demonstrated that in this region, one of the biggest hazards to biodiversity and resource conservation is the cattle production system, which is neither economically nor ecologically sustainable.

- The mainly small secondary forest fragments, which are scattered in an agricultural matrix, can still host a considerable part of the original biodiversity. Smaller fragments should be managed in order to maintain the connectivity and functionality.

- Key areas should be identified for restoration actions. The clear differences in the amount remaining and its spatial distribution within each sub-region must be considered when planning for biodiversity conservation. Landscape history should be considered in conservation planning, it can also explain the distribution patterns of species in fragmented landscapes.

- At the theoretical and methodological levels, conservation represents a fundamental challenge, this challenge include giving more attention to vital issues such as land use, interdisciplinary cooperation among the various science disciplines, in order to achieve a more integrated and comprehensive understanding of natural systems, development processes and the relationships between individuals and the environment.

- Sustainability should be understood as more than ecological and biophysical integrity; reducing the vitality and quality of natural systems drive us into a vicious circle of degradation and poverty. Sustainable development is not only about reversing the cycle and increasing the resilience, but also placing the humankind into a virtuous circle of improvement.

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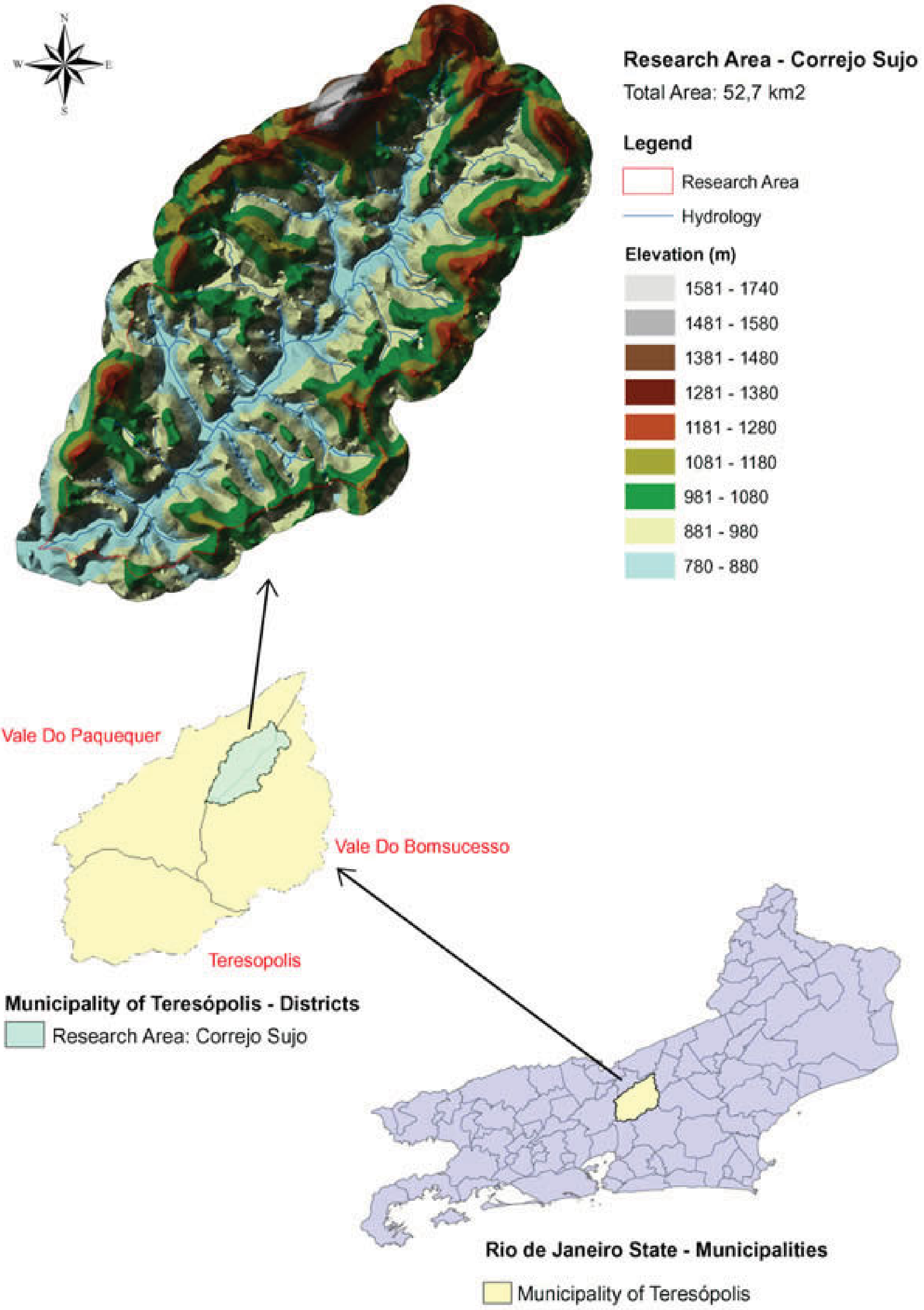
Appendix

Appendix 1

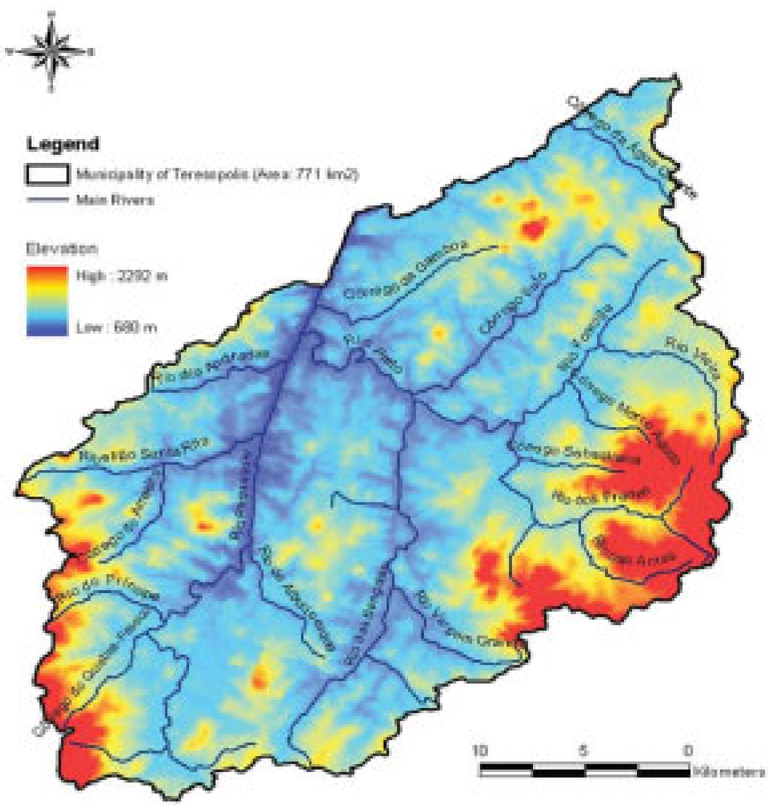
Map 1. Rio de Janeiro state, Municipality of Teresópolis and Côrrego Sujo basin. Based on data from IBGE (2003)



Source: BLUMEN (2006), Eds. Lange & Kretschmer 2006.

Map 2. Political division of the Teresópolis Municipality. Based on data from IBGE (2003)

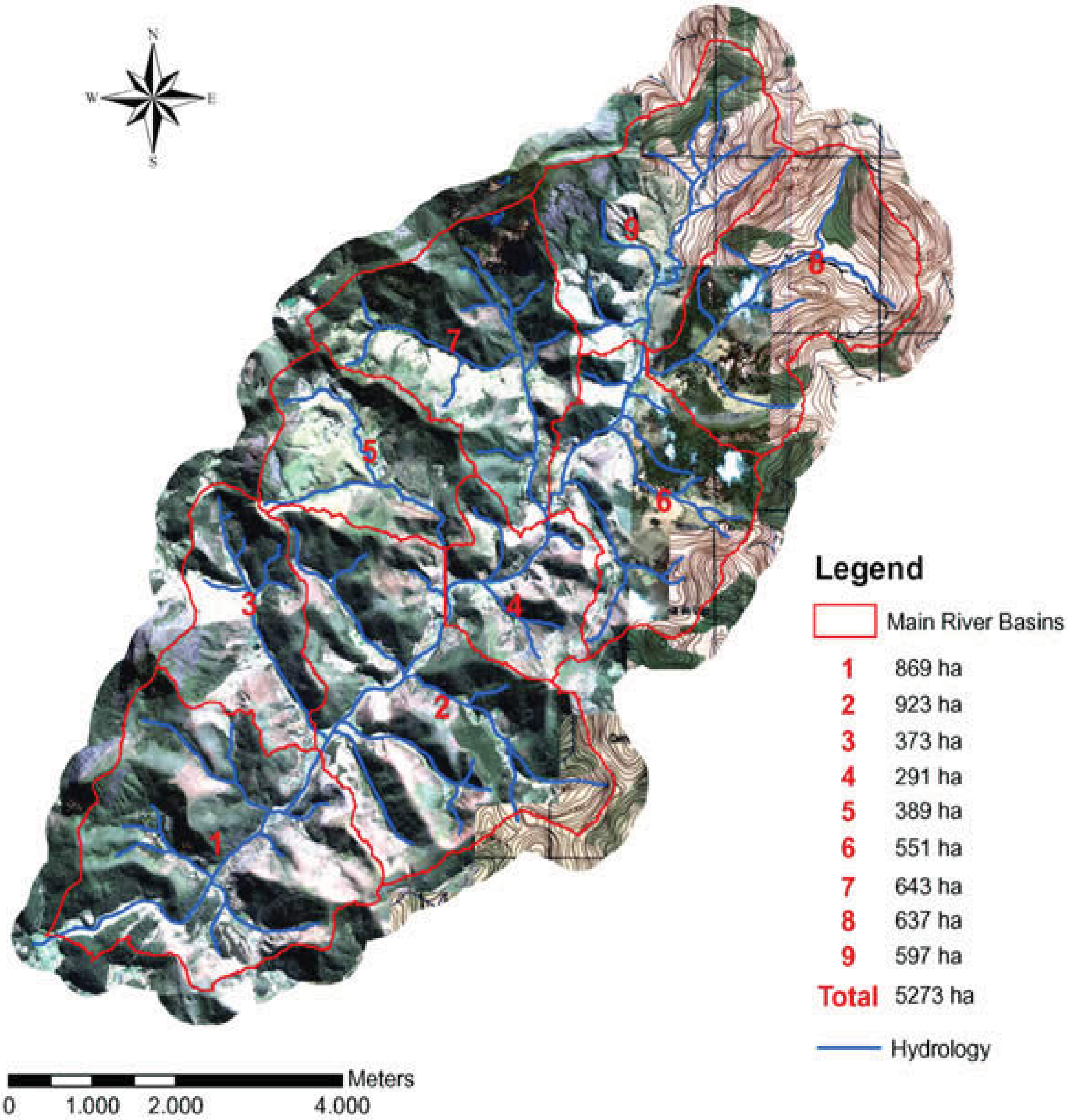
Source: BLUMEN (2006), Eds. Lange & Kretschmer 2006.



Map 3. Hydrology and elevation of the municipality of Teresópolis. Layers based on data from IBGE (1999 and 1983)

Source: BLUMEN (2006), Eds. Meier *et al*. 2006.

Map 4. Basin of Côrrego Sujo divided in 9 micro-basins. Based on data from IBGE (2003).



Source: BLUMEN (2006), Eds. Meier *et al*. 2006.

Appendix 2

Table 1: List of species inventoried in the 17 study sites located in the Montane Forest. The families were classified according to APG II (Stevens 2001 onwards). The ecological importance of each family and species in the whole sample, as well as in the tree strata (individuals with DBH ≥ 5 cm) and in the understorey (all individuals BDH < 5 cm, h ≥ 1 m) is expressed by their Family Importance Values (FIV; Mori et al. 1983) and their species Importance Value Index (IVI, Curtis & McIntosh 1951.) A = abundance (number of individuals), BA = basal area, F = frequency (number of study sites in which a species occurred)

Family	**Tree strata (DBH ≥ 5 cm)**				**Understorey (DBH < 5 cm, h ≥ 1 m)**				**Whole sample**	
Species	**A**	**BA (m^2)**	**F**	FIV / **IVI**	**A**	**BA (m^2)**	**F**	FIV / **IVI**	**F**	FIV / **IVI**
Acanthaceae				**-**				**0,6**		**0,4**
Justicia polita (Nees) Profice	-	-	-	-	2	0,0001	2	0,5	2	0,3
Annonaceae				**3,4**				**2,9**		**3,1**
Annona cacans Warm.	1	0,05	1	0,4	-	-	-	-	1	0,3
Guatteria candolleana Schltdl.	1	0,00	1	0,3	16	0,0042	5	2,2	5	1,1
Rollinia dolabripetala (Raddi) R.E. Fr.	4	0,20	2	1,2	-	-	-	-	2	0,9
Rollinia xylopiifolia (A. St.-Hil. & Tul.) R.E. Fr.	2	0,01	1	0,3	4	0,0025	1	0,7	1	0,3
Apocynaceae				**2,1**				**1,7**		**2,1**
Aspidosperma olivaceum Muell. Arg.	4	0,07	2	0,8	7	0,0018	3	1,1	3	0,9
Tabernaemontana sp.	6	0,06	1	0,7	-	-	-	-	1	0,5
Apocynaceae sp.	-	-	-	-	1	0,0001	1	0,2	1	0,1

Family ***Species***	**Tree strata (DBH ≥ 5 cm)**				**Understorey (DBH < 5 cm, h ≥ 1 m)**				**Whole sample**	
	A	**BA (m²)**	**F**	FIV / **IVI**	**A**	**BA (m²)**	**F**	FIV / **IVI**	**F**	FIV / **IVI**
Aquifoliaceae				**1,2**				**-**		**0,9**
Ilex integerrima Reissek	1	0,02	1	0,3	-	-	-	-	1	0,2
Ilex cf. theazans Mart.	1	0,00	1	0,3	-	-	-	-	1	0,1
Araliaceae				**7,5**				**4,1**		**6,0**
Dendropanax langsdorfii (Marchal) Frodin	17	0,23	6	2,9	5	0,0012	3	0,9	6	2,0
Dendropanax trilobus (Marchal) Frodin	10	0,03	4	1,4	17	0,0082	5	2,8	6	1,5
Schefflera angustissima (Marchal) Frodin	14	0,30	6	2,9	-	-	-	-	6	1,9
Schefflera longipetiolata (Pohl ex DC.) Frodin & Fiaschi	5	0,29	3	1,7	4	0,0003	3	0,8	5	1,7
Arecaceae				**31,3**				**45,8**		**29,5**
Euterpe edulis Mart.	349	2,56	12	31,8	257	0,1293	13	31,8	13	25,7
Geonoma pohliana Mart.	1	0,00	1	0,3	9	0,0048	5	2,0	6	1,0
Geonoma schottiana Mart.	-	-	-	-	42	0,0283	6	6,8	6	1,9
Geonoma wittigiana Glaz. ex Drude	-	-	-	-	54	0,0151	7	5,8	7	2,3
Geonoma sp.	1	0,00	1	0,2	10	0,0130	6	3,3	6	1,0
Asteraceae				**1,6**				**-**		**1,2**
Dasyphyllum spinescens (Less.) Cabrera	1	0,03	1	0,3	-	-	-	-	1	0,2

Family ***Species***	**Tree strata (DBH ≥ 5 cm)**				**Understorey (DBH < 5 cm, h ≥ 1 m)**				**Whole sample**	
	A	**BA (m²)**	**F**	FIV / **IVI**	**A**	**BA (m²)**	**F**	FIV / **IVI**	**F**	FIV / **IVI**
Vernonia diffusa Less.	3	0,06	1	0,6	-	-	-	-	1	0,4
Bignoniaceae				**0,7**				**0,9**		**0,6**
Tabebuia cf. bureavii Sandwith	2	0,01	1	0,3	5	0,0009	2	0,7	2	0,4
Boraginaceae				**1,3**				**0,6**		**1,0**
Cordia ecalyculata Vell.	6	0,14	4	1,5	1	0,0005	1	0,3	4	1,1
Celastraceae (incl. Hippocrateaceae)				**2,2**				**3,1**		**3,0**
Maytenus cf. communis Reissek	-	-	-	-	4	0,0011	3	0,9	3	0,5
Maytenus cf. salicifolia Reissek	-	-	-	-	1	0,0005	1	0,3	1	0,1
Maytenus cf. subalata Reissek	1	0,01	1	0,3	-	-	-	-	1	0,2
Maytenus sp.2	-	-	-	-	2	0,0001	1	0,3	1	0,2
Salacia elliptica (Mart.) Peyr.	8	0,17	4	1,8	3	0,0017	3	0,9	5	1,4
Chloranthaceae				**0,6**				**-**		**0,4**
Hedyosmum brasiliense Miq.	1	0,00	1	0,3	-	-	-	-	1	0,2
Chrysobalanaceae				**2,5**				**1,9**		**2,2**
Licania spicata Hook. f.	15	0,34	6	3,0	16	0,0043	7	2,6	10	3,0
Clusiaceae				**2,7**				**6,3**		**3,4**

Family ***Species***	**Tree strata (DBH ≥ 5 cm)**				**Understorey (DBH < 5 cm, h ≥ 1 m)**				**Whole sample**	
	A	**BA (m²)**	**F**	FIV / **IVI**	**A**	**BA (m²)**	**F**	FIV / **IVI**	**F**	FIV / **IVI**
Chrysochlamis saldanhae (Engl.) Oliveira Filho	4	0,07	3	1,0	1	0,0003	1	0,3	3	0,7
Garcinia gardneriana (Planch. & Triana) Zappi	2	0,03	2	0,6	3	0,0012	2	0,7	3	0,6
Tovomita glazioviana Engl.	6	0,02	3	1,0	53	0,0137	3	4,9	4	2,1
Connaraceae				**0,6**				**-**		**0,4**
Connarus sp.	1	0,00	1	0,3	-	-	-	-	1	0,2
Cunoniaceae				**2,9**				**-**		**2,5**
Lamanonia ternata Vell.	6	0,67	1	2,6	-	-	-	-	1	2,3
Dichapetalaceae				**0,7**				**-**		**0,5**
Stephanopodium organense (Rizzini) Prance	2	0,03	2	0,6	-	-	-	-	2	0,4
Elaeocarpaceae				**3,4**				**0,6**		**2,8**
Sloanea cf. garckeana K. Schum.	1	0,00	1	0,3	-	-	-	-	1	0,1
Sloanea monosperma Vell.	4	0,39	2	1,8	1	0,0001	1	0,2	2	1,5
Sloanea sp.	1	0,09	1	0,5	-	-	-	-	1	0,4
Erythroxylaceae				**0,9**				**1,5**		**0,9**
Erythroxylum cuspidifolium Mart.	4	0,03	2	0,7	11	0,0035	4	1,7	4	0,9
Euphorbiaceae				**11,0**				**0,6**		**8,7**

Family ***Species***	**Tree strata (DBH ≥ 5 cm)**				**Understorey (DBH < 5 cm, h ≥ 1 m)**				**Whole sample**	
	A	**BA (m^2)**	**F**	FIV / **IVI**	**A**	**BA (m^2)**	**F**	FIV / **IVI**	**F**	FIV / **IVI**
Alchornea triplinervia var. triplinervia (Spreng.) Muell. Arg.	36	1,67	12	9,5	1	0,0002	1	0,2	12	7,3
Croton macrobothrys Baill.	2	0,16	1	0,8	-	-	-	-	1	0,7
Croton organensis Baill.	1	0,00	1	0,3	-	-	-	-	1	0,2
Hieronima alchorneoides Allemão	1	0,02	1	0,3	-	-	-	-	1	0,2
Sapium glandulatum (Vell.) Pax	2	0,02	2	0,5	-	-	-	-	2	0,3
Humiriaceae				**3,0**				**0,6**		**2,7**
Vantanea compacta ssp. compacta (Schnizl.) Cuatrec.	3	0,75	3	3,0	1	0,0003	1	0,3	4	2,8
Icacinaceae				**0,8**				**-**		**0,6**
Citronella cf. megaphylla (Miers) R.A. Howard	2	0,05	1	0,4	-	-	-	-	1	0,3
Fabaceae				**10,3**				**18,4**		**13,3**
Caesalpinoideae				**2,1**				**-**		**1,7**
Senna macranthera (DC. ex Collad.) H.S. Irwin & Barneby	1	0,00	1	0,3	-	-	-	-	1	0,2
Tachigali sp.	2	0,27	1	1,1	-	-	-	-	1	1,0
Mimosoideae				**5,7**				**14,6**		**8,1**
Inga lanceifolia Benth.	32	0,15	8	3,9	159	0,0348	9	13,7	9	6,7
Inga lenticellata Benth.	2	0,02	2	0,5	-	-	-	-	2	0,3

Family ***Species***	**Tree strata (DBH ≥ 5 cm)**				**Understorey (DBH < 5 cm, h ≥ 1 m)**				**Whole sample**	
	A	**BA (m²)**	**F**	FIV / **IVI**	**A**	**BA (m²)**	**F**	FIV / **IVI**	**F**	FIV / **IVI**
Inga sessilis (Vell.) Mart.	3	0,08	2	0,8	1	0,0003	1	0,3	3	0,7
Pseudopiptadenia inaequalis (Benth.) Rauschert	6	0,04	1	0,7	5	0,0036	1	0,9	1	0,5
Faboideae				**2,5**				**3,8**		**3,5**
Dalbergia foliolosa Benth.	3	0,04	3	0,9	1	0,0002	1	0,2	4	0,7
Erythrina falcata Benth.	2	0,08	1	0,5	-	-	-	-	1	0,4
Machaerium cf. brasiliense Vogel	-	-	-	-	7	0,0005	4	1,1	4	0,6
Machaerium nyctitans (Vell.) Benth.	2	0,05	2	0,6	3	0,0013	3	0,8	5	0,9
Machaerium stipitatum (DC.) Vogel	-	-	-	-	5	0,0004	5	1,2	5	0,7
Zollernia cf. ilicifolia (Brongn.) Vogel	-	-	-	-	1	0,0001	1	0,2	1	0,1
Lauraceae				**29,4**				**22,1**		**29,9**
Beilschmiedia rigida (Mez) Kosterm.	1	0,40	1	1,5	-	-	-	-	1	1,3
Cinnamomum glaziovii Mez	5	0,16	4	1,5	5	0,0027	3	1,1	6	1,4
Cinnamomum riedelianum Kosterm.	-	-	-	-	2	0,0002	2	0,5	2	0,3
Cryptocarya moschata Nees & Mart. ex Nees	7	0,53	5	3,0	-	-	-	-	5	2,4
Cryptocarya saligna Mez	12	0,28	7	2,9	10	0,0041	6	2,1	9	2,5
Endlicheria glomerata Mez	7	0,11	4	1,5	3	0,0004	2	0,6	4	1,1

Family	Tree strata (DBH ≥ 5 cm)				Understorey (DBH < 5 cm, h ≥ 1 m)				Whole sample	
Species	**A**	**BA (m^2)**	**F**	FIV / **IVI**	**A**	**BA (m^2)**	**F**	FIV / **IVI**	**F**	FIV / **IVI**
Nectandra leucantha Nees	1	0,07	1	0,4	2	0,0003	2	0,5	2	0,5
Ocotea daphnifolia (Meisn.) Mez	2	0,01	1	0,3	1	0,0009	1	0,3	1	0,2
Ocotea cf. diospyrifolia (Meisn.) Mez	-	-	-	-	1	0,0000	1	0,2	1	0,1
Ocotea dispersa (Nees) Mez	24	0,72	12	5,9	75	0,0125	12	7,3	16	6,7
Ocotea elegans Mez	15	1,08	9	5,9	23	0,0053	9	3,4	14	5,9
Ocotea glaziovii Mez	5	0,09	1	0,8	2	0,0005	1	0,3	2	0,7
Ocotea puberula (Rich.) Nees	5	0,05	4	1,2	3	0,0008	2	0,6	5	0,9
Ocotea schottii (Meisn.) Mez	5	0,05	2	0,8	25	0,0034	6	2,7	6	1,6
Ocotea silvestris Vattimo-Gil	2	0,06	2	0,7	1	0,0000	1	0,2	3	0,6
Ocotea aff. vaccinoides Mez	-	-	-	-	1	0,0001	1	0,2	1	0,1
Ocotea sp.2	2	0,61	2	2,3	-	-	-	-	2	2,1
Ocotea sp.3	1	0,12	1	0,6	-	-	-	-	1	0,5
Persea pyrifolia Nees & Mart. ex Nees	-	-	-	-	1	0,0003	1	0,3	1	0,1
Persea aff. venosa Nees & Mart. ex Nees	1	0,01	1	0,3	-	-	-	-	1	0,2
Rhodostemonodaphne macrocalyx (Meisn.) Rohwer ex Madriñán	1	0,01	1	0,3	-	-	-	-	1	0,2
Lauraceae sp.	**-**	**-**	**-**	**-**	**1**	**0,0001**	**1**	**0,2**	**1**	**0,1**

Family ***Species***	**Tree strata (DBH ≥ 5 cm)**				**Understorey (DBH < 5 cm, h ≥ 1 m)**				**Whole sample**	
	A	**BA (m²)**	**F**	FIV / **IVI**	**A**	**BA (m²)**	**F**	FIV / **IVI**	**F**	FIV / **IVI**
Malpighiaceae				**1,7**				**0,6**		**1,4**
Byrsonima laevigata (Poir.) DC.	7	0,26	6	2,3	1	0,0001	1	0,2	7	1,8
Melastomataceae				**13,2**				**12,2**		**12,3**
Leandra acutiflora (Naudin) Cogn.	-	-	-	-	6	0,0008	4	1,1	4	0,6
Leandra dentata Cogn.	2	0,09	2	0,8	2	0,0002	1	0,3	2	0,6
Leandra scabra DC.	-	-	-	-	1	0,0000	1	0,2	1	0,1
Meriania paniculata (DC.) Triana	10	0,07	4	1,6	6	0,0024	1	0,8	4	1,1
Miconia brasiliensis (Spreng.) Triana	9	0,03	4	1,4	1	0,0002	1	0,2	4	0,8
Miconia budlejoides Triana	13	0,08	5	1,9	4	0,0005	2	0,6	5	1,3
Miconia doriana Cogn.	1	0,00	1	0,3	31	0,0046	9	3,7	9	1,9
Miconia formosa Cogn.	3	0,01	3	0,8	3	0,0009	1	0,4	4	0,6
Miconia pusilliflora (DC.) Naudin	6	0,06	3	1,1	5	0,0004	3	0,8	5	1,1
Miconia sellowiana Naudin	6	0,07	2	1,0	1	0,0001	1	0,2	2	0,6
Miconia tristis Spring.	1	0,01	1	0,3	2	0,0001	1	0,3	2	0,3
Miconia willdenowii Klotzsch	2	0,30	2	1,4	4	0,0007	1	0,5	3	1,4
Miconia sp.1	1	0,01	1	0,3	1	0,0001	1	0,2	2	0,3

Family ***Species***	**Tree strata (DBH ≥ 5 cm)**				**Understorey (DBH < 5 cm, h ≥ 1 m)**				**Whole sample**	
	A	**BA (m^2)**	**F**	FIV / **IVI**	**A**	**BA (m^2)**	**F**	FIV / **IVI**	**F**	FIV / **IVI**
Miconia sp.2	-	-	-	-	1	0,0001	1	0,2	1	0,1
Tibouchina arborea (Gardner) Cogn.	8	0,26	4	2,0	-	-	-	-	4	1,5
Meliaceae				**11,0**				**2,2**		**10,0**
Cabralea canjerana ssp. canjerana (Vell.) Mart.	22	2,70	11	11,6	11	0,0027	7	2,1	14	10,6
Guarea macrophylla Vahl ssp. *tuberculata* (Vell.) T.D. Penn.	3	0,05	2	0,7	1	0,0015	1	0,4	2	0,5
Monimiaceae				**7,6**				**8,8**		**7,9**
Mollinedia cf. engleriana Perkins	1	0,03	1	0,3	-	-	-	-	1	0,2
Mollinedia cf. puberula Perkins	12	0,06	5	1,8	35	0,0175	10	5,8	10	2,6
Mollinedia cf. schottiana (Spreng.) Perkins	-	-	-	-	7	0,0015	2	0,9	2	0,4
Mollinedia cf. triflora (Spreng.) Tul.	5	0,23	2	1,4	4	0,0013	2	0,7	4	1,4
Mollinedia sp.2	4	0,12	1	0,8	2	0,0001	2	0,5	2	0,7
Mollinedia sp.3	-	-	-	-	1	0,0002	1	0,3	1	0,1
Mollinedia sp.5	9	0,31	4	2,2	9	0,0008	5	1,4	7	2,2
Mollinedia sp.6	2	0,03	2	0,6	-	-	-	-	2	0,4
Moraceae				**7,4**				**8,2**		**6,9**
Sorocea bonplandii (Baill.) W.C. Burger, Lanj. & Wess. Boer	79	0,65	14	9,4	88	0,0259	14	10,1	16	8,3

Family ***Species***	**Tree strata (DBH ≥ 5 cm)**				**Understorey (DBH < 5 cm, h ≥ 1 m)**				**Whole sample**	
	A	**BA (m²)**	**F**	FIV / **IVI**	**A**	**BA (m²)**	**F**	FIV / **IVI**	**F**	FIV / **IVI**
Myrsinaceae				**2,1**				**5,5**		**4,0**
Cybianthus glaber A. DC.	-	-	-	-	9	0,0020	4	1,4	4	0,7
Myrsine gardneriana A. DC.	9	0,10	5	1,8	1	0,0004	1	0,3	6	1,3
Myrsine hermogenesii (Jung-Mend. & Bernacci) M.F. Freitas & Kinoshita	-	-	-	-	2	0,0007	1	0,4	1	0,2
Myrsine parvula (Mez) Otegui	-	-	-	-	3	0,0001	1	0,3	1	0,2
Myrsine umbellata Mart.	1	0,02	1	0,3	-	-	-	-	1	0,2
Stylogyne pauciflora Mez	-	-	-	-	23	0,0050	3	2,3	3	1,0
Myrtaceae				**47,4**				**56,4**		**47,9**
Campomanesia cf. guaviroba (DC.) Kiaersk.	1	0,01	1	0,3	-	-	-	-	1	0,2
Campomanesia laurifolia Gardner	1	0,02	1	0,3	-	-	-	-	1	0,2
Eugenia cf. cinerascens Gardner	2	0,01	1	0,3	8	0,0044	1	1,1	2	0,5
Eugenia cf. magnifica Spring ex Mart.	15	0,19	7	2,8	18	0,0074	8	3,3	9	2,5
Eugenia subavenia O. Berg	34	0,27	11	4,9	60	0,0223	15	8,5	15	5,1
Eugenia tinguyensis Cambess.	9	0,06	5	1,7	23	0,0080	6	3,2	7	1,9
Eugenia sp.1	1	0,05	1	0,4	2	0,0002	2	0,5	2	0,5

Family ***Species***	**Tree strata (DBH ≥ 5 cm)**				**Understorey (DBH < 5 cm, h ≥ 1 m)**				**Whole sample**	
	A	**BA (m^2)**	**F**	FIV / **IVI**	**A**	**BA (m^2)**	**F**	FIV / **IVI**	**F**	FIV / **IVI**
cf. Eugenia sp.2	7	0,04	2	0,9	5	0,0010	1	0,6	2	0,7
Marlierea martinellii G.M. Barroso & Peixoto	6	0,28	6	2,3	10	0,0035	7	2,2	11	2,5
cf. Marlierea sp.1	2	0,01	2	0,5	11	0,0013	3	1,2	4	0,8
Marlierea sp.2	1	0,01	1	0,3	6	0,0034	2	1,1	2	0,5
Myrceugenia cf. miersiana (Gardner) D. Legrand et Kausel	2	0,01	2	0,5	9	0,0024	5	1,6	6	1,0
Myrceugenia cf. myrcioides (Cambess.) O. Berg	3	0,01	3	0,8	2	0,0003	2	0,5	4	0,6
Myrceugenia cf. ovata (Hook. et Arn.) O. Berg	3	0,01	3	0,8	4	0,0016	2	0,8	4	0,7
Myrcia tenuivenosa Kiaersk.	2	0,02	2	0,6	6	0,0007	2	0,7	3	0,6
Myrcia cf. tijucensis Kiaersk.	3	0,01	2	0,6	4	0,0004	4	0,9	4	0,7
Myrciaria disticha O. Berg	2	0,02	2	0,6	-	-	-	-	2	0,4
Myrciaria cf. floribunda (H. West ex Willd.) O. Berg	2	0,02	2	0,6	1	0,0001	1	0,2	3	0,5
Neomitranthes amiblymitra (Burret) Matos	7	0,23	6	2,2	22	0,0030	9	3,0	11	2,7
Siphoneugena kiaerskoviana (Burret) Kausel	1	0,08	1	0,5	-	-	-	-	1	0,4
Myrtaceae sp.1	1	0,03	1	0,3	-	-	-	-	1	0,2
Myrtaceae sp.2	-	-	-	-	1	0,0002	1	0,2	1	0,1
Myrtaceae sp.3	21	0,36	6	3,5	9	0,0034	6	1,9	9	2,9

Family ***Species***	Tree strata (DBH ≥ 5 cm)				Understorey (DBH < 5 cm, h ≥ 1 m)				Whole sample	
	A	**BA (m²)**	**F**	FIV / **IVI**	**A**	**BA (m²)**	**F**	FIV / **IVI**	**F**	FIV / **IVI**
Myrtaceae sp.4	4	0,13	4	1,4	2	0,0008	2	0,6	6	1,2
Myrtaceae sp.5	1	0,01	1	0,3	3	0,0007	3	0,8	4	0,6
Myrtaceae sp.6	3	0,01	3	0,8	3	0,0005	3	0,7	5	0,8
Myrtaceae sp.7	19	0,20	5	2,7	12	0,0045	7	2,4	7	2,3
Myrtaceae sp.9	2	0,01	1	0,3	4	0,0038	1	0,9	1	0,3
Myrtaceae sp.10	-	-	-	-	1	0,0000	1	0,2	1	0,1
Myrtaceae sp.11	2	0,07	2	0,7	3	0,0002	1	0,3	2	0,6
Myrtaceae sp.12	1	0,00	1	0,2	3	0,0019	2	0,7	2	0,3
Myrtaceae sp.14	1	0,02	1	0,3	-	-	-	-	1	0,2
Myrtaceae sp.15	2	0,00	2	0,5	2	0,0003	2	0,5	3	0,5
Myrtaceae sp.16	2	0,00	1	0,3	3	0,0008	2	0,6	2	0,4
Myrtaceae sp.18	2	0,02	2	0,6	3	0,0002	2	0,5	2	0,4
Myrtaceae sp.20	-	-	-	-	9	0,0007	1	0,7	1	0,4
Myrtaceae sp.22	-	-	-	-	4	0,0023	3	1,0	3	0,5
Myrtaceae sp.23	2	0,03	2	0,6	6	0,0027	2	1,0	3	0,7
Myrtaceae sp.24	1	0,03	1	0,3	-	-	-	-	1	0,2

Family ***Species***	**Tree strata (DBH ≥ 5 cm)**				**Understorey (DBH < 5 cm, h ≥ 1 m)**				**Whole sample**	
	A	**BA (m²)**	**F**	FIV / **IVI**	**A**	**BA (m²)**	**F**	FIV / **IVI**	**F**	FIV / **IVI**
Myrtaceae sp.25	1	0,00	1	0,3	-	-	-	-	1	0,2
Myrtaceae sp.26	1	0,02	1	0,3	1	0,0009	1	0,3	1	0,2
Myrtaceae sp.27	1	0,01	1	0,3	1	0,0011	1	0,4	1	0,2
Myrtaceae sp.28	1	0,02	1	0,3	2	0,0023	2	0,8	3	0,5
Myrtaceae sp.29	1	0,01	1	0,3	-	-	-	-	1	0,2
Myrtaceae sp.31	1	0,01	1	0,3	-	-	-	-	1	0,2
Myrtaceae sp.33	9	0,04	5	1,6	8	0,0020	4	1,3	6	1,3
Myrtaceae sp.35	5	0,05	3	1,0	6	0,0021	4	1,3	6	1,1
Myrtaceae sp.36	31	0,41	9	4,8	23	0,0066	7	3,2	10	3,8
Myrtaceae sp.37	5	0,30	5	2,1	1	0,0001	1	0,2	5	1,6
Myrtaceae sp.38	-	-	-	-	2	0,0014	1	0,5	1	0,2
Myrtaceae sp.40	-	-	-	-	2	0,0002	1	0,3	1	0,2
Myrtaceae sp.41	-	-	-	-	2	0,0002	1	0,3	1	0,2
Myrtaceae sp.42	-	-	-	-	5	0,0036	3	1,3	3	0,5
Myrtaceae sp.43	-	-	-	-	2	0,0013	1	0,4	1	0,2
Myrtaceae sp.44	-	-	-	-	1	0,0001	1	0,2	1	0,1

Family ***Species***	**Tree strata (DBH ≥ 5 cm)**				**Understorey (DBH < 5 cm, h ≥ 1 m)**				**Whole sample**	
	A	**BA (m²)**	**F**	FIV / **IVI**	**A**	**BA (m²)**	**F**	FIV / **IVI**	**F**	FIV / **IVI**
Myrtaceae sp.45	-	-	-	-	1	0,0001	1	0,2	1	0,1
Myrtaceae sp.46	-	-	-	-	2	0,0009	1	0,4	1	0,2
Myrtaceae sp.47	-	-	-	-	1	0,0002	1	0,2	1	0,1
Myrtaceae sp.48	-	-	-	-	5	0,0005	1	0,5	1	0,2
Myrtaceae sp.49	-	-	-	-	1	0,0000	1	0,2	1	0,1
Nyctaginaceae				**13,6**				**9,7**		**13,4**
Guapira opposita (Vell.) Reitz	83	2,60	14	15,7	110	0,0295	16	12,0	16	14,9
Olacaceae				**2,4**				**-**		**1,9**
Heisteria aff. silvianii Schwacke	4	0,32	2	1,6	-	-	-	-	2	1,3
Schoepfia brasiliensis A. DC.	2	0,02	1	0,4	-	-	-	-	1	0,2
Oleaceae				**0,6**				**0,7**		**0,5**
Chionanthus trichotomus (Vell.) P.S. Green	1	0,01	1	0,3	1	0,0009	1	0,3	1	0,2
Phytolaccaceae				**1,2**				**-**		**1,0**
Seguieria langsdorffii Moq.	1	0,20	1	0,8	-	-	-	-	1	0,7
Picramniaceae				**0,7**				**2,6**		**1,2**
Picramnia glazioviana Engl.	3	0,01	2	0,6	27	0,0063	4	2,8	4	1,3

Family	Tree strata (DBH ≥ 5 cm)				Understorey (DBH < 5 cm, h ≥ 1 m)				Whole sample	
Species	**A**	**BA (m²)**	**F**	FIV / **IVI**	**A**	**BA (m²)**	**F**	FIV / **IVI**	**F**	FIV / **IVI**
Piperaceae				**1,2**				**3,4**		**3,0**
Piper caldense C. DC.	-	-	-	-	1	0,0002	1	0,2	1	0,1
Piper cf. hilianum C. DC.	-	-	-	-	3	0,0014	2	0,7	2	0,3
Piper lhotzkyanum (Miq.) Kunth	1	0,00	1	0,3	-	-	-	-	1	0,2
Piper malacophyllum (C. Presl) C. DC.	-	-	-	-	1	0,0003	1	0,3	1	0,1
Piper richardiifolium (Kunth) Kunth ex C. DC.	1	0,01	1	0,3	-	-	-	-	1	0,2
Piper translucens Yunck.	-	-	-	-	16	0,0002	1	1,0	1	0,5
Proteaceae				**2,1**				**1,5**		**1,8**
Roupala montana Aubl. var. *brasiliensis* (Klotzsch) K.S. Edwards	11	0,28	8	3,0	9	0,0041	4	1,7	9	2,4
Quiinaceae				**0,7**				**0,7**		**0,5**
Quiina glaziovii Engl.	2	0,01	2	0,5	2	0,0002	2	0,5	4	0,6
Rosaceae				**0,6**				**0,7**		**0,5**
Prunus myrtifolia (L.) Urb.	1	0,01	1	0,3	2	0,0002	2	0,5	3	0,5
Rubiaceae				**28,7**				**50,3**		**31,0**
Alibertia sp.1	3	0,04	2	0,7	-	-	-	-	2	0,4
Alibertia sp.2	4	0,02	2	0,7	1	0,0002	1	0,3	2	0,4

Family ***Species***	**Tree strata (DBH ≥ 5 cm)**				**Understorey (DBH < 5 cm, h ≥ 1 m)**				**Whole sample**	
	A	**BA (m²)**	**F**	FIV / **IVI**	**A**	**BA (m²)**	**F**	FIV / **IVI**	**F**	FIV / **IVI**
Alibertia sp.3	1	0,01	1	0,3	5	0,0011	2	0,7	2	0,4
Amaioua intermedia Mart.	2	0,01	1	0,3	-	-	-	-	1	0,2
Bathysa mendoncaei K. Schum.	8	0,17	3	1,6	5	0,0022	3	1,1	4	1,3
Chomelia estrellana Muell.Arg.	4	0,06	2	0,8	5	0,0010	2	0,7	3	0,8
Coussarea contracta (Walp.) Muell.Arg. var. *panicularis* Muell. Arg.	6	0,03	5	1,4	3	0,0020	2	0,8	5	0,9
Faramea truncata (Vell.) Muell. Arg.	1	0,00	1	0,2	3	0,0013	2	0,7	2	0,3
Faramea sp.	1	0,00	1	0,3	-	-	-	-	1	0,1
Posoqueria cf. acutifolia Mart.	2	0,01	2	0,5	2	0,0003	2	0,5	4	0,6
Posoqueria latifolia (Rudge) Roem. & Schult.	12	0,30	7	2,9	5	0,0017	4	1,2	9	2,4
Psychotria appendiculata Muell. Arg.	-	-	-	-	28	0,0029	1	1,9	1	0,9
Psychotria leiocarpa Cham. & Schltdl.	-	-	-	-	20	0,0022	5	2,1	5	1,1
Psychotria nuda (Cham. & Schltdl.) Wawra	-	-	-	-	12	0,0042	2	1,5	2	0,6
Psychotria pubigera Schltdl.	-	-	-	-	123	0,0268	15	12,0	15	5,1
Psychotria suterella Muell. Arg.	140	0,65	13	13,1	107	0,0991	15	21,0	15	10,6
Psychotria vellosiana Benth.	50	0,46	13	6,9	25	0,0118	10	4,5	14	5,0
Rudgea francavillana Muell. Arg.	-	-	-	-	43	0,0146	6	5,0	6	1,9

Family ***Species***	**Tree strata (DBH ≥ 5 cm)**				**Understorey (DBH < 5 cm, h ≥ 1 m)**				**Whole sample**	
	A	**BA (m²)**	**F**	FIV / **IVI**	**A**	**BA (m²)**	**F**	FIV / **IVI**	**F**	FIV / **IVI**
Rudgea nobilis Muell. Arg.	*5*	*0,04*	*4*	*1,1*	*6*	*0,0012*	*3*	*1,0*	*6*	*1,1*
Simira glaziovii (K. Schum.) Steyerm.	*1*	*0,12*	*1*	*0,6*	-	-	-	-	*1*	*0,5*
Rutaceae				**0,6**				**-**		**0,4**
Zanthoxylum rhoifolium Lam.	1	0,00	1	0,3	-	-	-	-	1	0,2
Sabiaceae				**1,4**				**-**		**1,1**
Meliosma sellowii Urb.	6	0,17	3	1,4	-	-	-	-	3	1,0
Salicaceae (incl. Flacourtiaceae)				**3,1**				**3,0**		**3,3**
Casearia obliqua Spreng.	7	0,13	3	1,4	-	-	-	-	3	0,9
Casearia pauciflora Cambess.	-	-	-	-	4	0,0011	2	0,7	2	0,3
Xylosma cf. prockia (Turcz.) Turcz.	-	-	-	-	1	0,0001	1	0,2	1	0,1
Flacourtiaceae sp.1	6	0,08	4	1,3	1	0,0002	1	0,2	4	0,9
Flacourtiaceae sp.2	1	0,01	1	0,3	4	0,0016	3	0,9	4	0,6
Sapindaceae				**5,4**				**2,5**		**4,7**
Cupania crassifolia Radlk.	4	0,30	3	1,7	3	0,0013	2	0,7	3	1,4
Cupania furfuracea Radlk.	1	0,04	1	0,4	-	-	-	-	1	0,3
Matayba guianensis Aubl.	15	0,14	9	3,0	5	0,0022	5	1,4	11	2,2

Family ***Species***	**Tree strata (DBH ≥ 5 cm)**				**Understorey (DBH < 5 cm, h ≥ 1 m)**				**Whole sample**	
	A	**BA (m²)**	**F**	FIV / **IVI**	**A**	**BA (m²)**	**F**	FIV / **IVI**	**F**	FIV / **IVI**
Matayba sp.	2	0,15	2	0,9	-	-	-	-	2	0,7
cf. Sapindaceae sp.	-	-	-	-	1	0,0001	1	0,2	1	0,1
Sapotaceae				**8,4**				**5,1**		**8,0**
Chrysophyllum viride Mart. & Eichler	-	-	-	-	2	0,0011	2	0,6	2	0,3
Diploon cuspidatum (Hoehne) Cronquist	1	0,01	1	0,3	-	-	-	-	1	0,2
Micropholis crassipedicellata (Mart. & Eichler ex Miq.) Pierre	15	1,22	3	5,2	19	0,0066	5	2,7	6	5,2
Pouteria aff. torta (Mart.) Radlk.	12	0,26	8	3,0	9	0,0075	7	2,7	11	2,6
Pouteria sp.	1	0,00	1	0,3	-	-	-	-	1	0,2
Solanaceae				**4,0**				**4,3**		**5,6**
Cestrum toledii Carv. & Schnoor	1	0,03	1	0,3	-	-	-	-	1	0,2
Cestrum sp.1	1	0,08	1	0,5	-	-	-	-	1	0,4
Cestrum sp.2	-	-	-	-	2	0,0002	1	0,3	1	0,2
Solanum argenteum Dunal	-	-	-	-	4	0,0011	3	0,9	3	0,5
Solanum cinnamomeum Sendtn.	1	0,09	1	0,5	-	-	-	-	1	0,4
Solanum leucodendron Sendtn.	9	0,15	4	1,7	-	-	-	-	4	1,1
Solanum sp.	-	-	-	-	1	0,0001	1	0,2	1	0,1

Family ***Species***	**Tree strata (DBH ≥ 5 cm)**				**Understorey (DBH < 5 cm, h ≥ 1 m)**				**Whole sample**	
	A	**BA (m²)**	**F**	FIV / **IVI**	**A**	**BA (m²)**	**F**	FIV / **IVI**	**F**	FIV / **IVI**
Solanaceae sp.2	-	-	-	-	3	0,0016	3	0,9	3	0,4
Solanaceae sp.3	-	-	-	-	1	0,0001	1	0,2	1	0,1
Solanaceae sp.4	-	-	-	-	1	0,0008	1	0,3	1	0,1
Thymelaeaceae				**1,3**				**2,0**		**1,4**
Daphnopsis martii Meisn.	-	-	-	-	3	0,0007	3	0,8	3	0,4
Daphnopsis sp.	10	0,04	4	1,5	6	0,0031	5	1,6	7	1,4
Urticaceae (incl. Cecropiaceae)				**3,9**				**0,9**		**3,1**
Cecropia hololeuca Miq.	1	0,14	1	0,7	-	-	-	-	1	0,6
Coussapoa microcarpa (Schott) Rizzini	1	0,33	1	1,3	-	-	-	-	1	1,1
Myriocarpa stipitata Benth.	8	0,08	2	1,1	2	0,0019	1	0,5	2	0,7
Vochysiaceae				**7,7**				**1,8**		**6,5**
Qualea glaziovii Warm.	2	0,38	1	1,5	-	-	-	-	1	1,3
Vochysia cf. glazioviana Warm.	7	0,60	3	2,8	1	0,0001	1	0,2	3	2,3
Vochysia oppugnata (Vell.) Warm.	1	0,14	1	0,7	1	0,0001	1	0,2	1	0,6
Vochysia saldanhana Warm.	8	0,34	4	2,3	2	0,0002	1	0,3	4	1,7
Indet				**1,8**				**5,1**		**4,3**

Family ***Species***	**Tree strata (DBH ≥ 5 cm)**				**Understorey (DBH < 5 cm, h ≥ 1 m)**				**Whole sample**	
	A	**BA (m²)**	**F**	FIV / **IVI**	**A**	**BA (m²)**	**F**	FIV / **IVI**	**F**	FIV / **IVI**
Spec.2	1	0,00	1	0,3	1	0,0016	1	0,4	2	0,3
Spec.3	1	0,01	1	0,3	-	-	-	-	1	0,2
Spec.4	1	0,01	1	0,3	-	-	-	-	1	0,2
Spec.8	-	-	-	-	1	0,0002	1	0,2	1	0,1
Spec.9	-	-	-	-	1	0,0001	1	0,2	1	0,1
Spec.11	-	-	-	-	2	0,0007	2	0,5	2	0,3
Spec.12	-	-	-	-	1	0,0001	1	0,2	1	0,1
Spec.13	-	-	-	-	1	0,0002	1	0,2	1	0,1
Spec.14	-	-	-	-	1	0,0001	1	0,2	1	0,1
Spec.15	-	-	-	-	1	0,0001	1	0,2	1	0,1

Table 2: Tree species detected in the three fragments:David (D), Maturano (M) and Sorvete (S). in Teresópolis –RJ.

Family / Species	**D**	**M**	**S**
ANNONACEAE			
Annona cacans Warm.			x
Guatteria candolleana Schlecht.		x	
Guatteria mexiae R.E.Fr.		x	
Rollinia sylvatica (A. St.-Hil.) Mart.		x	
Xylopia brasiliensis Spreng.			x
APOCYNACEAE			
Aspidosperma spec. 1			x
Aspidosperma tomentosum Mart.			x
Tabernaemontana hystrix Steud.			x
AQUIFOLIACEAE			
Ilex brevicuspis Reiss.		x	
Ilex paraguaiensis A. St.-Hil.			x
ARECACEAE			
Syagrus oleracea Becc.		x	
ASTERACEAE			
Piptocarpha macropoda Baker.	x	x	
Vernonia diffusa Less.	x	x	
BIGNONIACEAE			
Jacaranda macrantha Cham.	x		
Sparattosperma leucanthum (Vell.) K.Schum.	x		x
Tabebuia spec. 1			x
CELASTRACEAE			
Maytenus brasiliensis Mart.		x	
Maytenus communis Reiss.			x
Maytenus evonymoides Reiss.	x		x
Maytenus spec. 1			x
CLUSIACEAE			
Chrysochlamys saldanhae (Engl.)Oliveira Filho		x	

Family / Species	D	M	S
ELAEOCARPACEAE			
Sloanea spec. 1			x
EUPHORBIACEAE			
Croton echinocarpus Baill.		x	
Croton floribundus Spreng.	x	x	x
Sapium glandulatum (Vell.) Pax.	x		
FABACEAE (ex Leguminosae)			
Acacia polyphylla DC.			x
Apuleia leiocarpa (Vogel) J.F. Macbr.	x	x	x
Bauhinia longifolia (Bong.) Steud.			x
Inga barbata Benth.			x
Inga spec. 1	x	x	
Machaerium nyctitans (Vell.) Benth.		x	
Machaerium spec. 1			x
Machaerium stipitatum (DC.) Vog.	x	x	
Ormosia fastigiata Tul.			x
Piptadenia gonoacantha (Mart.) J. F. Macbr.	x	x	x
Piptadenia paniculata Benth.	x	x	
Platymiscium pupescens Micheli.		x	
*Platypodium elegan*s Vog.			x
Pseudopiptadenia contorta (DC.) G.P. Lewis & M.P.M. de Lima			x
Senna macranthera (DC. ex Colladon) H.S. Irwin & R.C. Barneby		x	
Senna multijuga (L.C. Richard) H.S. Irwin & R.C. Barneby	x		
Tachigali paratyensis (Vell.) H.C. Lima			x
Tachigali rugosa (Mart.ex Benth.) Zarucchi & Pipoly			x
LAURACEAE			
Aniba firmula (Nees et Mart.) Mez		x	
Cinnamomum spec. 1		x	
Nectandra oppositifolia Nees & Mart. ex Nees	x	x	
Ocotea glaziovii Mez.		x	
Ocotea pulchella (Nees) Mez			x

Family / Species	D	M	S
Ocotea silvestris Vattimo-Gil			x
Persea americana Mill.	x		
Phyllostemonodaphne geminiflora (Mez) Kosterm		x	x
MALVACEAE			
Chorisia speciosa St. Hill.			x
MELASTOMATACEAE			
Leandra spec. 1		x	
Leandra spec. 2		x	
Leandra sulfurea Cogn.		x	
Miconia cinnamomifolia (DC.) Naudin	x	x	
Miconia eichlerii Cogn.	x		
Miconia latecrenata Naud.	x		
Miconia tristis Spring. ex Mart.			x
Tibouchina canescens Cogn.		x	
MELIACEAE			
Cabralea canjerana (Vell.) Mart.	x	x	
Trichilia catigua A. Juss			x
Trichilia elegans A. Juss			x
MORACEAE			
Brosimum gaudichaudii Trec.			x
Ficus luschnathiana Miq.	x		
MYRSINACEAE			
Myrsine coriacea (Sw.) R.Br. ex Roem. & Schult.		x	
Myrsine parvula (Mez) Otegui		x	
Myrsine venosa A. DC.	x		
MYRTACEAE			
Campomanesia hirsuta Gardn.			x
Myrta. spec. 1		x	
Myrta. spec. 3			x
Myrta. spec. 5			x
Myrcia fallax (Rich.) DC.	x		

Family / Species	D	M	S
Myrcia spec. 1		x	
Myrcia splendens (Sw.) DC.			x
NYCTAGINACEAE			
Guapira hirsuta (Choisy) Lundell.		x	x
Guapira opposita (Vell.) Reitz.		x	x
PHYTOLACCACEAE			
Seguieria langsdorffii Moq.	x		x
POLYGONACEAE			
Coccoloba fastigiata Meisn.		x	
RHAMNACEAE			
Colubrina glandulosa Fresen		x	
Rhamnus spec. 1		x	
RUBIACEAE			
Alibertia spec. 1			x
Guettarda viburnoides Cham. & Schlecht		x	
Psychotria pleiocephala Müll. Arg.	x		
Psychotria vellosiana Benth.	x	x	x
RUTACEAE			
Dyctioloma vandellianum A. Juss		x	
Zanthoxylum rhoifolium Lam.	x	x	
Zanthoxylum spec. 1			x
SALICACEAE (incl. Flacourtiaceae)			
Casearia decandra Jacq.		x	
Casearia obliqua Spreng.			x
Casearia sylvestris Sw.		x	x
Xylosma prockia (Turcz.) Turcz.		x	
SAPINDACEAE			
Allophylus sericeus Radlk.	x	x	x
Cupania oblongifolia Mart.			x
Cupania schizoneura Radlk.	x	x	x
Cupania vernalis Cambess.	x		x

Family / Species	D	M	S
SOLANACEAE			
Solanum cernuum Vell.		x	
Solanum leucodendron Sendt.	x		
URTICACEAE (incl. Cecropiaceae)			
Cecropia glaziovi Snethlage.	x	x	x
Cecropia lyratiloba Miq.		x	
VOCHYSIACEAE			
Vochysia schwackeana Warm.	x	x	
INDET.			
Indet. spec. 1	x		
Indet. spec. 4		x	
Indet. spec. 5	x	x	
Indet. spec. 6			x
Indet. spec. 7	x		
Indet. spec. 8			x
Indet. spec. 9			x

Table 3: Birds sampled, trophic guilds, preferred habitats and nesting substractes at two sites in PARNASO- 10,600 ha (Serra dos Órgãos National Park; 22º24'36"S and 42º58'48"W), in Teresópolis, state of Rio de Janeiro, Brazil. August 2003 to June 2005.

	Point 1	Point 2	Trophic Guild**	Habitat***	Nesting****
Accipitridae					
Accipter striatus	1	0	Diurnal carnivorours	F	V
Rupornis magnirostris	0	1	Diurnal carnivorours	FF	V
Falconidae					
Micrastur ruficollis	1	0	Diurnal carnivorours	F	TO
Columbidae					
Columba plumbea	1	0	Canopy frugivorous	F	V
Geotrygon montana	0	1	Ground frugivorous	F	V
Leptotila rufaxilla	1	2	Ground frugivorous	F	V
Trochilidae					
*Clytolaema rubricauda**	2	0	Nectarivorous	F	V
*Phaethornis eurynome**	3	1	Nectarivorous	F	V
*Thalurania glaucopis**	1	0	Nectarivorous	F	V
*Stephanoxis lalandi**	0	1	Nectarivorous	F	V
Trogonidae					
Trogon rufus	0	1	Canopy frugivorous	F	TE
Ramphastidae					
*Selenidera maculirostris**	1	0	Canopy frugivorous	F	TO
Picidae					

	Point 1	Point 2	Trophic Guild**	Habitat***	Nesting****
*Piculus aurulentus**	0	1	Insectivorous	F	TE
Thamnophilidae					
Dysithamnus mentallis	3	5	Understory insectivores	F	V
*Mymortherula gularis**	2	1	IUnderstory insectivores	F	V
*Pyriglena leucoptera**	0	2	Understory insectivores	F	S
Formicariidae					
Batara cinerea	0	1	Understory insectivores	F	V
Grallaria varia	0	1	Ground Insectivorous	F	V
Conopophagidae					
*Conopophaga lineata**	2	0	Understory insectivores	F	S
Furnariidae					
*Anabacerthia amaurotis**	5	2	Understory insectivores	F	TE
*Heliobletus contaminatus**	2	2	Canopy insectivorous	F	TE
Lochmias nematura	2	4	Ground insectivores	F	G
Philydor rufus	1	1	Understory insectivores	F	G
Sclerurus scansor	6	4	Ground insectivores	F	G
Syndactyla rufosuperciliata	1	2	Understory insectivores	F	TO
Dendrocolaptidae					
Sittasomus griseicapilus	1	6	Trunk-twig insectivore	F	TO
Lepidocolaptes fuscus *	5	7	Trunk-twig insectivore	F	TO
*Xiphocolaptes albicollis**	1	1	Trunk-twig insectivore	F	TO

	Point 1	Point 2	Trophic Guild**	Habitat***	Nesting****
Tyrannidae					
*Mionectes rufiventris**	1	10	Understory insectivores	F	V
Platyrinchus mystaceus	2	0	Understory insectivores	F	V
*Attila rufus**	0	2	Canopy insectivores	F	G
Leptopogon amaurocephalus	2	0	Understory insectivores	F	V
Pipridae					
*Chiroxiphia caudata**	11	9	Understory omnivorous	F	V
Cotingidae					
*Carpornis cucullatus**	1	1	Canopy insectivores	F	V
Muscicapidae					
Turdus albicollis	6	8	Edge Omnivorous	F	V
Turdus amaurochalinus	1	0	Edge Omnivorous	FF	V
Turdus rufiventris	1	6	Edge Omnivorous	FF	V
Platycichla flavipes	4	2	Understory frugivorous	F	V
Emberezidae					
*Tachyphonus coronatus**	1	0	Edge Omnivorous	F	V
Tachyphonus cristatus	0	2	Understory omnivorous	F	V
Trichothraupis melanops	8	5	Understory omnivorous	F	V
Habia rubica	2	3	Understory insectivores	F	V

	Point 1	Point 2	Trophic Guild**	Habitat***	Nesting****
*Haplospiza unicolor**	1	0	Bamboo-tangles insectivores	F	V
Basileuterus leucoblepharus	2	4	Understory insectivores	F	V
Basileuterus culicivorus	1	0	Understory insectivores	F	V

* Endemic species of the Atlantic Forest (Pacheco & Bauer 2000).

** Trophic guilds according to Willis (1979)

***Habitats: **F**, Forest species; **FF**, facultative forest species, according to Pacheco & Bauer (2000).

**** Nesting subtracts: **V:** species that nest over vegetation, **TE:** species that excavates in trunks of trees and arboreal termite nests (species that burrow only in decaying wood), **TO**: species that occupy pre-existing cavities in tree trunks, but are unable to dig them; S: species that nest on the ground and **G**: species that burrow galleries in the ground (Sick 1997).

Table 4: Number of captures, habitat, feeding guild and nesting substratum in four fragments of Atlantic Forest in Teresópolis, Rio de Janeiro, Brazil. Data from August 2003 to August 2005.

TÁXON	FRAGMENTS Area (ha)				HABITAT**	TROPHIC GUILD***	NESTING** **
	F1 (4)	F2 (9)	F3 (23)	F4 (64)			
TINAMIDAE							
Crypturellus tataupa	0	0	0	1	F	GF	V
ACCIPITRIDAE							
Rupornis magnirostris	0	0	1	0	FF	DC	V
COLUMBIDAE							
Leptotila rufaxilla	2	3	2	4	F	GF	V
CUCULIDAE							
Piaya cayana	0	0	1	0	F	UI	V
TROCHILIDAE							
Phaethornis eurynome *	0	0	0	1	F	NE	V
Thalurania glaucopis *	0	2	0	0	F	NE	V
PICIDAE							
Picumnus cirratus	0	0	0	1	F	TF	TE
Colaptes melanochloros	0	0	0	1	FF	TF	TE
Veniliornis maculifrons *	0	0	0	2	F	TF	TE
THAMNOPHILIDAE							
Mackenziana severa *	0	0	1	1	F	BBI	V
Thamnophilus caerulescens	2	3	2	2	F	UI	V
Dysithamnus mentalis	0	0	0	1	F	UI	V
Pyriglena leucoptera *	4	6	15	11	F	UI	S
CONOPOPHAGIDAE							
Conopophaga lineata	2	5	8	6	F	UI	S
FURNARIIDAE							
Synallaxis ruficapilla *	3	0	3	2	F	UI	V

TÁXON	FRAGMENTS Area (ha)				HABITAT**	TROPHIC GUILD***	NESTING** **
	F1 (4)	F2 (9)	F3 (23)	F4 (64)			
Anabazenops fuscus *	1	0	2	1	F	BBI	TE
Syndactyla rufosuperciliata	0	3	0	1	F	UI	TE
*Anabacerthia amaurotis**	0	0	0	2	F	UI	TE
Philydor rufus	0	1	0	0	F	UI	G
Xenops rutilans	0	0	0	1	F	TF	TE
Lochmias nematura	0	1	0	0	F	UI	G
DENDROCOLAPTIDAE							
Sittasomus griseicapillus	0	2	1	2	F	TF	TO
Lepidocolaptes fuscus *	2	4	2	8	F	TF	TO
Campylorhamphus falcularius *	0	1	1	0	F	TF	TO
TYRANNIDAE							
Mionectes rufiventris *	0	0	1	1	F	UI	V
Leptopogon amaurocephalus	0	0	1	1	F	UI	V
Hemitriccus diops *	0	0	4	0	F	BBI	V
Todirostrum plumbeiceps	0	1	0	0	F	BBI	V
Tolmomyias sulphurescens	0	2	1	0	F	UI	V
Platyrinchus mystaceus	0	1	1	4	F	UI	V
Lathrotriccus euleri	2	3	1	3	F	UOM	V
Myiarchus swainsoni	1	0	0	0	F	CI	V
PIPRIDAE							
Chiroxiphia caudata *	0	5	6	6	F	UOM	V
MUSCICAPIDAE							
Turdus rufiventris	8	14	16	5	FF	EO	V
Turdus leucomelas	2	6	2	3	F	EO	V
Turdus amaurochalinus		3	3		FF	EO	V
Turdus albicollis	0	0	4	3	F	UOM	V

TÁXON	FRAGMENTS Area (ha)				HABITAT**	TROPHIC GUILD***	NESTING****
	F1 (4)	F2 (9)	F3 (23)	F4 (64)			
VIREONIDAE							
Cyclarhis gujanensis	0	0	2	1	F	CI	V
Hylophilus poicilotis *	0	0	1	0	F	IB	V
EMBERIZIDAE							
Basileuterus culicivorus	2	2	2	3	F	UI	V
Trichothraupis melanops	5	4	8	5	F	UOM	V
Tachyphonus coronatus *	5	8	4	4	F	EO	V
Thraupis sayaca	0	0	1	0	FF	EO	V
Tangara desmaresti *	0	0	2	0	F	EF	V
*Arremon taciturnus**	3	4	1	0	F	EG	S
Total OF indivíduals	44	84	100	87		-	-

* Endemic Atlantic Forest species, according to Pacheco & Bauer (2000).

** Habitats: **F**, Forest species; **FF**, facultative forest species, according to Pacheco & Bauer (2000).

*** Trophic guilds: **CFI -** Canopy frugivorous-insectivorous; **EF -** Egde frugivorous; **UOM** - Understory omnivorous; **EO** - Edge Omnivorous; **GF -** Ground frugivorous; **DC -** Diurnal carnivorours; **TF** - trunk-twig insectivores; **UI** - understory insectivores; **BI**: bamboo-tangles insectivores; **CI** - canopy insectivores; **NE** - nectarivorous and **EG** - edge granivores. Following Willis (1979).

**** Nesting substracts: **V:** species that nest over vegetation, **TE:** species that excavates in trunks of trees and arboreal termit nests (species that burrow only in decaying wood), **TO**: species that occupy pre-existing cavities in tree trunks, but are unable to dig them; S: species that nest on the ground and **G**: species that burrow galleries in the ground (Sick 1997, Antunes 2003).

Table 5. Phyto species in agricultural plots (vegetables, grassland, sylvopastoral, agroforestry)

A. Species from silvopastoral plots

Common name	Family	Specie
Aroeira pimenta	Anacardiaceae	*Schinus terebinthifolio*
Carqueja	Asteraceae	*Baccharis trimera*
Assa peixe	Asteraceae	*Vernonia polianthes*
	Asteraceae	*Vernonia polianthes*
	Asteraceae	*Indet*
Ipê	Bignoniaceae	*Tabebuia sp*
Embauba	Cecropiaceae	*Cecropia peltata*
Embauba	cecropiaceae	*Cecropia sp*
Sangue de drago	Euphorbiaceae	*Cróton floribundus*
Canelinha	Lauraceae	*Nectandra sp*
	Lauraceae	*Nectandra sp*
	Lauraceae	*Indet*
Angico	Leg mimosoideae	*Anadenanthera sp*
Pau Jacaré	Leg mimosoideae	*Piptadenia gonoacantha*
	Leg mimosoideae	*Piptadenia moniliformes*
Jacaranda	Leg papilonoideae	*Machaerium sp*
Timbo	Leguminosae	*Lonchocarpus sp*
	Leguminosae	*Indet*
Tibucina	Melastomataceae	*Miconia sp*
Tibucina	Melastomataceae	*Tibuchina sp*
Tibucina	Melastomataceae	*Tibuchina sp1*
Tibucina	Melastomataceae	*Tibuchina sp2*
Cedro roxo	Meliaceae	*Cedrela fissilis*
Araçá	Myrtaceae	*Psidium sp*
	Palmae	*Syagrus romanzhofiana*
Braquiaria	Poaceae	*Brachiaria decumbens*
meladeira	Poaceae	*Melinis minutiflora*

Camboata	Sapindaceae	*Cupania sp*
Fumo bravo	Solanaceae	*Solanum sp*
	Tiliaceae	*Luehea divaricata*
Açoita cavalo	Tiliaceae	*Luehea divaricata*
Açoita cavalo	Tiliaceae	*Luehea sp*
	Tiliaceae	*Luhea sp*
Capinxigui	Ulmaceae	*Trema micrantha*
Pau de tucano	Verbenaceae	*Aeghiphila sp*

B. *Plant species in agricultural plots in Teresópolis*

B-1. HERBACEOUS (HBC)

Family	Specie
Amaranthaceae	*Amaranthus deflexus*
Amaranthaceae	*Amaranthus sp*
Asteraceae	*Artemisia verlotorum*
Asteraceae	*Bidens pilosa L.*
Asteraceae	*Galinsoga sp*
Asteraceae	*Indet*
Balsaminaceae	*Impatiens sp*
Commelinaceae	*Commelina benghalensis l.*
Convolvulaceae	*Indet*
Convolvulaceae	*Ipomonea hederifolia L.*
Curcubitaceae	*Momordica charantia L.*
Euphorbiaceae	*Euphorbia heterophylla*
Gramineae	*Brachiaria decumbens*
Gramineae	*Coix lacrima-jobi L.*
Gramineae	*Melostack sp*
Labiatae	*Hyptis sp*
Labiatae	*Leonurus sibiricus L.*
Leguminosae	*Aeschynomene denticulata*
Leguminosae	*Crotalaria incana*

Leguminosae	*Crotalaria sp1*
Leguminosae	*Indet*
Leguminosae	*Indigofera hirsuta L.*
Leguminosae	*Lonchocarpus sp*
Leguminosae	*Vigna sp*
malvaceae	*Malvastrum sp*
malvaceae	*Sida rhombifolia*
malvaceae	*Sida sp*
Melastomataceae	*Tibuchina sp*
Plantaginaceae	*Plantago tomentosa Lam.*
Rutaceae	*Zanthoxylum rhoifolium Lam.*
Solanaceae	*Solanum americanum*
Tiliaceae	*Luehea sp*
Tiliaceae	*Triunfetta bartramia*
Umbeliferae	*Apium sp*
Poaceae	*Pennisetum clandestinum*
Chenopodiaceae	*Chenopodium ambrosioides*
Poaceae	*Melinis minutiflora*
Poaceae	*Pennisetum purpureum*
Poaceae	*Panicum maximum*
Portulacaceae	*Portulaca oleracea*

B-2. BUSH (ABT)	
Solanaceae	*Acnistus arborescens*
Myrtaceae	*Gomidesia sp*
Piperaceae	*Piper sp*
Sapindaceae	*cipo*
Leguminosae	*sp1*
Indet	*cipo*
Euphorbiaceae	*Indet*
Asteraceae	*sp2*

B-3. TREES (AR)	
Anacardiaceae	*Schinus terebinthifolius*

Solanaceae	*Acnistus dracunculifolia*
Sapindaceae	*Allophylus sp*
Moraceae	*Ficus sp*
Myrsinaceae	*Rapanea ferruginea*
Myrtaceae	*Eugenia sp*
Myrtaceae	*Myrciaria sp*
Leguminosae	*Peltophorum dubium*
Leguminosae	*Senna macranthera*
Leguminosae	*Senna sp1*
Euphorbiaceae	*Ricinus communis L.*
Flacourtiaceae	*Casearia sp1*
Indet	*Indet*
Lauraceae	*Nectandra sp*

B-4. VEGETABLE (SCC)

Common name	Family	Specie
Abóbora	Cucurbitaceae	*Cucurbita Moschata*
Acelga	Chenopodiaceae	*Beta vulgaris var. cicla*
Achicoria	Asteraceae	*Taraxacum officinale*
Agriao	Brassicaceae	*Barbarea verna*
Aipo	Umbelliferae	*Apium graveolens*
Alface	Asteraceae	*Lactuca sativa*
Alho Porro	Lilliaceae	*Allium porrum*
Almeirão	Asteraceae	*Cichorium intybus*
Berros	Brassicaceae	*Lepidium sativum*
Cebolinha	Alliaceae	*Allium fistulosum*
Cenoura	Umbelliferae	*Daucus carota*
Chicória	Asteraceae	*Cichorium endivia*
Coentro	Umbelliferae	*Coriandrum sativum*
Couve	Brassicaceae	*Brassica pekinensis*
Couve-Flor	Brassicaceae	*Brassica oleracea*
Culandro	Umbelliferae	*Eryngium foetidum*
Dente-de-leão	Asteraceae	*Taraxacum offlcinalis*
Erva Cidreira	Lamiaceae	*Melissa officinalis*
Erva Doce	Umbelliferae	*Pimpinella anisum*

Espinafre	Aizoaceae	*Tetragonia tetragonioides*
Moranga de Mesa	Cucurbitaceae	*Cucurbita maxima*
Mostarda Crespa	Brassicaceae	*Brassica juncea*
Nabo	Brassicaceae	*Brassica rapa*
Pepino	Cucurbitaceae	*Cucumis sativus*
Pimenta	Solanaceae	*Capsicum frutescens*
Pimentão	Solanaceae	*Capsicum annuum*
rabano	Brassicaceae	*Raphanus sativus*
Repolho	Brassicaceae	*Brassica oleracea*
Rúcula	Brassicaceae	*Eruca sativa*
Salsa Crespa	Umbelliferae	*Petroselinum crispum*

B-5. AROMATICS AND MEDICINAL (AMP)

Camomila	Asteraceae	*Matricaria recutita*
Hortelã/Menta	Lamiaceae	*Mentha piperita*
manjericao	Lamiaceaee	*Ocimum basilicum L*
Manjerona	Lamiaceae	*Origanum majorana*
Orégano	Lamiaceae	*Origanum vulgaris*
Tomilho	Labiatae	*Thymus vulgaris*

B-6. FRUIT TREE (F)

Avocado	Lauraceae	*Persea. americana Mill.*
Banana	Musaceae	*Musa acuminata*
Cafe	Rubiaceae	*Coffea arabica*
durazno	Rosaceae	*Prunus persica*
Fig	Moraceae	*Ficus carica L.*
Jabuticaba	Myrtaceae	*Myrciaria cauliflora*
Laranja	Rutaceae	*Citrus sinenis*
lima	Rutaceae	*Citrus limetta*
limao	Rutaceae	*Citrus aurantiifolia*
maracuja	Passifloraceae	*Passiflora edulis*
Marianera	Solanaceae	*Acnistus arborescens*

Nispero	Rosaceae	*Eriobotrya japónica*
Pokâ	Rutaceae	*Citrus reticulata Blanco*

B-7. ANNUAL (LCC)		
Aji	Solanaceae	*Capsicum frutescens*
Algodao	Malvaceae	*Gossypium barbadense*
Amaranto	Amaranthaceae	*Amaranthus hybridus*
Artichoke	Asteraceae	*Cynara scolymus L.*
Batata doce	Convolvulaceae	*Ipomoea batatas*
Berinjela	Solanaceae	*Solanum melongena*
Beterraga	Amaranthaceae	*Beta vulgaris*
Cana de azucar	Poaceae	*Saccharum officinarum*
Chuchu	Cucurbitaceae	*Sechium edule*
Ervilha	Fabaceae	*Pisum sativum*
Feijao verde	Fabaceae	*Phaseolus vulgaris*
Fejoao	Fabaceae	*Phaseolus vulgaris L*
Girasol	Asteraceae	*Helianthus annuus L.*
Guandu	Fabaceae	*Cajanus cajan*
hinojo	Umbelliferae	*Foeniculum vulgare*
Inhame	Araceae	*Xanthosoma sagittifolium*
Jiló	Solanaceae	*Solanum gilo*
Maiz	Poaceae	*Zea mais*
Mandioca	Euphorbiaceae	*Manihot esculenta Crantz*
Maxixe	Cucurbitaceae	*Cucumis anguria*
Quiabo	Solanaceae	*Abelmoschus esculentus*
Tayoba	Araceae	*Colocasia esculenta*
Tomate	Solanaceae	*Licopersicum sculentum*
Yakon	Asteraceae	*Smallanthus Sonchifolius*

C. Silvopastoral Plot

Family	Specie
Anacardiaceae	*Schinus terebinthifolio*
Asteraceae	*Baccharis trimera*
Asteraceae	*Vernonia polianthes*
Asteraceae	*Vernonia polianthes*
Asteraceae	*Sp1*
Asteraceae	*Sp2*
Asteraceae	*Indet*
Bignoniaceae	*Tabebuia sp*
Cecropiaceae	*Cecropia peltata*
cecropiaceae	*Cecropia sp*
Euphorbiaceae	*Cróton floribundus*
Lauraceae	*Nectandra sp*
Lauraceae	*Nectandra sp*
Lauraceae	*Indet*
Leg mimosoideae	*Anadenanthera sp*
Leg mimosoideae	*Piptadenia gonoacantha*
Leg mimosoideae	*Piptadenia moniliformes*
Leg papilonoideae	*Machaerium sp*
Leguminosae	*Lonchocarpus sp*
Leguminosae	*Indet*
Melastomataceae	*Miconia sp*
Melastomataceae	*Tibuchina sp*
Melastomataceae	*Tibuchina sp1*
Melastomataceae	*Tibuchina sp2*
Meliaceae	*Cedrela fissilis*
Myrtaceae	*Psidium sp*
Palmae	*syagrus romanzhofiana*
Poaceae	*Brachiaria decumbens*
Poaceae	*Melinis minutiflora*

Sapindaceae	*Cupania sp*
Solanaceae	*Solanum sp*
Tiliaceae	*Luehea divaricata*
Tiliaceae	*Luehea divaricata*
Tiliaceae	*Luehea sp*
Tiliaceae	*Luhea sp*
Ulmaceae	*Trema micrantha*
Verbenaceae	*Aeghiphila sp*

D. Areas in regeneracion

Family	Specie
D-1. TREE	
Anacadiaceae	*Schinus terebinthifolius*
Leg-Papilonoideae	*Lanchocarpus sp*
Erythroxylaceae	*Erythroxylum pulcrum*
Sapotaceae	*indet*
Rutaceae	*zanthoxylum spp.*
Euphorbiaceae	*Croton floribundus*
Leg-Papilonoideae	*Lonchocarpus sp.*
Leg mimosoideae	*indet*
D-2. BUSHES	
Asteraceae	*Baccharis dracunculifolia*
Myrtaceae	*Psidium cattleiano*
Melastomataceae	*Tibuchina sp*
Solanaceae	*Solanum sp.*
Asteraceae	*Vernonia polianthes*
Bignoniaceae	*Tabebuia sp*

D-3. SUBARBUSTIVE

Leg-Papilonoideae	*Aeschynomene denticulata*
Leg-Papilonoideae	*Senna obtusifolia*

Tiliaceae	*Triunfeta sp*
D-4. HERBACEOUS	
Asteraceae	*Indet*
Asteraceae	*Baccharis trimera*
Asteraceae	*Indet*
Polypodiaceae	*Anemia sp.*
Asteraceae	*Mikania sp.*
Verbenaceae	*Lantana camara*