PADRÕES ESPACIAIS DE LOTES VAGOS E DA INFRAESTRUTURA VERDE EM PAISAGENS URBANAS

MARISE BARREIROS HORTA

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Tese apresentada ao Programa de Pós-Graduação em Ecologia, Conservação e Manejo da Vida Silvestre da Universidade Federal de Minas Gerais, como requisito parcial para obtenção do título de Doutor em Ecologia, Conservação e Manejo da Vida Silvestre

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Belo Horizonte

2020

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SPATIAL PATTERNS OF VACANT LOTS AND GREEN INFRASTRUCTURE IN URBAN LANDSCAPES

Thesis presented to the Postgraduate Program in Ecology, Conservation and Management of Wildlife of the Federal University of Minas Gerais in partial fulfillment of the requirements for the degree of Doctor in Ecology, Conservation and Management of Wildlife

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Belo Horizonte

2020

043 Horta, Marise Barreiros.
Padrões espaciais de lotes vagos e da infraestrutura verde em paisagens urbanas [manuscrito] / Marise Barreiros Horta – 2020.
157 f. : il. ; 29,5 cm.

Orientador: Dr. Geraldo Wilson Fernandes. Coorientadora Dra. Sònia Maria de Carvalho Ribeiro.
Tese (doutorado) – Universidade Federal de Minas Gerais, Instituto de Ciências Biológicas. Programa de Pós-Graduação em Ecologia, Conservação e Manejo da Vida Silvestre.

1. Ecologia. 2. Área Urbana. 3. Áreas Verdes. 4. Ecologia urbana. I. Fernandes, Geraldo Wilson. II. Ribeiro, Sònia Maria de Carvalho. III. Universidade Federal de Minas Gerais. Instituto de Ciências Biológicas. IV. Título.

CDU: 502.7

Ficha catalográfica elaborada pela bibliotecária Rosilene Moreira Coelho de Sá – CRB 6 – 2726

UNIVERSIDADE FEDERAL DE MINAS GERAIS
INSTITUTO DE CIÊNCIAS BIOLÓGICAS
PROGRAMA DE PÓS-GRADUAÇÃO EM ECOLOGIA, CONSERVAÇÃO E MANEJO DA VIDA SILVESTRE

FOLHA DE APROVAÇÃO

Spatial Patterns of Vacant Lots and Green Infrastructure in Urban Landscapes

MARISE BARREIROS HORTA

Tese defendida e aprovada em 05 de fevereiro de 2020 pela banca examinadora constituída pelos (as) Senhores (as)

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ECMVS

Ata da Defesa de Tese

N° 194
Entrada:2015/1

Marise Barreiros Horta

No dia cinco de fevereiro de 2020, às 8:30 horas, na sala 236 bloco I 3 do Instituto de Ciências Biológicas da Universidade Federal de Minas Gerais, teve lugar a defesa de tese de doutorado no Programa de Pós-Graduação em Ecologia, Conservação e Manejo da Vida Silvestre, de autoria do(a) doutorando(a) Marise Barreiros Horta, intitulada: "**AVALIAÇÃO DOS PADRÕES ESPACIAIS DE LOTES VAGOS E DA INFRAESTRUTURA VERDE EM PAISAGENS URBANAS**". Abrindo a sessão, o(a) orientador(a) e Presidente da Comissão, Doutor(a) Sònia Maria de Carvalho Ribeiro, após dar a conhecer aos presentes o teor das normas regulamentares do trabalho final, passou a palavra para o(a) candidato(a) para apresentação de seu trabalho. Estiveram presentes a Banca Examinadora composta pelos Doutores: Maria Auxiliadora Drumond (UFMG-ICB), Fernando de Moura Resende (UFMG-ICB), Yumi Oki (UFMG-ICB), Edinilson dos Santos (PBH (PREFEITURA DE BELO HORIZONTE)) e demais convidados. Seguiu-se a arguição pelos examinadores, com a respectiva defesa do(a) candidato(a). Após a arguição, apenas os senhores examinadores permaneceram no recinto para avaliação e deliberação acerca do resultado final, sendo a decisão da banca pela:

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“Nada, a não ser a insensatez, pode sustentar ainda a crença narcísica de que a natureza e as outras formas de vida foram criadas para o homem e de que somos, portanto, sua razão de ser. Somos parte da teia da biosfera e dependemos imediatamente dela para viver. A natureza é o ponto de partida e de chegada de si mesma, pois é, em sua acepção etimológica, justamente ‘natura’, isto é, ação de fazer nascer. Não se pode fazer morrer o que se faz nascer, apenas para que adquira a forma de mercadoria, de lucro e de lixo.”

Luiz Marques (Capitalismo e Colapso Ambiental)

“Nothing but foolishness can further support the narcissistic belief that nature and other life forms were created for man and that we are therefore her reason for being. We are part of the web of the biosphere and immediately depend on it to live. Nature is the point of departure and arrival of itself, for it is, in its etymological sense, precisely 'natura', that is, the action of being born. What you are born with cannot be put to death just so that it becomes the form of commodity, profit, and garbage.”

Luiz Marques (Capitalismo e Colapso Ambiental)

Acknowledgements

I am very grateful to all the people and institutions that opened this opportunity so that I could broaden my knowledge in various interdisciplinary directions, but especially regarding the enhancement of academic skills, as well as the deepening of the scientific method and its applicability.

I am thankful to my supervisors, Prof. Dr. Geraldo Wilson Fernandes (supervisor) and Prof. Dr. Sònia Maria de Carvalho Ribeiro (co-supervisor) for opening the opportunity, for their availability and contributions with their many ideas in the selection of the research theme and its development. I am very grateful to them also for the many contributions of learning, teaching and suggestions throughout the process of writing the thesis.

My special thanks to CAPES (Brazilian Federal Agency for Support and Evaluation of Graduate Education) for providing the scholarship during all the years of the studies, without which it would not be possible to move the venture forward. To the postgraduate program in Ecology, Conservation and Wildlife Management of the Federal University of Minas Gerais, my genuine thanks for the opportunity.

I also thank PBH (Belo Horizonte Municipal Administration) and PRODABEL (Belo Horizonte Informatics and Information Municipal Company) for the provision of the spatial dataset of the municipality of Belo Horizonte, Minas Gerais. This was made possible mainly through employees Felipe Antônio Carneiro Rodrigues and Rodrigo Nunes Ferreira who kindly provided data and explanations necessary for their exploration, to which I am very grateful.

My sincere thanks to the partnership of several colleagues and professors in the elaboration of the thesis articles, namely: Brenner Henrique Maia Rodrigues, Fernando Figueiredo Goulart, Francisco Medeiros Martins, Jean François Mas, Pedro Fialho Cordeiro, Tulaci Bhakti. I would also like to express my gratitude to the following professionals in the field of botany, vegetation cover mapping and environmental sciences who were willing to participate with their expert knowledge in the research conducted: Erika Ferreira da Silva, Inês Ribeiro de Andrade, João Monnerat Lanna, Laís Ferreira Jales, Laura M. G. Salles Bachi, Luciana Eler França, Mariana Terrôla Martins Ferreira, Natália Costa Soares, Tereza Cristina Souza Sposito.

I am very grateful to all the professors in the various courses I have done and to the staff of the various units I attended (ICB- Instituto de Ciências Biológicas, IGC- Instituto de Geociências, FAFICH- Faculdade de Filosofia e Ciências Humanas da UFMG, EAUFMG- Escola de Arquitetura da UFMG).

I thank my family, especially my mother, sister and brothers for their encouragement. This gratitude extends to Jean François Mas for his patience, affection and innumerable help, which began during the process of submitting projects for acceptance into a doctoral program, until the other stages of the doctorate, preparation of articles and conclusion of the thesis.

To all of you my immense gratitude.

Resumo

Estudos dos padrões espaciais da infraestrutura verde dos lotes vagos e das áreas vulneráveis das cidades são fundamentais para o embasamento de ações voltadas à sustentabilidade urbana. A presente tese teve como principais objetivos caracterizar a paisagem urbana de Belo Horizonte, localizada no sudeste do Brasil, no que se refere aos aspectos da composição particular dos padrões da cobertura do solo dos lotes vagos; da configuração ou dos arranjos desses lotes e da conectividade funcional em áreas verdes vulneráveis da cidade, fornecida por uma espécie de ave eficaz na dispersão de sementes de plantas tropicais. Para alcançar os objetivos foram utilizadas combinações de dados ecológicos, informações socioeconômicas, mapeamentos, análises estatísticas, análises espaciais e modelagem de processos ecológicos. Os resultados para a composição dos lotes vagos da cidade mostraram uma cobertura do solo diversificada e a predominância de lotes compostos por vegetação herbácea-arbustiva. Além disso, houve uma representatividade expressiva de lotes constituídos por aglomerados de árvores e vegetação nativa, capazes de beneficiar a cidade e sua população, através do fornecimento de funções ecológicas e serviços ecossistêmicos potenciais de regulação e suporte. Com relação à configuração da paisagem foi evidenciado que os padrões dos arranjos dos lotes vagos são definidos principalmente pelas métricas relacionadas à área e distância entre lotes. Essas métricas, por sua vez, responderam principalmente aos fatores socioeconômicos densidade populacional e número de áreas protegidas dentro de perímetro de 1500 metros ao redor do lote. Lotes de diferentes coberturas de solo encontraram-se mais próximos entre si e conectados a áreas protegidas, o que reforça a conectividade estrutural, que pode beneficiar elementos da fauna e flora urbanas. Além disso, lotes de alta qualidade de vegetação tenderam a uma distribuição em distâncias mais próximas, mas em bairros com baixo número de áreas protegidas, o que pode enfatizar a importância desses lotes em termos de expansão de áreas verdes preservadas da cidade. Em relação às rotas de menor custo ou com maior probabilidade de serem utilizadas pela ave tucanuçu (*Ramphastos toco*) para movimentação e dispersão na região norte de Belo Horizonte, os resultados demonstraram uma baixa conectividade integral na região estudada; ocorrência de poucas manchas florestais relevantes para a conectividade; e áreas de importância para a conectividade funcional sob ameaça de desmatamento e desaparecimento. Em termos gerais, o que foi evidenciado é que as informações geradas no estudo podem contribuir ao planejamento urbano com bases sustentáveis. A ocorrência temporária de lotes vagos com seus tipos variados de cobertura vegetal e do solo, assim como sua configuração particular, impacta positivamente a qualidade ambiental da cidade. Por outro lado, a regulação do uso do solo não tem contido o uso excessivo e a exposição de lotes usados à total impermeabilização, contrariando a legislação, que prevê proporções de permeabilidade de 10% a 20%. Nota-se também a necessidade de reavaliação do planejamento para áreas verdes vulneráveis da região norte, com inserção de aspectos da conservação da conectividade ecológica e consequentemente da biodiversidade.

Palavras-chave: áreas verdes urbanas, conectividade funcional, ecologia urbana, funções ecológicas, padrões da paisagem, serviços ecossistêmicos

Abstract

Studies of the spatial patterns of the green infrastructure of vacant lots and vulnerable areas in cities are fundamental to support actions aimed at urban sustainability. The present thesis had as main objectives to characterize the urban landscape of Belo Horizonte, located in southeastern Brazil, with regard to aspects of the particular composition of the land cover patterns of vacant lots; the configuration or patterns of the vacant lot arrangements and functional connectivity in vulnerable green areas of the city provided by a bird species effective in dispersing seeds of tropical plants. To achieve the objectives, combinations of ecological data, socioeconomic information, mapping, statistical analysis, spatial analysis and modeling of ecological processes were used. The results for the composition of vacant lots in the city showed a diversified land cover and the predominance of lots composed of herbaceous-shrubby vegetation. In addition, there was an expressive representation of lots consisting of trees clumps and native vegetation, capable of benefiting the city and its population, through the provision of ecological functions and potential ecosystem services for regulation and support. Regarding the landscape configuration, it was evidenced that the patterns of the vacant lot arrangements are defined mainly by the metrics related to the area and distance between lots. These metrics, in turn, responded mainly to socioeconomic factors, population density and number of protected areas within the 1500 meters perimeter around the lot. Lots of different land cover were found closer together and connected to protected areas, which reinforces structural connectivity, which can benefit elements of urban fauna and flora. In addition, high vegetation quality lots tended to be distributed over closer distances, but in neighborhoods with a low number of protected areas, which can emphasize the importance of these lots in terms of expanding the city's preserved green areas. In relation to the routes with the lowest cost or the highest probability of being used by the touco toucan (*Ramphastos toco*) for movement and dispersion in the northern region of Belo Horizonte, the results showed a low integral connectivity in the studied region; occurrence of few forest patches relevant to connectivity; and areas of importance for functional connectivity under threat of deforestation and disappearance. In general terms, what was evidenced is that the information generated in the study can contribute to urban planning on a sustainable basis. The temporary occurrence of vacant lots with their varied types of vegetation and land cover, as well as their particular configuration, positively impacts the environmental quality of the city. On the other hand, the regulation of land use has not contained excessive use and exposure of used lots to total impermeability, contrary to the legislation that provides for permeability ratios of 10% to 20%. There is also a need to reassess the planning for vulnerable green areas in the northern region, including aspects of conservation of ecological connectivity and consequently biodiversity.

Keywords: ecological functions, ecosystem services, functional connectivity, landscape patterns, urban ecology, urban green areas

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GENERAL INTRODUCTION

1. Introduction

The urban landscapes, especially those more densely populated, are found to be concentrators mostly of built and impermeable surfaces usually missing green areas (Grimm et al., 2008; Szlavecz et al., 2011; Dobbs et al., 2017). The steady land use dynamics in these areas leads to biodiversity and ecosystem services losses, reducing the potential improvements for people well-being provided by nature (Breuste et al., 2013a). At the same time, one of the major problems for biodiversity conservation and ecosystem services provision in urban sites is the scarcity of available areas, which are target of many conflicts (Muratet et. al., 2008). In this respect, vacant lots and empty land stand out as potential places for biodiversity conservation, ecosystem services provision and for the increase of the availability of green infrastructure in cities. The green infrastructure involves natural and seminatural elements such as green corridors, street trees, urban forests, green roofs, vegetable gardens, private domestic gardens, parks, public greenspaces, among others (Tzoulas et al., 2007; Vasiljević et al., 2018). It is a broad concept created to embrace the overall environmental quality through the provision of a large supply of ecosystem services and to facilitate the inclusion of natural features in the urban planning process (Sandström, 2002; Kim et al., 2015; Ferguson et al., 2018). Depending on the land cover of the vacant lots, they can contribute to increasing green infrastructure in cities. Thus, these underutilized spaces consisting of vacant lots can offer perspectives for transformations in urban land use that contribute to community development and to the provision of ecosystem services in order to create a social and ecological infrastructure in cities (Kremer et al., 2013).

The emergence of the vacant lots within the vacancy process in cities occurs when the development of a determined use becomes unsuitable, undesirable or impossible (Adams, 2005). This happens for instance due to physical conditions, which may constitute a permanent restraint, favoring a continuous supply of vacant land (Bowman and Pagano, 2004). Mostly, however, vacancy is not a permanent situation but otherwise a transitory feature of the urban context, as an answer to the economic, political and social dynamics, challenging adjustments in the land use patterns (Gore and Nicholson, 1991; Kivell, 1993). Structural changes, especially those of an economic nature, can generate a significant amount of vacant land in cities (Hall, 2002). Several terms and definitions are used for urban vacant areas. There is a consensus that they are unused urban land, publicly or private owned, covering several elements such as vacant lots, brownfields, land being held by speculators, idle land, neglected areas, underutilized places, unoccupied sites, abandoned land, greenfields, derelict sites (Larangeira, 2003; Bowman and Pagano, 2004; Newman et al., 2018). Recent research by Newman et al. (2018) proposes the term vacant urban areas to designate both vacant land and abandoned structures of the built environment. In an attempt to organize vacant land types in North American cities Northam (1971) divided them into five types. This classification was performed according to sites characteristics (see **Fig. 1**), such as size, distribution and ownership, comprising the following types:

1- Remnant parcels (most numerous, small lots, irregular shapes, part of allotments, less important for development given shape and size);
2- Unbuildable (less numerous, larger, parcels with physical constraints such as steep slope - exceeding 10% to 15% - lots subject to flooding, unstable subsurface materials);
3- Corporate reserve (less numerous, large lots, located generally in the city center, land owned mainly by utility companies for future expansion or relocation);
4- Hold for speculation (modest size, land owned by corporations, estates or single party, awaiting further profit on sell, located more on the city periphery);
5- Institutional reserve (owned by public and semi-public organizations for further development, being planned as schools, religious facilities, public service).

In a current study conducted by Kim et al. (2018) it was developed a tool useful for categorizing vacant urban areas according to the social and ecological benefits of the lots, for planning purposes. Their typological approach resulted into 5 (five):

1- Post-industrial sites (contaminated properties resultant from industrial growth and decline, changing zones policies, infrastructure abandonment; affect neighborhoods properties values, safety, health, quality of life; some examples are power plants, landfills, brownfields, military sites, airports);
2- Derelict sites (parcels or lots that may have unused buildings and structure or not; some are unsafe areas used for illegal activities);
3- Unattended with vegetation sites (empty and inactive parcels; may contain natural vegetation, ecosystem value and high potential for development into conservation areas);

4- Natural sites (areas with physical constraints by environmental conditions, such as, wetlands, drainage areas, hillsides, river flood plains);

5- Transportation related sites (parcels related to transportation systems, including railroad tracks, highways, and conservation corridors).

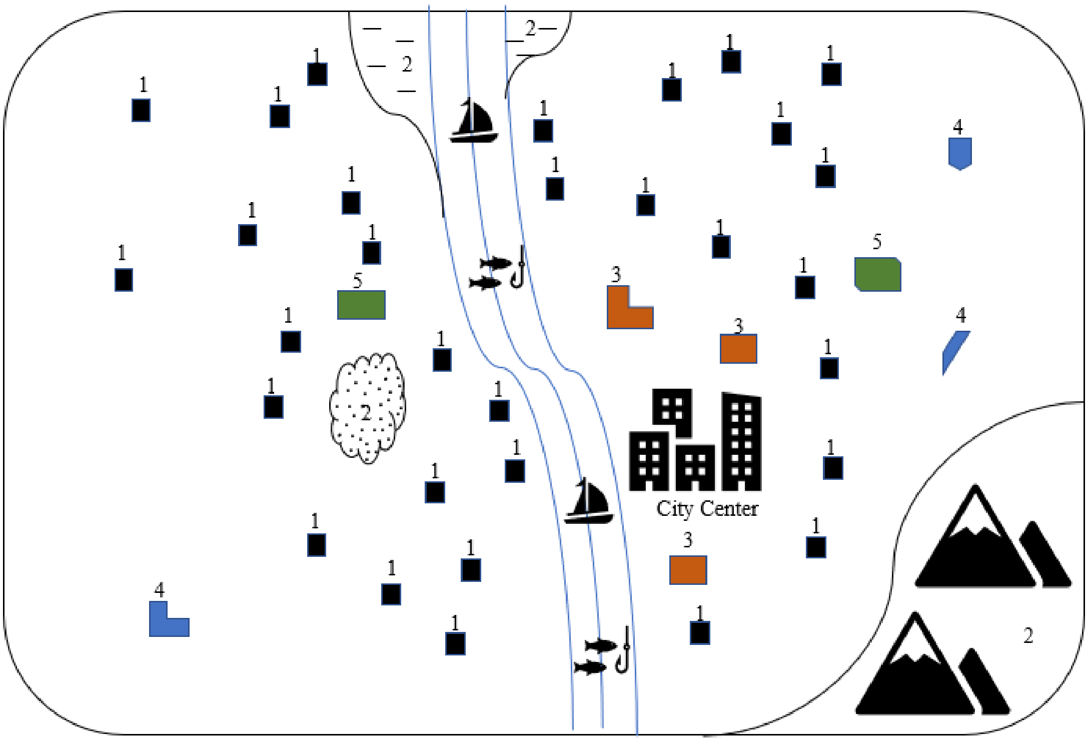

Figure 1: Vacant land types for North American cities: 1- Remnant parcel; 2- Unbuildable; 3- Corporate reserve; 4- Hold for speculation; 5- Institutional reserve (Source: Northam, 1971)

In general, vacant land and abandoned structures, encompassing vacant lots, family's residencies, industrial buildings, in addition to empty housing and space, are recognized as a problem in many cities worldwide (Nassauer and Raskin, 2014). Among the negative aspects are the discouragement for investments and the many risks they represent for the communities in the neighborhood they occur, such as fire increase, crime raisings, health problems, safety concerns, municipal costs, among others (Mallach, 2012; Garvin et al., 2013). The urban vacant land is therefore associated with various unfavorable images and symbolisms, including decay, abandonment, degradation and danger (Bowman and Pagano, 2004). In addition, vacant land and abandoned buildings have a great impact on their surroundings and brings about considerable social and economic costs in the cities. Those costs include their maintenance and potential loss of investments (Mallach, 2012). Despite the negative images associated with the unoccupied and unused areas of cities recent research shows that both the scarcity and excess of vacant urban areas may contribute to the cities decline (Newmann et al., 2018). In the case of the shortage of urban empty areas, housing densification may occur, and this process is usually associated with the loss of environmental traits and life quality, especially under the views of the city's inhabitants (Kyttä et al., 2013). Vacant land surplus on the other hand, can overload the city's economy and contribute to urban decay (Combes 2000; Newman et al., 2018). This stems from the fact that excess vacant land damages the local economy and fiscal health due to the substantial loss of value of vacant properties and the concomitant devaluation of neighboring properties. This situation requires government actions, such as investment in safety and police services, code enforcement, property maintenance, which affect also government expenditures (Mallach and Vey, 2011).

In contrast to this negative connotation, vacant land has been increasingly considered as a source of opportunities, standing out as a key element for the city's development (Bowman and Pagano, 2004). An important point to be highlighted among the benefits arising from vacant land is their potential to fulfill the role of biodiversity repositories, contributing to ecological functions establishment in urban areas (Zhang et al., 2013). In this sense the value of the vacant land is due to the fact that it can function as a natural remnant, composed in many cases of native flora and fauna (Bowman and Pagano, 2004). This concern about considering the natural aspects and the green infrastructure of the cities is highly relevant in a context in which the projections of expansion of the urban areas in the next decades encompass expectations that around 70% of the population of the planet will be living in the cities (UN, 2014). Vacant land can indeed work as an important source of urban nature, green infrastructure and wilderness specially if they can regenerate through ecological succession, constituting an opportunity for environmental restoration in urban sites (Beatley, 2011; Rink and Herbst, 2012; Kim et al., 2015). Other strategies for reducing the negative impacts of vacancy consists in greening the empty space of the vacant lot either through the planting of trees and grasses or with the implementation of community gardens (Heckert and Mennis, 2012; Drake and Lawson, 2014). Vacant land has been also transformed in some cities as places for leisure and public improvements, such as boulevards with cafes and plaza fountain, streetscapes well designed, mixed-use development (Bowman and Pagano, 2004).

The vacancy issue in cities became apparent in the early 1970s affecting large industrial cities particularly in Europe, North America and Australia. The industries began to collapse in those towns in which the dynamism and flexibility of the economy were insufficient to assimilate new types of uses (Kivell, 1993). Deindustrialization, decentralization, and population decline are situations that aggravate vacancy in cities (Newman et al., 2018). Thus, in many developed countries vacancy is seen as a result of population loss, which characterizes the cities of the industrial period. High levels of vacant and abandoned properties are usually related to urban shrinkage in those old industrial cities, which present a relevant amount of population loss usually equal or greater than 25% (Bernt, 2016). Although shrinking cities share elementary characteristics such as a substantial and continuous population decrease, the shrinkage phenomenon is complex but not always considered as such (Bernt, 2016; Hasse et al., 2016). This complexity stems from the urban shrinkage driven forces ranging from those that lead to population decline (including economic recession, demographic change, suburbanization and urban sprawl), to environmental disasters, as well as political and administrative changes (Haase et al., 2016). In any case, population loss and shrinkage exert prominent impacts on land use such as vacancy, underutilization of areas, establishment of brownfields, and reduction of urban densification (Haase et al., 2014). A simple sequence of urban shrinkage driven by economic forces might start with a crisis that determines, for instance, a fabric closure (**Fig. 2**). This situation leads to contractions on demand, employment and income, affecting new investments. The continuity of those events contributes to the emigration of workers and enterprises from these localities and consequent decline of population. Then, vacancy and impoverishment of the affected areas are established (Bernt, 2016).

The scheme of urban shrinkage events presented in **Fig. 2** is very common, but not all cases of vacancy are related to the population decline or to economic crisis. Vacant land occurs also in cities with high land prices (Morandé et al., 2010). The causes of vacancy in those places may be associated with developmental constraints that prevent the reuse of unoccupied sites. Among those constraints can be mentioned the prevention of price reductions even in the context of a high supply of vacant land. In such cases it may be necessary to pursue policies that promote the development process (Adams et al., 1985). Vacancy can be also a result of the urban development associated with land speculation (Kivel, 1993; Morandé et al., 2010). Land speculation in the property market is a term used as synonym of investment (Malpezzi and Wachter, 2005; Triantafyllopoulos, 2010). However, the broader meaning evolves the future value of land and refers to the purchase of land by investors, who without making improvements expect opportunities in the future that allow for greater profits (Evans, 2004). In developing countries, some of those referred contexts can be associated with vacancy in cities that are still expanding in their majority. In those countries the cities sprawl is a common occurrence and the high number of vacant lots may be related to a maintenance of the provision of these lands for a future use (Bowman and Pagano, 2004). Recent research has shown that vacant land is frequently related to expansion of cities or elasticity whereas structural abandonment is more linked to population drop in cities (Newmann et al., 2018).

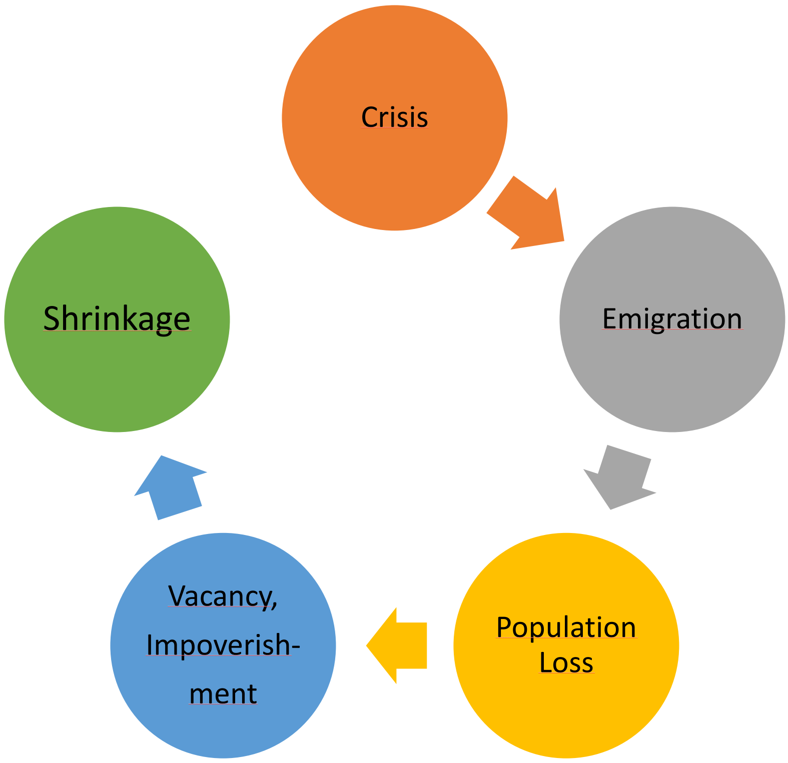

Figure 2: Simplified sequence of urban shrinkage driven by economic forces (Source: Bernt, 2016)

The studies of the vacant lots in urban landscapes have been the subject of attention of urban land use planners and ecologists in several places around the globe (Kremer et al., 2013), but in Brazil the information on the occurrence and composition of these lands in the cities are scarce and usually related to the control of municipal taxes. It is a country in which 86.6% of the population currently lives in cities (Plecher, 2019) featuring a collection of more than fifteen cities with over one million inhabitants, and two cities among the twenty most overpopulated in the world (São Paulo and Rio de Janeiro). Despite this, there is a neglect of natural ecosystem and green areas in the urban context (Herzog, 2013) perhaps because although environmental policies have advanced in the country - mainly in their legal and institutional aspects - they have not been able to overcome environmental degradation and social, political and economic conflicts (Lima, 2011). There is a clear lack of green areas, which are usually unevenly and sparsely distributed in Brazilian urban landscapes (Sperandelli et al., 2013), although environmental management has been gradually inserted in urban planning in the last three decades, through the incorporation of environmental preservation and valuation criteria to the usual territorial planning approaches (Costa, 2008).

As previously mentioned, vacant lots have been considered worldwide as key elements for economic and socio-environmental development, potentially functioning as sources of neighborhood revitalization, quality of life, job creation and business growth (Mallach and Vey, 2011). This set of potential socioenvironmental benefits related to urban vacant lots adds importance to the investigation of the occurrence of these lots, their spatial distribution, land cover patterns, vegetation types and spatial characteristics of their structure and function, which can provide insight into ways of using these sites. Among the benefits of alternative uses can be highlighted the increase of green infrastructure, the conservation of biodiversity, the provision of ecosystem services - such as the mitigation of the effects of climate change - and the promotion of human well-being, contributing to greater environmental sustainability (Kremer et al., 2013; McPhearson et al., 2013; Kim et al., 2015).

2. The Study Area

The study area encompasses the city of Belo Horizonte with a territorial area of approximately 33,100 ha, located in the southeastern Brazilian region. The estimated population is about 2.6 million people. This municipality has an average elevation of 900 m, with climate classified as tropical altitude, and average temperatures ranging between 15 ^{o}C and 28 ^{o}C. It is inserted in the transition of the Atlantic Forest and Cerrado (Savanna) biomes (IBGE, 2005), combining plant species from both (Grandi et al., 1992). Emerging as the state capital and located in the Iron Quadrangle, a region rich in iron ore, Belo Horizonte developed within an area prone to industrialization (Euclydes, 2012). However, this vocation was postponed for many periods in its history having the city, incorporated in its beginnings, the idea of a garden city, shaded and capable of promoting the environmental quality of its inhabitants (Miranda, 2011). Political and economic forces guided the changes in this situation and from the 70's onwards industrialization and urban expansion were boosted (Euclydes, 2012).

Currently, the total protected areas inside the city comprise about 3,190 ha, and those protected by municipal management make up 890 ha (UFMG, 2011a; Xavier, 2018). This set of protected areas has, however, few of strict protection, which corresponds to 2.7% of the municipal territory. These conservation areas are unevenly distributed, with a void of protected areas in the northern region of Belo Horizonte, which is in the process of expanding (UFMG, 2011a; UFMG, 2011b). The vulnerability of this region due to the low incidence of protected areas added to its ongoing expansion, points to the importance of elucidation of the current conditions of ecological connectivity of the landscape. For the vacant lots in the city, although many mechanisms to reduce the idleness of these places have been proposed in previous plans (UFMG, 2011a; UFMG, 2011b), they have not been incorporated in city planning so far. Any measure in this direction, whether aimed at social uses (including fairs, soccer fields, sports centers, playgrounds or places of walking, places for parties) or ecological ones (including environmental preservation areas and urban agriculture) will require a diagnosis of the conditions of the vacant lots.

3. Objectives

The studies carried out in this thesis converge with some of the directions pointed out in the plans recently produced for the city of Belo Horizonte with regard to the need for research that incorporates natural and cultural aspects aiming at improvements in the municipality planning (UFMG, 2011a; UFMG, 2011b). The main objectives of this thesis are:

1- To characterize the land cover patterns of the vacant lots occurring in the urban landscape of Belo Horizonte, state of Minas Gerais, Brazil;
2- To verify land cover´s potential to provide ecological functions and ecosystem services;
3- To characterize vacant lots´ landscape patterns and its potential association with socioeconomic factors that can act as driven forces of their arrangements;
4- To propose and build an original approach to ascertain the functional connectivity provided by a bird species connector in vulnerable green areas of the city.

The definition of this set of objectives was based on the assumption that the study of the spatial patterns of the green infrastructure of vacant lots and vulnerable areas in cities are fundamental to support actions aimed at urban sustainability. For reaching the objectives it is utilized a methodological conception based on the use of socio-ecological data, mapping, statistical analysis and spatial tools to allow the characterization of urban vacant lots and green areas in their ecological and socioeconomic dimensions.

4. Outline of the Thesis

This thesis contains three chapters the first of which addresses the characterization of Belo Horizonte´s vacant lots regarding their vegetation quality, land cover patterns, ecological functions and potential ecosystem services. In Chapter 2 it is explored the association between landscape metrics of the vacant lots and socioeconomic factors of their neighborhoods to understand the human forces acting in this landscape. In Chapter 3, the study areas constituted remnant green areas of the northern region of the city, which are currently target of city expansion projects. This chapter presented an original combination of two functional connectivity methodologies with a designation of species of connector bird. This species present various characteristics that facilitate its movement in urban areas and is suitable for a bird-plant connectivity model. At the beginning and end of the thesis, a brief introduction to the topic and final remarks are presented.

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CHAPTER 1
VACANT LOTS LAND COVER PATTERNS AND THEIR CONTRIBUTION TO ECOLOGICAL FUNCTIONS

Abstract:

Green infrastructure of vacant lots performs socio-ecological functions and provides a spectrum of ecosystem services in urban environments. By assessing the land cover patterns of these sites one can deduce ecological functions and potential ecosystem services. This is the approach used in this study, in which we mapped and classified the vegetation quality of 2,828 vacant lots representing 11% of this feature distributed in the city of Belo Horizonte, southeastern Brazil. We also carried out a cluster analysis of the land cover that were weighted according to their ecological functions and performance. Most of the lots totaling 1,024 (36.21%) were in the moderate vegetation quality class, which included largest plot area of 38.33 ha and median overall size of 403 m^2. The highest vegetation quality lots made up 244 (8.63%). Of total lots 1,370 corresponded to used and 1,458 to unused ones. Both included diverse vegetation cover combinations of up to ten land cover types, highlighting two dominants: herbaceous-shrubby vegetation and tree clumps. Among the four land cover patterns obtained, the cluster of trees (1,193 lots or 42.18%) had the highest ecological performance and the greatest potential for regulating and supporting ecosystem services. This cluster concentrated the highest average land cover of tree clumps (49%) and the highest averages for native vegetation formations, from 2% to 6%. Our study showed a variety of land cover and expressive percentage of lots with capabilities to provide ecological functions and ecosystem services, which can support urban sustainability actions and policies.

Keywords: ecosystem services, urban ecology, urban vacancy, vegetation quality

1.1. Introduction

Urban landscapes usually concentrate constructed and impermeable areas, lacking green infrastructure (Grimm et al., 2008; Szlavecz et al., 2011). They are marked by the dominant human action, being characterized by environmental degradation through pollution, construction and establishment of concrete infrastructures, as well as by the constant creation of new land cover (Grimm et al., 2000; Szlavecz et. al., 2011). Cities land cover include a complexity of components such as built up areas, streets and access roads, bare soil, water, grassy fields, remaining forest areas, isolated trees, unoccupied spaces, among others (Lu and Weng, 2004; Forman, 2014). In these landscapes, the constant dynamics of land use transformation directly affects ecological systems and biodiversity, bringing important consequences such as fragmentation, habitat loss, isolation, changes in species composition and losses of ecosystem services (Bierwagen, 2007; Breuste et al., 2013a). The more the city sprawls and the higher the levels of urbanization, the greater the fragmentation of the landscape and environmental losses, with a growing replacement of ecological functions by human functions, reducing the capacity of the ecological systems to contribute to human well-being and quality of life (Alberti and Marzluff, 2004).

Ecological functions refer to the roles that species or groups of organisms play in the community or ecosystem they occur, which can be translated as use and service functions (Dussault, 2019). Both the ecological functions of species and ecosystems have played a central role in the scope of ecological economics, enabling the generation of a whole theoretical framework for the theme ecosystem services in the last decades (de Groot et al., 2002; Burkhard et al., 2009; de Groot et al., 2010). The identification of ecosystem goods and services implicates the translation of ecological complexity - including structures and processes - into several ecosystem functions grouped in regulation, habitat functions, production and information or cultural functions (de Groot et al., 2000; Oikonomou et al., 2011; Banerjee et al., 2013). The regulation function refers to the capacity of natural and semi-natural systems to regulate essential ecological processes and life support arrangements through bio-geochemical cycles and biospheric processes providing services such as air quality regulation, flood protection, erosion control, water purification. Habitat functions are related to the supply, by natural ecosystems, of refuge for plants and animals, maintaining biological and genetic diversity. The production function includes the results of the conversion of energy, water, nutrients, carbon dioxide by autotrophs into different carbohydrate structures. These, in turn, are used by secondary producers to create a larger variety of living biomass including food, raw materials, fuel and energy, fertilizers, medicines, genetic and ornamental resources. Information functions are referential and cultural ecosystem functions that contribute to human health through opportunities for reflection, spiritual enhancement, scientific education and cognitive development, recreation and aesthetic experience (de Groot et al., 2000; de Groot et al., 2002; Banerjee et al., 2013).

Ecosystem functions thus provide a large spectrum of goods and services that are valuable to humans. The relationship between ecosystems and human well-being lies therefore in the provision of benefits and services by ecosystems to society, through the supply of goods and products arising from biophysical resources or ecosystem processes (de Groot et al., 2010; Bolliger et al., 2011). The biophysical structure of the ecosystem (e.g. vegetation cover) and associated processes (e.g. primary productivity) have functions (e.g. biomass) that provide ecosystem services (e.g. harvestable products). In socioeconomic terms, the benefits from ecosystem services contribute to well-being and quality of life, and their economic valuation can make products available in markets that have impacts on human well-being (de Groot et al., 2010). In recent years efforts have been made by the scientific community to expand the studies and the effective application of the concepts of ecosystem services (Costanza et. al., 1997; MEA, 2005; McDonald, 2009; Elmqvist et. al., 2013; Wratten et. al., 2013; IPBES, 2019). Beyond this commitment is the aspiration for individuals and institutions to recognize the value of nature, and thus to increase conservation investments, which in turn, ensure an improvement in human well-being (Daily, 2009; IPBES, 2019).

The Millenium Ecosystems Assessment (MEA, 2005) defines ecosystem services as the benefits people derive from nature dividing them into: provisioning services (essential for life maintenance, including food, water, wood, fiber); regulating services (climate regulation, flood control, disease control, water quality); cultural services (providing recreational, aesthetic and spiritual benefits) and supporting services (including soil formation, photosynthesis, nutrient cycling, habitat). Ecosystem services therefore aggregate nature's contribution to human well-being and comprise the conditions and processes by which natural ecosystems and their component species sustain human life (Daily, 1997; Breuste et al., 2013a). They are generated by a complexity of natural cycles, ranging from a wide range of biogeochemical cycles (such as carbon movement through living and physical environments) to a smaller scale, such as the life cycle of microorganisms (Daily, 1997). In the cities where there is a high concentration of human population many ecosystem services are generated on a small scale often defined by patches of vegetation or even individual trees (Fitter et al., 2010).

From the various urban land cover, vegetation is the largest provider of urban ecosystem services (Bolund and Hunhammar, 1999; Breuste et al., 2013b). In fact, vegetation plays a notable role in providing ecosystem services and benefits in urban areas including regulation of the microclimate, water supply, air filtration, noise reduction, rainwater drainage, sewage treatment, provision of cultural and aesthetic values, scenic beauty, sense of identity, provision of areas for economic, commercial and residential activities (Breuste et al., 2013b). Vegetation influences the climate of cities causing positive impacts to the regime of winds, temperature, humidity and precipitation (Avissar, 1996). Although carbon dioxide emissions are largely attributed to urban environments, the city's green areas can capture and store carbon, minimizing some of the negative effects of emissions (Strohbach and Haase, 2012; Suchenwirth et. al., 2014). The urban vegetation itself includes a set of spontaneous, cultivated, introduced and native plant species that are part of urban woods, parks, street trees, protected green areas, backyards, gardens and green spaces (Endsley, 2018; Sukopp and Werner, 1983). The degree of contribution of vegetation to the provision of ecosystem services varies according to the characteristics of its components, in terms of its physiognomy, forms of life and structure. In the case of air purification and filtration for example, broadleaf trees with larger leaf surfaces tend to contribute more, as do those that do not lose their leaves seasonally (Bolund and Hunhammar, 1999). Temperature regulation, on the other hand, is favored by the high perspiration of trees (Bolund and Hunhammar, 1999). Noise reduction can be achieved not only by trees but also by lawns that gradually decreases the noise level (Bolund and Hunhammar, 1999).

The evaluation of ecosystem services relies to a large extent on land cover and use based assessments that are suitable to large scale studies, or to areas where the principal service relates directly to land use. In addition, the evaluation of land cover/ use can assist in the assessment of ecosystem services in situations of limited data or unavailability of specialists, and for cases where the center of interest lies in the potential presence of ecosystem services itself rather than supply quantification (Burkhard et al., 2009; Maes et al., 2012; Jacobs et al., 2015). Land cover and its patterns therefore are key elements in ecological studies because they can translate the impacts of human actions on natural ecosystems, while allowing an assessment of the ecological functions and potential ecosystem services of the remaining environments. The assessments of land cover's ability to provide ecosystem services are usually performed by building a matrix in which the land cover types are placed on the y axis and on the x axis are added the ecosystem services, predefined by specific literature (Burkhard et al., 2009; Jacobs et al., 2015). The land cover's capacity to provide ecosystem services is subsequently classified into categories (e.g. from no relevant capacity to very high capacity) through expert assessments and these assumptions can be validated later, as appropriate, by measuring and quantifying through primary data collection (Burkhard et al., 2009; Maes et al., 2012). The field data collection usually serves as the basis for other methodologies for obtaining direct quantifications, especially for provisioning services - such as timber, food, water supply - while for regulating, supporting and cultural services there is a need to have proxies for their quantification, which can be obtained from models and/or indicators (Maes et al., 2012).

In urban landscapes one of the major problems for improving the provision of ecosystem services relates to the scarcity of available areas, with conflicts being prominent in these remaining sites (Muratet et. al., 2008). Under these conditions, vacant lots stand out as potential places for the enhancement of ecosystem services and green infrastructure (Shuster et al. 2011; Horta et al., 2018). As one of the components of urban landscapes, vacant lots have different origins, and may have been created as permanent zones, in areas where buildings are prohibited, or be the result of destruction and abandonment, due to migration, demographic changes, deindustrialization, urban sprawl and people's preferences for new types of residential choices (Smith, 2008; Kim et al., 2018). These spaces include either land that has remained vacant during the formation of the city around them, or those that had previous occupation and were abandoned at a certain point of the temporal scale (Nefs, 2006). Vacant lots can also result from a response to differences and inequalities in access to urban land, the impact of a deregulated real market and real estate speculation, as in the case of many developing countries (Larangeira, 2003).

Regardless of their origin, vacant lots are mostly recognized as a social, economic, environmental and aesthetic problem, having become symbols of decay, degradation and neglect (Spirn et al., 1991; Kim, 2016). They are, however, key elements for the implementation of socio-environmental and economic development strategies, offering opportunities for transformations that favor urban sustainability (Bowman and Pagano, 2004; Kremer et al., 2013; Anderson and Minor, 2017). These underutilized spaces can offer perspectives for transformations in urban land use that contribute to community development and the provision of ecosystem services to form a social and ecological infrastructure in cities (Kremer et al., 2013; Horta et al., 2018). In many places around the world those areas have been mapped and characterized according to their ecosystem services, and have served to carry out many activities, functioning as places for education and research; community gardens; vegetable farming; recreation; rest; accessibility; restoration of biodiversity; source of wildlife resources, conservation and others (Anderson and Minor, 2017; Felson and Pollack, 2014; Hara et al., 2013). Vacant lots have, therefore, played a multifunctional role in aggregating several ecosystem services, among which: provisioning (e.g. food production); regulating services (e.g. carbon storage, air pollution removal, local temperature regulation, runoff mitigation); supporting services (e.g. habitat provision for biodiversity, pollination) and cultural ones (e.g. recreation) (McPhearson et al., 2013). The characterization of urban vacant lots in terms of use and its land cover patterns is very important for better understanding the processes of vacancy in cities, as a well as a contributor to the design of alternative uses of these sites (Kremer et al., 2013).

Within this context, the main objective of the present study is to characterize the land cover patterns of the vacant lots occurring in the urban landscape of Belo Horizonte, southeastern Brazil. This land cover assessment also supports the verification of its potential for the provision of ecological functions and related ecosystem services. The conception of this work is based, therefore, on the hypothesis that there is a diverse vegetation and land cover components in the vacant lots of the city Belo Horizonte capable to perform important ecological functions, which can be translated into potential ecosystem services. We assumed that the land cover of these lots and its vegetation component mainly perform the regulating (water infiltration and storage, microclimate regulation, air purification and filtration, carbon sequestration and storage, soil conservation) and habitat functions (habitat provisioning, biodiversity conservation), considering that the other functions are rarer in the urban landscape or need quantification, not being directly extracted from the land cover (Fitter et al., 2010). A highlight of the present study in relation to others is the detailing of the vegetation cover of the vacant lots, while most studies usually make use of vegetation indices and greenness (NDVI – Normalized Difference

Vegetation Index) (Pearsall and Christman, 2012; Kremer et al., 2013; McPhearson et al., 2013). In this sense, we characterized land cover through variations in vegetation quality of the vacant lots in the city. The concept of vegetation quality has been most frequently included on research on the environmental sensitivity of critical areas for the definition of degradation and desertification levels, where vegetation quality indexes are developed and assessed along with soil conditions and climate (Basso et al., 2000; Hadeel et al., 2010). Vegetation quality in those studies is usually verified through land cover and may include various quantifiable factors, such as the vegetation role in soil erosion protection, the vegetation role in drought resistance, plant cover and others (Hadeel et al., 2010).

In the present study we used to define the vegetation quality categories, structural and physiognomic criteria of vegetation, such as size represented by the presence or absence of arboreal vegetation as opposed to dominant herbaceous or shrub elements. Vegetation quality classes thus vary from the less and simplest to the most structurally complex vegetation formation. Through this it was possible to group the land cover diversity of each lot into a single category of vegetation quality, enabling its mapping. Besides that, by characterizing vegetation, land cover and gaining expert opinions on the ecological functions selected from literature of the land cover units, we measured the ecological performance of vacant lots or the total sum of the ecological functions evaluated in the study (Lovel et al., 2010). This measurement was possible through statistical grouping of the complexity of the vacant lots land cover – due to the various combinations possible in a single lot - into clusters, giving an idea of the main composition of the lots and the ecological functions performed. Thus, by using a combination of different methodologies we characterized the lots of Belo Horizonte according to their vegetation quality, land cover patterns, ecological functions and potentiality of provision of some ecosystem services, which can contribute to the formulation of actions and public policies aimed at urban sustainability.

1.2. Materials and Methods

1.2.1. Study Area

The study was conducted in the city of Belo Horizonte, capital of the state of Minas Gerais, in southeastern Brazil. This municipality has an average elevation of 900 m, with climate classified as tropical savanna (aw), with average temperatures ranging between 15 ^{o}C and 28 ^{o}C. It is inserted in the transition of the Atlantic Forest and Cerrado (Savanna), combining plant species from both (Grandi et al., 1992; IBGE, 2005). The total territorial area is about 33,100 hectares and the estimated population is ca. 2.6 million. The city presents nine administrative units delimited from its location and history of occupation which are: Barreiro, East, North, Northeast, Northwest, Pampulha, South Center, West and Venda Nova (**Fig. 2.1**). A preliminary characterization performed for the vacant lots in the municipality of Belo Horizonte by Horta et al. (2020), based on data from the year 2015, showed the occurrence of 22,047 lots. When verifying associations between the number of vacant lots for each administrative unit in the city and demographic variables and area size, it was found that there was an increase in the number of vacant lots in administrative units with a larger total area size. There was also a positive and significant association between the number of vacant lots and the population growth rates recorded for the various administrative units in the last decade (r^2 = 0.8252; p = 0.0007). According to the study, these trends point to influences from other factors on the high occurrence of vacant lots in the city, unrelated to population reduction and shrinkage, usually associated with vacant lots surplus in several cities in north America and Europe (Bernt, 2016; Hasse et al., 2016). In this sense, Bowman & Pagano (2004) had already verified that cities prone to expansion have higher number of vacant lots, usually occurring in these cases, a maintenance of the provision of vacant lots, for future use of these lands.

Although vacant lots in Belo Horizonte are rarely targeted for socioeconomic and ecological improvement initiatives, a temporary occupation of some of these lots occurred through an experimental urban collective action project, devised by Lousie Ganz (Ganz, 2008). The intention of the project was to transform privately owned lots into temporary public spaces for collective use through interventions throughout the city, providing residents of various neighborhoods with access to nearby spaces. In these spaces there were activities outside the lucrative and entrepreneurial spectrum, seeking to establish relationships between the local population and the temporality of the lots, mobilizing people for the daily use of these spaces. For this, the lots were traversed, selected and mapped, and there was also a negotiation process of the loan of the lots with the respective owners, defining the time of use and activities to be performed. Among the temporary interventions were the planting of grass; grass planting with rest and leisure; implantation of leisure area with swimming pool; implementation of living room in lots with traces of constructions; harnessing the topography of lots to establish resting places; beauty salon deployment under vacant lot tree. The objective of the initiative was within a sociopolitical proposal insofar as, according to the author, the action of going beyond the delimitation of private property and public space allows the disclosure of important issues for the understanding of relations and struggles of society and humanity, especially on the issue of land tenure.

1.2.2. Vacant Lots Dataset and Sampling Design

The official vacant lots database of Belo Horizonte was primarily designed for the control over the incidence of taxes on built-up areas in the city. The dataset used in this study consisted of an official municipal map with associated information of the vacant lots of Belo Horizonte (year 2017), provided by the city hall (Prodabel/PBH), including information on land ownership (public or private). From the total of 26,906 vacant lots a representative sample was carried out for a confidence level of 95% of the entire population of lots in the city and for each administrative unit. The equation used was $n=N.Z2*p*(1-p) / Z2*p*(1-p) + e2*(N-1)$ were: n-calculated sample; *N*-population; *Z*-normal variable; *p*-actual probability of the event; *e*-sampling error (Cochran, 1977). A total of 2828 vacant lots (11% of total lots) were randomly selected and the estimation of samples for the nine administrative units obtained was: Barreiro (2,670 lots; 311 sampled-12%); East (1,384 lots; 207 sampled-15%); North (2,126 lots; 277 sampled-13%); Northeast (4,922; 349 sampled-7%); Northwest (3,441; 208 sampled-6%); Pampulha (4,266;407 sampled-10%); South Center (2,082; 355sampled-17%); West (3,307;346 sampled-10%); Venda Nova (2,708;368 sampled- 14%).

The zoning of the city regarding the occupation of areas and allowed population density was used to verify the expected soil permeability rates for the various lots evaluated in the sampling. The various regions of the city are zoned according to ease or difficulties of the occupation, due to physical and topographical adversities, or due to a lack of infrastructure for water supply or sewage, and the precariousness or saturation of the road system (Belo Horizonte, 2010). It is from the definition of these zones that there are standards related, for example, to the rate of permeability of the soil, which must be met for the construction of buildings in the lot. In the database of vacant lots in the city of Belo Horizonte the following areas of occupation of the lots were included: ZA (regions of high population density and intense use of urban infrastructure in which the densification should be contained); ZAR1/2 (1-regions with restricted occupancy due to precarious or saturated road system and 2-with precarious infrastructure and topographical conditions); ZAP (regions which can be densified due to favorable infrastructure and topography conditions); ZHIP (corresponds to the hypercentral zone where a greater densification and verticalization of the buildings is allowed); ZCBH (central zone of Belo Horizonte subject to greater densification); ZCBA (central zone of the region of Barreiro subject to greater densification); ZCVN (central zone of the Venda Nova region subject to greater densification) (Belo Horizonte, 2010). The selected vacant lots sample covered all these zones, except for the last one (ZCVN) that did not include any lot in the database. The expected rate of permeability of the soil for each lot in all these zones that cover the sampling of the study is between 10% and 20% (de Marco and de Assis, 2013).

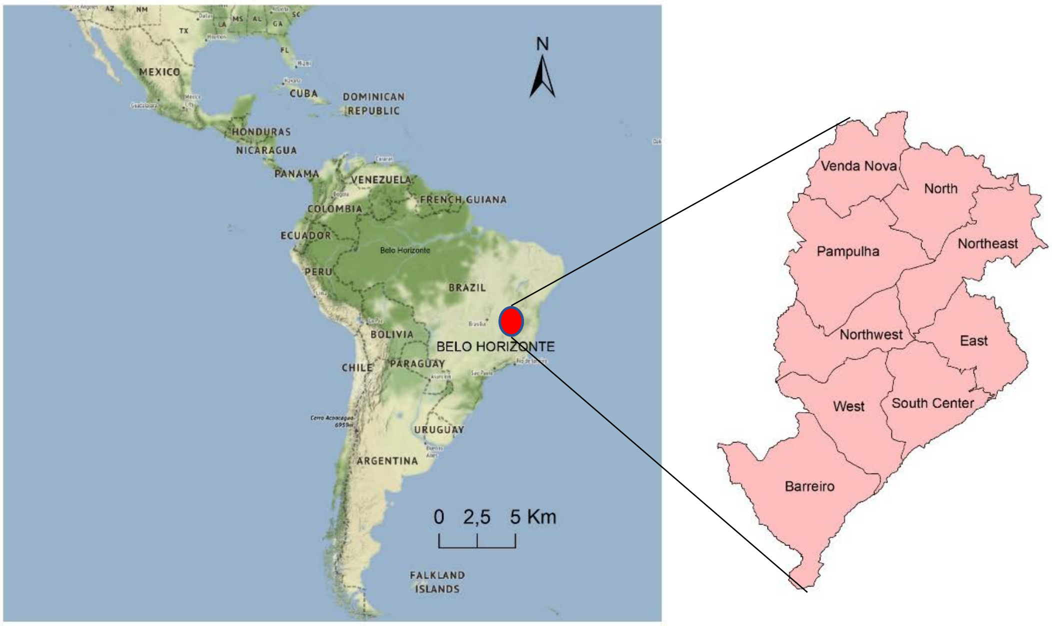

Figure 1.1: Study area comprising the city of Belo Horizonte and its nine administrative units (South America) terrain map from http://maps.stamen.com/#terrain/7/-20.612/-43.281)

Regarding the management of vacant lots two main municipal laws contain procedures that should be adopted in these spaces. Both Law 10534/2012 (Belo Horizonte, 2012), which refers to urban cleaning and urban solid waste management, as well as Law 9725/2009 (Belo Horizonte, 2009) on building code, recommend that vacant lots must be kept fenced out (with access gate and openings to the external environment that allow visualization), cleaned, drained and weed thinned. The brush cutting should allow thinning only of the herbaceous-shrubby vegetation, without the removal of stumps or roots, preserving the shrub vegetation and having as standard of finish the average distance of 10cm to 15cm above the level of the ground, allowing the use of scraper to remove rubbish and debris. For the removal or cutting of trees or tree vegetation, it is necessary a project approval that defines the best use of the vegetation, according to Law 8327/2002 (Belo Horizonte, 2002). In addition, any tree, located in the municipality, can be declared immune to the cut if evaluated as such.

1.2.3. Land Cover Mapping

The mapping of land cover was performed using the high-resolution satellite image GeoEye (09/24/2016, 41cm resolution, provided by Prodabel/PBH) and the digitized map of the boundaries of the 2,828 samples of vacant lots. Each individual lot was interpreted in detail utilizing QGIS and ArcView GIS softwares (ESRI, Redlands, California, USA), and the observations of the percentage of occurrence of each one of the land covers were recorded in a spreadsheet. We identified ten land cover components of the lots namely: agriculture; bare soil; forest advanced-intermediate stage of regeneration; forest initial stage of regeneration; herbaceous-shrubby vegetation; impermeable surfaces (asphalt, cement, construction); pasture; savanna (Cerrado); tree clumps or tree groupings; water. Considering the occurrence of lots with use in the database and sampling, for the used lots a land use mapping was carried out, using the same methodology and materials adopted for land cover (for types and definitions see **App. 1.1**). The elucidation of the land use of these lots allowed a concise examination of the dynamics of use of the lots in recent years, considering the creation of the database in 2008. The differentiation of the types of successional stages of the forest and of these in relation to tree clumps was made through the observation of the presence of remnants of forest formations in the surroundings, attesting the continuity with the vegetation of the lot. The interpretation of the various land cover classes and land use was based on the literature on national, regional and local phytogeography and authors' expertise and professional background in the field, and was performed by a single person, avoiding propagation of errors (Tempfli et al., 2009; Perera et al., 2012).

A visual interpretation of key elements in the high-resolution satellite image such as texture, pattern, shape, size, height/elevation, location/association was carried out for mapping the land cover and land use, the latter only for the case of the used plots that were found in the database (Tempfli et al., 2009). In addition, vegetation studies for forest remnants of Belo Horizonte were used, covering sampling of georeferenced plots in the field, including information on maximum, average, and minimum diameters and heights of the trees, which allowed to the insertion of remnants in successional forest stages (Felix, 2009; Miranda, 2014). For the definition of forest succession stages, the Resolution of the National Environment Council (Resolução Conama 392/2007) was used, which defines the primary and secondary vegetation of Atlantic forest in the state of Minas Gerais (Brasil, 2007). According to this resolution the forest in advanced stage of regeneration presents upper canopy with trees above 12 meters and average trunk diameter of 18 cm. For the intermediate stage of regeneration, the upper strata are between 5 m and 12 m, and mean trunk diameters between 10 cm and 20 cm. The early-stage forest presents upper canopy with trees up to 5 m and average diameters up to 10 cm. Given the difficulty of separation and occurrence of situations where the two forest physiognomies (advanced an intermediate) were merged, the forest in advanced stage of regeneration composed a single class with that in the intermediate stage. The vegetation of savanna (Cerrado) mainly comprised physiognomies of savanna shrubby vegetation (Campo Sujo) and denser vegetation (Campo Cerrado) (Rizzini, 1979). Both are less densely vegetated forms, with a predominance of shrubs and grasses, in the case of Campo Sujo ecosystem and with sparse trees, intersecting the shrub-herbaceous layer in the case of the Campo Cerrado (Rizzini, 1979; Oliveira-Filho and Ratter, 2002; Fernandes et al., 2018).

In order to represent each lot as a mapping unit, vegetation quality classes were created, based on the vegetation composition and land cover of each plot comprising low, moderate, high and very high vegetation quality situations. Cases of absence of vegetation were included into the categories “no vegetation permeable” (with bare soil present) and “no vegetation impermeable” (with total presence of impermeable surfaces such as asphalt, cement and construction). Visual estimates of the percentage of occurrence of each land cover were made. The classification of vegetation quality was given by the characteristics of the component that occurred in a higher percentage. The classification of the vegetation into quality classes therefore was made based on the vegetation cover with the highest percentage of occurrence, its structural complexity related to the size that ranged from herbaceous and low shrub vegetation to arboreal vegetation with mature trees, and in the verification of whether or not it was a remnant of native vegetation, as in the case of forests and savannas (**Table 1.1**).

Thus, vegetation quality was considered lower for lots with predominantly up to 50% of structurally simplified vegetation (e.g. herbaceous-shrubby vegetation, pasture, agriculture) or with a low occurrence of arboreal vegetation (up to 25%), which was more complex or a native remnant (e.g. forest advanced-intermediate stage, forest initial stage, tree clumps, savanna). In the same way, intermediate plots or classified as belonging to moderate vegetation quality class presented a structurally complex vegetation composed of forest advanced-intermediate, forest initial stage, tree clumps, and savanna, in percentages between 25% and 50%. In the same class were also represented plots with herbaceous-shrubby vegetation, pasture, and agriculture with percentages between 50% and 100%. The plots included in the high vegetation quality class presented in their composition only arboreal vegetation and native forest and savanna cover (forest advanced-intermediate, forest initial stage, tree clumps, savanna) occurring in percentages between 50% and 75%. The class of very high vegetation quality also gathered exclusively tree and natural forest and savanna vegetation (forest advanced-intermediate, forest initial stage, tree clumps, savanna) with cover between 75% and 100%. In cases where the lots had no vegetation but composed of permeable components they were inserted in the class “No Vegetation Permeable”. Given the full occupation of some lots by impermeable surfaces (asphalt, cement, constructions) these were framed as “No Vegetation Impermeable”. From the elucidation of the different components of the lots it was also possible to quantify their percentage of permeability and segmentation into intervals (0-25%,> 25% - 50%,> 50% - 75%,> 75% - 100%).

Table 1.1**:** Components of the vegetation quality classes of vacant lots sampled and respective defining percentage in the city of Belo Horizonte, Brazil

Vegetation Quality Classes	Acronym	Components	Percentage
Very High Vegetation Quality	VHVQ	Forest Advanced-Intermediate Stage of Regeneration	> 75% - 100%

Vegetation Quality Classes	Acronym	Components	Percentage
Very High Vegetation Quality	VHVQ	Forest Initial Stage of Regeneration	> 75% - 100%
Very High Vegetation Quality	VHVQ	Savanna; Tree Clumps	> 75% - 100%
High Vegetation Quality	HVQ	Forest Advanced-Intermediate Stage of Regeneration	> 50% - 75%
High Vegetation Quality	HVQ	Forest Initial Stage of Regeneration	> 50% - 75%
High Vegetation Quality	HVQ	Savanna; Tree Clumps	> 50% - 75%
Moderate Vegetation Quality	MVQ	Forest Advanced-Intermediate Stage of Regeneration	> 25% - 50%
Moderate Vegetation Quality	MVQ	Forest Initial Stage of Regeneration	> 25% - 50%
Moderate Vegetation Quality	MVQ	Savanna; Tree Clumps	> 25% - 50%
Moderate Vegetation Quality	MVQ	Herbaceous-Shrubby Vegetation; Pasture; Agriculture	> 50% - 100
Low Vegetation Quality	LVQ	Forest Advanced-Intermediate Stage of Regeneration	>0% – 25%
Low Vegetation Quality	LVQ	Forest Initial Stage of Regeneration	>0% – 25%
		Savanna; Tree Clumps	>0% - 25%
Low Vegetation Quality	LVQ	Herbaceous-Shrubby Vegetation; Pasture;	
Low Vegetation Quality	LVQ	Agriculture	>0% - 50%
No Vegetation Permeable	NVP	Bare Soil	100%
No Vegetation Permeable	NVP	Water	100%
No Vegetation Impermeable	NVI	Asphalt, Cement, Construction	100%

1.2.4. Land Cover Clusters and Ecological Performance

We used cluster analysis in our study to extract general and more homogeneous information that represents the complexity of land cover combinations of the surveyed lots. Cluster analysis is a statistical method for identifying groups in raw data helping users find structure in that material (van Tongeren, 1995). Through clustering of data by machine learning processes, the input data is partitioned into subsets so that each one shares common traits, as they are divided into reasonably homogeneous groups or clusters (Scott and Knott, 1974; Gjorgjioski et al., 2008). We utilized this method because the vegetation quality classes, which mainly portray the dominant land cover among others that can occur in a single plot, cannot be directly translated into ecological functions. The ecological functions on the other hand can be derived from each land cover through cluster analysis. Thus, to perform this procedure, we first selected the most appropriate ecological functions for interpretation only through land cover – as assumed for this research - and consulted a group of eleven experts to obtain their assessment of the importance of each land cover for each function. The chosen ecological functions obtained from literature comprised some abundant in urban environments and more easily interpreted through land cover including: regulating functions (water infiltration and storage, microclimate regulation, air purification and filtration, carbon sequestration and storage, soil conservation) and habitat functions (habitat provisioning, biodiversity conservation) (de Groot et al., 2002; Lovell et al., 2010; Lovell and Taylor, 2013).

To obtain expert opinion we built a matrix adapted from Burkhard et al. (2009) containing on the x axis the seven ecological functions investigated and on the y axis the ten land cover, comprising: agriculture; bare soil; forest advanced-intermediate stage of regeneration; forest initial stage of regeneration; herbaceous-shrubby vegetation; impermeable surfaces; pasture; savanna; tree clumps; water. The experts consulted consisted of nine professionals in the field of botany, vegetation cover mapping and environmental sciences, from the private and public sector. They were consulted via email messages and provided for each of the given land cover weights from 0 to 4 according to their importance or contribution to each of the ecological functions, namely: 0 (no importance or contribution to the ecological function considered); 1 (low importance or contribution to the ecological function considered); 2 (moderate importance or contribution to the ecological function considered); 3 (high importance or contribution to the ecological function considered); 4 (very high importance or contribution to the ecological function considered). The final weight matrix of the ecological functions of each land cover was obtained by calculating the average values provided by experts (**App.1.2**).

The cluster analysis was performed using IBM SPPS Statistics from the input data referring to the percentages of each land cover belonging to each lot - with a maximum total of 100% - obtained from the interpretation of key features from the high-resolution satellite image GeoEye 2016. The 2828 lots were included in the analysis and all land cover not in the lots were zero-filled. To define the number of clusters required for analysis, the R program and the specific NbClust package were used to determine the relevant number of clusters in the dataset, thus avoiding an arbitrary choice of clusters, which does not reflect the ideal homogeneity for interpretation (Charrad et al., 2014; R Core Team, 2018). With the definition of the optimal number of clusters in 4, the results of the processing phase were worked according to the resulting average percentage of land cover per cluster, and a matrix of the average percentage of each land cover per cluster was generated. It is worth noting that in cluster analysis each observation or sample belongs to the group closest to the average, in this case the average percentage of land cover in the lot. Through the resulting cluster matrix with the average percentages, the ecological function value of each cluster component was calculated, which corresponded to the weighted sum of the weights provided by the experts to each land cover (**App. 1.2**) multiplied by the land cover percentage for that specific cluster, and divided by the total percentage, around 100% (99%-102%), as follows:

$$\boldsymbol{EF_{1....7}\ C_{1...4} = \Sigma\ (LC\%_{1...10} / LCT\% * EF_{1....7}\ W_{1....10})}$$

$EF_{1...7}$ – Ecological Function from 1 to 7

$C_{1...4}$ – Cluster from 1 to 4

Σ – Sum

LC% - Land Cover percentage for each land cover in each of the clusters

LCT% - Land Cover total percentage or the sum of all percentages for each land cover

$EFW_{1....10}$ – Ecological Function from 1 to 7, Weight of each Ecological Function for the 10 land cover types

The ecological performance evaluated in the study was adapted from Lovell et al. (2010) which used a measure of landscape performance based on the sum total of the values of the various ecological functions. Similarly, the ecological performance for each cluster in the present study was defined and calculated by the total sum of the results of each ecological function. According to our data characteristics, the maximum value that can be obtained for the ecological performance of each cluster is 28, considering that seven ecological functions were analyzed, each one with a maximum weight of 4. Thus, for ecological performance evaluation it is considered a low performance results that were between >0 to 7; moderate in the range of >7 to 14; high for ranges >14 to 21; very high at intervals of >21 to 28. The calculations made to obtain the full value of the ecological performance are represented as follows:

$$\boldsymbol{EP_{1....7}\ C_{1...4} = \Sigma\ EF_{1....7}}$$

$EP_{1....7}$ – Ecological Performance for ecological functions 1 to 7

$C_{1...4}$ – Cluster from 1 to 4

Σ – Sum

$EF_{1....7}$ – Ecological Function from 1 to 7

1.3. Results

1.3.1. Land Cover Mapping

The 26,906 vacant lots that occurs in the city of Belo Horizonte is represented in our study by 2,828 lots or 11% of the population of randomly selected lots, covering an area of de 4,771,235 m^2 or 477.12 ha. The spatial distribution of these lots and their organization in vegetation quality classes are shown in **Figures 1.2** and **1.3**. The Moderate Vegetation Quality (MVQ) class aggregated the largest number of vacant lots totalizing 1,024 parcels or 36.21%. This class, together with the classes Low Vegetation Quality (LVQ - 646 lots or 22.84%) and No Vegetation Permeable (NVP - 319 lots or 11.28%), comprised 1,989 parcels, equivalent to 70.33% of the sampled lots. The highest vegetation quality classes presented lower representativity, with 128 lots or 4.53% for the High Vegetation Quality (HVQ) class and 116 lots or 4.10% for Very High Vegetation Quality (VHVQ). The class of parcels without vegetation but permeable (No Vegetation Permeable – NVP) are composed entirely by bare soil; those composed thoroughly of impermeable surfaces called No Vegetation Impermeable (NVI) comprised 595 lots, equivalent to 21.04% of the sampled lots.

When observing the distribution of vegetation quality in the nine administrative units of the city, it is evident the repetition of the pattern, in which there is a predominance of lots in the moderate vegetation quality class (**Fig. 1.4**). The Northeast regional unit is the only one that presented a slight advantage of the number of lots in the class of lots without vegetation and impermeable (NVI - 111 lots) in relation to moderate vegetation quality (MVQ - 95 lots). The maximum number of lots of highest vegetation quality per class was 19, occurring in the North (HVQ - 19), West (HVQ - 19) and Venda Nova (VHVQ - 19) administrative units. By adding the Very High Vegetation Quality (VHVQ) and High Vegetation Quality (HVQ) classes, which together total 244 lots, the outstanding administrative units in terms of vegetation quality included: Venda Nova (36 lots); South Center (33 lots); West (31 lots) and North (31 lots).

Regarding variations in size of area occupied by the various vegetation quality categories the classes low vegetation quality (1,814,977 m^2/ 181.50 ha) and moderate vegetation quality (1,708,776 m^2/ 170.88 ha) gathered 3,523,800/ 352.38 ha or 74% of the total area of the sampled lots. The other classes subsequently presented the following area sizes: high vegetation quality (516,609 m^2/ 51.66 ha); no vegetation impermeable (416,911 m^2/ 41.69 ha); no vegetation permeable (232,952 m^2/ 23.29 ha); very high vegetation quality (81,009 m^2/ 8.10 ha). Most of the lots were distributed in the smallest size class which includes lots from 36 m^2 to 1,000 m^2 demonstrating this general pattern for the various classes (**Fig. 1.5**). The average size of lots in this class was 402 m^2 and the overall average for all sampling set found was 1,687 m^2. The largest size plot with total area of 383,375 m^2 (38.33 ha) is composed by the moderate vegetation quality class, located in the administrative unit of Barreiro (**Table 1.2**). The lot with the second largest area (266,634 m^2/ 24.66 ha) is composed of high vegetation quality and is situated in the North administrative unit. The other two lots with areas greater than 10 ha were composed of moderate (158,748 m^2/ 15,87 ha) and high vegetation quality (100,753 m^2/ 10.07ha) classes, both located in the Northeast administrative area. The overall median size of lots sampled in the city was 403 m^2.

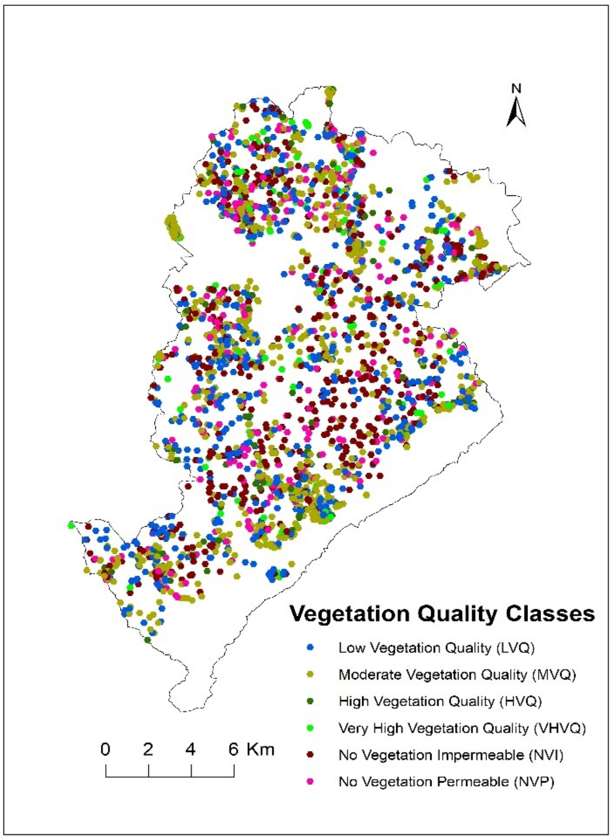

Figure 1.2: Land cover map of the vacant lots sampled in the city of Belo Horizonte, Brazil

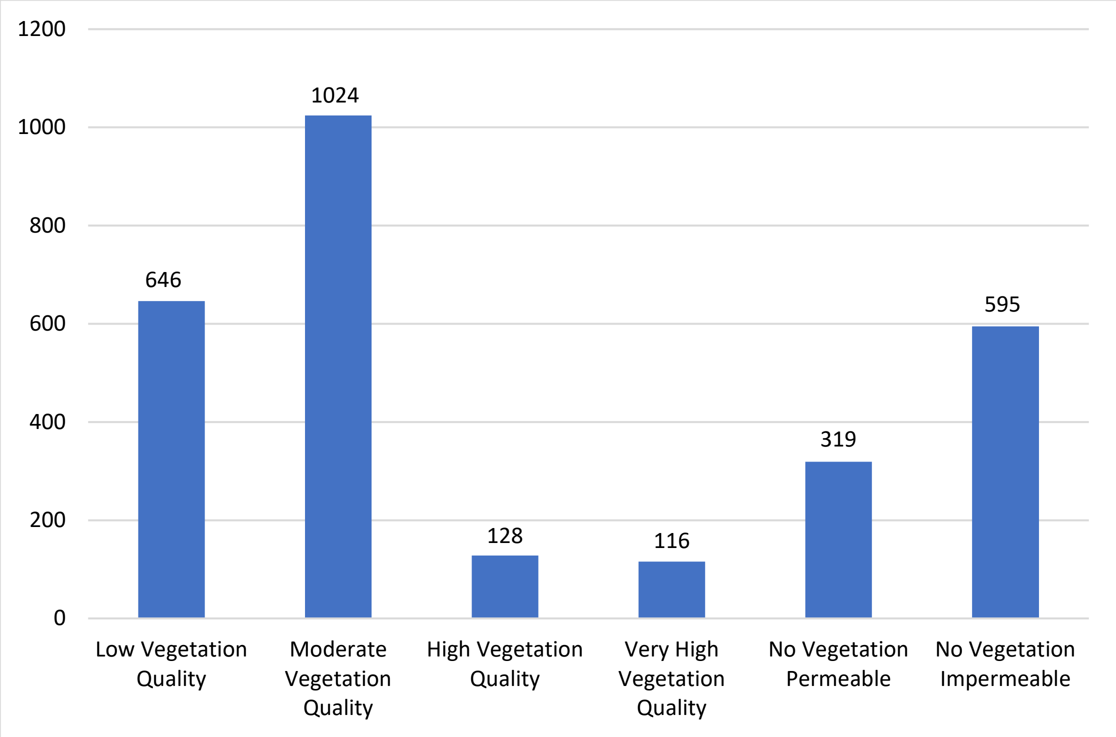

Figure 1.3: Total population of vacant lots sampled in the city of Belo Horizonte organized according to their distribution in vegetation quality classes (LVQ – Low Vegetation Quality; MVQ – Moderate Vegetation Quality; HVQ – High Vegetation Quality; VHVQ – Very High Vegetation Quality; NVP – No Vegetation Permeable; NVI – No Vegetation Impermeable) (N=2,828)

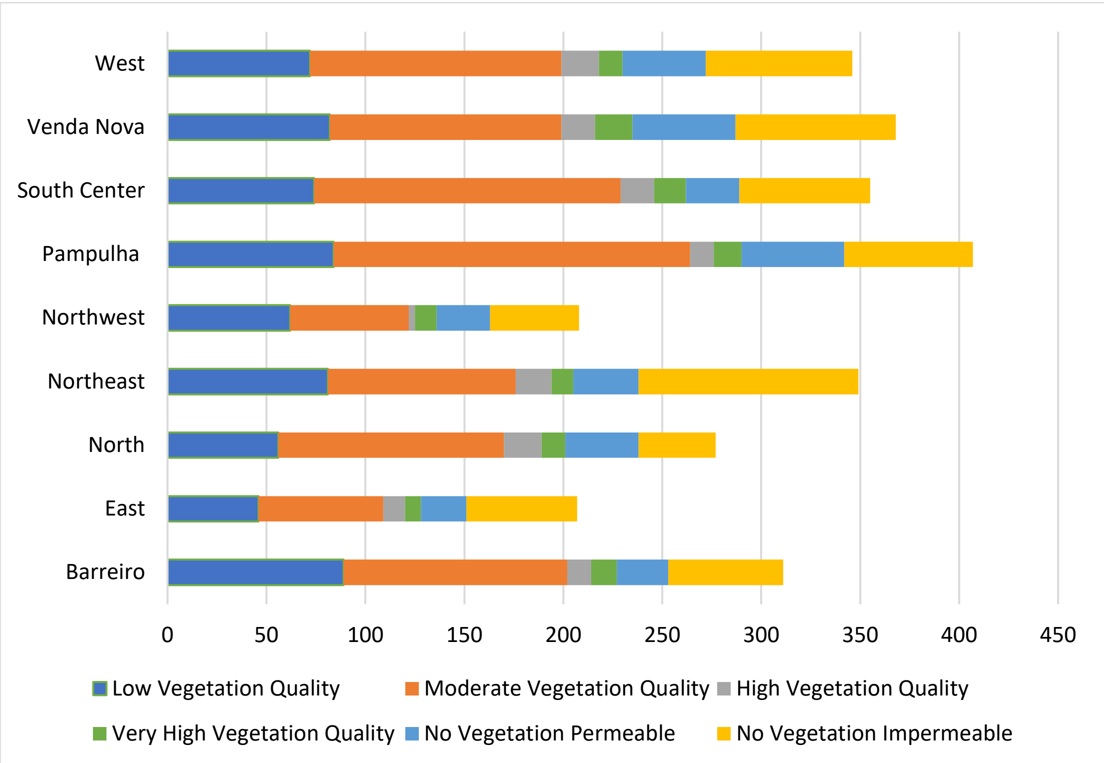

Figure 1.4: Distribution of the classes of vegetation quality in the various administrative units of the city (N=2,828)

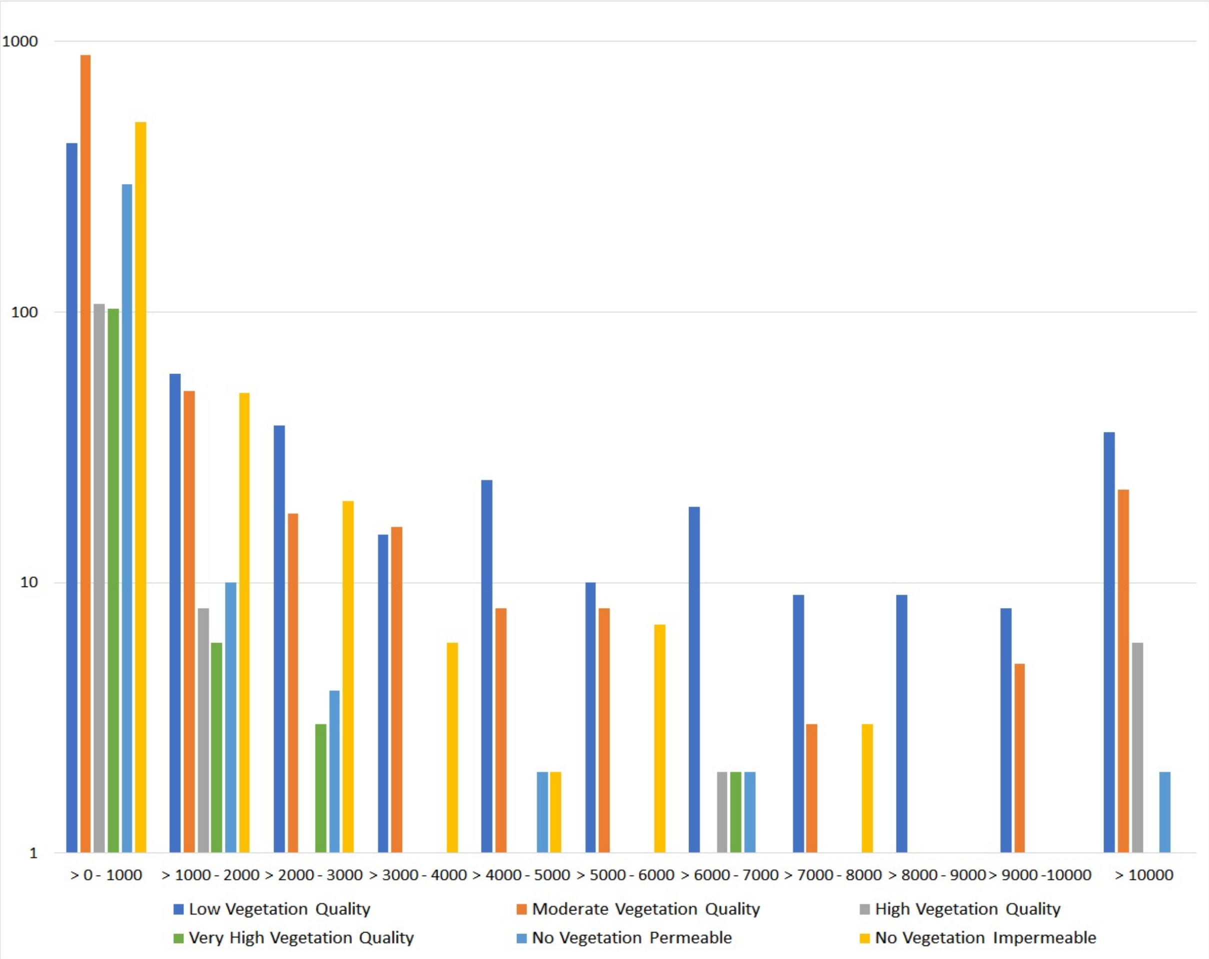

Figure 1.5: Distribution of lots in size classes for each vegetation quality category (N=2,828)

Table 1.2**:** Minimum, median and maximum lots size by each class of vegetation quality and administrative unit (N=2,828)

Vegetation Quality and Administrative Units	**Minimum Size (m^2)**	**Median Size (m^2)**	**Maximum Size (m^2)**
Low Vegetation Quality	37	510	92,323
Moderate Vegetation Quality	36	409	383,375
High Vegetation Quality	98	403	246,634
Very High Vegetation Quality	64	374	8,874
No Vegetation Permeable	36	366	34,280
No Vegetation Impermeable	36	373	9,517
Barreiro	68	380	383,375
East	36	413	89,422
North	129	374	246,634
Northeast	36	331	158,748
Northwest	36	456	74,682

Vegetation Quality and Administrative Units	Minimum Size (m^2)	Median Size (m^2)	Maximum Size (m^2)
Pampulha	36	403	20,807
South Center	150	443	32,411
West	37	473	92,323
Venda Nova	54	367	46,335

The dataset of the vacant lots sampled from the official municipal sources of Belo Horizonte (PBH/Prodabel) presented a wide occurrence of lots in use totaling 1,370 parcels or 48.44% (size of area occupied of 3,061,253 m^2/ 306.12 ha), whereas the unused lots covered 1,458 lots or 51.55% (total area size of 1,319,797 m^2/ 131.98 ha). Most of these lots were in densification-prone areas (ZAP: used 629 plots; unused 817 plots) and occupancy-restricted regions (ZAR1/2: used 552 plots; unused 573 plots), both with expected soil permeability between 10% and 20%. When comparing the attributes of the used and unused lots with respect to the quality of vegetation, while unused lots were mostly represented in the moderate vegetation quality class (857 plots or 58.77%), used lots were mainly composed by the category without vegetation and impermeable (595 or 43.43%) (**Fig. 1.6; Fig. 1.7**). Very high vegetation quality was scarcely represented in used lots (6 plots or 0.44%) but best represented in unused lots (110 lots or 7.54%). High vegetation quality also has a higher occurrence in unused lots (94 or 6.45%) in relation to plots with use (34 or 2.48%). The low vegetation quality class had high representativity in used lots (459 lots or 33.50%) and occupied for the unused lots the third position in number of plots covered by this category (187 or 12.83%). Lots that are permeable but without vegetation (no vegetation permeable) had 14.40% (210 plots) representation in unused lots and 7.96% (109 plots) in used ones.

As expected, permeability is a common characteristic of unused lots, while for used ones most of the lots (886 or 64.67%) were represented in the lower permeability class of 0-25% (**Fig. 1.6**). It is worth remembering that of the total number of lots of this class of lower permeability, 595 or 43.43% were totally impermeable and occupied by impervious surfaces such as construction, asphalt, and cement. Fully impermeable lots were concentrated mainly in zones suitable for densification (ZAP-314 lots or 23% of the used plots) and regions with occupancy restrictions (ZAR1/2-220 lots or 16% of the used plots). The expected permeability rate for these regions and the others covered in the sampling is 10% to 20%. The highest permeability values for the lots used, between >75% and 95%, occurred in a smaller number of lots (115 or 8.47%). As far as ownership is concerned, of the total lots 93.60% were private lots and 6.40% were public. Most used and unused lots therefore belonged to private owners, comprising respectively 1,257 plots (91.75%) and 1390 lots (95.34%). Regarding the quality of vegetation, the distribution pattern of the lots in classes was the same for public and private unused lots with a higher concentration of lots in the moderate vegetation quality class (public: 36 lots; private: 821 lots) (**App. 1.3**). For the lots used two classes of vegetation quality divided the first positions in terms of the number of lots represented: lots without vegetation and impermeable (public: 36 lots; private: 559 lots) and lots with low quality of vegetation (public: 55 lots; private: 404 lots). The vast majority of used (1,020 or 74.45%) and unused (1,320 or 90.53%) lots were concentrated in the class of smaller area size (0-1,000 m^2), with low representativity towards the other classes (**Fig. 1.6**).

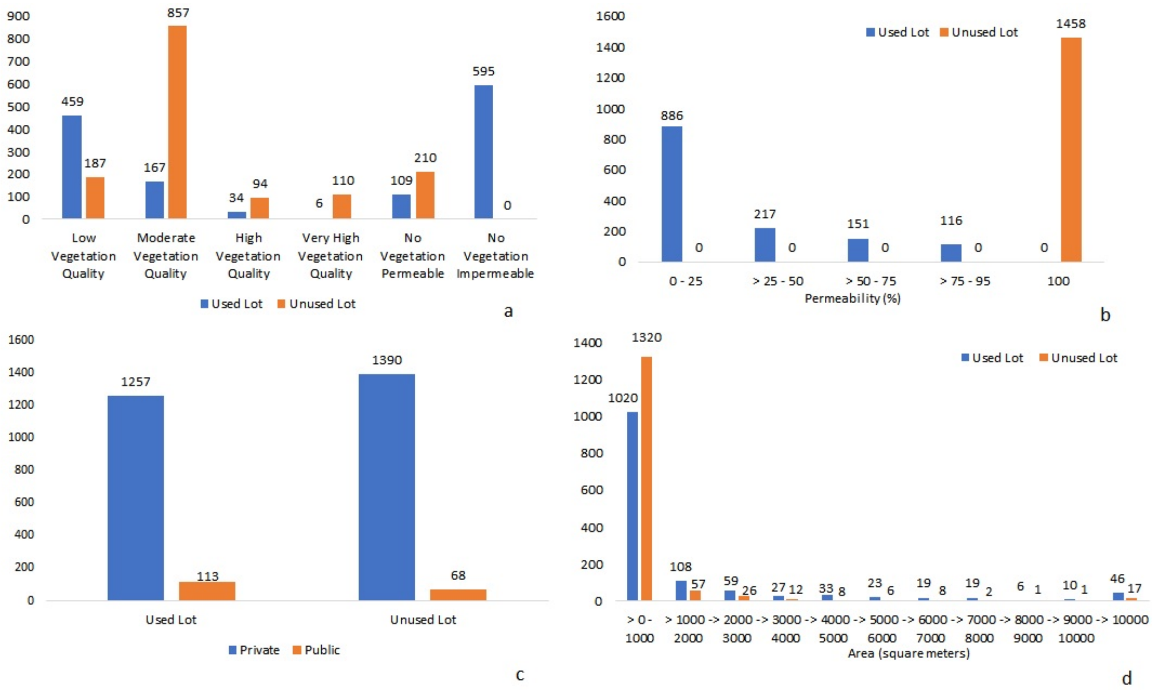

Figure 1.6: Situation of used and unused lots sampled according to: a- number of lots per vegetation quality class; b- number of lots per permeability intervals; c- number of lots per land ownership (private/public); d- number of lots per area size intervals (Used N=1,370; Unused N=1,458)

Figure 1.7: Lots types, composition and vegetation quality categories (N=2828) (LVQ- Low Vegetation Quality; MVQ- Moderate Vegetation Quality; HVQ- High Vegetation Quality; VHVQ- Very High Vegetation Quality; NVP- No Vegetation Permeable; NVI- No Vegetation Impermeable)

The land cover of the unused lots (1,458) found for the delineation of vegetation quality classes was diverse comprising 39 combinations of nine vegetation and other land cover types: agriculture; bare soil; forest advanced-intermediate stage of regeneration; forest initial stage of regeneration; herbaceous-shrubby vegetation; pasture; savanna; tree clumps; water (**Table 1.3)**. Six land cover mosaic stood out in the sampling occupying over 100 lots and accounting for 90.53% of total unused plots: herbaceous shrubby-vegetation (298 plots or 20.44%); herbaceous shrubby-vegetation/bare soil (292 plots or 20.03%); herbaceous shrubby-vegetation/tree clumps (222 plots or 15.23%); bare soil (210 plots or 14.40%); tree clumps/bare soil (151 plots or 10.35%) and herbaceous shrubby-vegetation/tree clumps/bare soil (147 plots or 10.08%). The total of 24 land cover combinations presented native forests in their composition, distributed in 98 lots or 6.72% (from numbers 2 to 25, **Table 1.3**). Most of these lots (94 or 95.91%) belonged to the moderate (42 lots), very high (28 lots) and high (24) vegetation quality categories.

Regarding the land cover combinations for each vegetation quality class, that of very high vegetation quality had the highest concentration of lots for the typology tree clumps with 30 lots (**Table 1.3**). The high vegetation quality class obtained greater representation of lots composed by herbaceous-shrubby vegetation/tree clumps (30), herbaceous-shrubby vegetation/tree clumps/bare soil (12) and forest initial stage/herbaceous-shrubby vegetation (6). The class moderate vegetation quality collector of the largest number of unused lots (857) presented as main land cover: herbaceous-shrubby vegetation (298); herbaceous-shrubby vegetation/bare soil (216); herbaceous-shrubby vegetation/tree clumps (168); herbaceous-shrubby vegetation/tree clumps/bare soil (88). The most represented land covers in the low vegetation quality class were herbaceous-shrubby vegetation/bare soil (75); tree clumps/bare soil (63) and herbaceous-shrubby vegetation/tree clumps /bare soil (45). It is worth mentioning that the occurrence of trees in the lower vegetation quality classes occurred in low percentages (up to 25% for the low and between 25% and 50% for the moderate vegetation quality class). The “No Vegetation Permeable” class was totally composed of bare soil (210 lots).

Table 1.3: Land cover combinations and its distribution by vegetation quality classes in unused lots (N=1,458)

Land Cover*	**LVQ**	**MVQ**	**HVQ**	**VHVQ**	**NVP**	**Total**
1-Bare Soil	-	-	-	-	**210**	***210***
2-Forest Advanced-Intermediate Stage/Tree Clumps/Herbaceous Shrubby Vegetation	-	1	-	-	-	**1**
3-Forest Advanced-Intermediate Stage/Savanna/Bare Soil	-	-	-	1	-	**1**

Land Cover*	LVQ	MVQ	HVQ	VHVQ	NVP	Total
4-Forest Advanced-Intermediate Stage/Savanna/Herbaceous Shrubby Vegetation/Bare Soil	-	1	-	-	-	**1**
5-Forest Advanced-Intermediate Stage	-	-	-	10	-	***10***
6-Forest Advanced-Intermediate Stage/Bare Soil	-	-	2	-	-	**2**
7-Forest Advanced-Intermediate Stage/Forest Initial Stage	-	1	1	1	-	**3**
8-Forest Advanced-Intermediate Stage/Forest Initial Stage/Herbaceous Shrubby Vegetation	-	2	1	-	-	**3**
9-Forest Advanced-Inter. Stage/Forest Initial Stage/Herbaceous-Shrubby Vegetation/Bare Soil	-	1	-	-	-	**1**
10-Forest Advanced-Intermediate Stage/Herbaceous Shrubby Vegetation	-	3	5	4	-	***12***
11-Forest Advanced-Intermediate Stage/Herbaceous-Shrubby Vegetation/Bare Soil	-	4	-	-	-	**4**
12-Forest Advanced-Intermediate Stage/Pasture	-	-	1	-	-	**1**
13-Forest Advanced-Intermediate Stage/Savanna	-	-	2		-	**2**
14-Forest Initial Stage	-	-	-	5	-	**5**
15-Forest Initial Stage/Bare Soil	-	1	1	3	-	**5**
16-Forest Initial Stage/Herbaceous Shrubby Vegetation/Tree Clumps	-	1	-		-	**1**
17-Forest Initial Stage/Herbaceous Shrubby Vegetation	1	12	6	2	-	***21***
18-Forest Initial Stage/Herbaceous-Shrubby Vegetation/Bare Soil	1	11	3	2	-	***17***
19-Forest Initial Stage/Herbaceous-Shrubby Vegetation/Pasture/Bare Soil	-	-	1	-	-	**1**
20-Forest Initial Stage/Savanna/Bare Soil	-	-	1	-	-	**1**
21-Forest Initial Stage/Savanna/Herbaceous Shrubby Vegetation/Bare Soil	1	-	-	-	-	**1**
22-Forest Initial Stage/Tree Clumps/Herbaceous-Shrubby Vegetation/Bare Soil	-	1	-	-	-	**1**
23-Forest Initial Stage/Tree Clumps/Herbaceous-Shrubby Vegetation	-	1	-	-	-	**1**
24-Forest Initial Stage/Tree Clumps/Herbaceous-Shrubby Vegetation/Bare Soil	-	1	-	-	-	**1**
25-Forest Initial Stage/Tree Clumps/Herbaceous-Shrubby Vegetation/Water/Bare Soil	1	1	-	-	-	**2**
26-Herbaceous-Shrubby Vegetation	-	**298**	-	-	-	***298***
27-Herbaceous-Shrubby Vegetation/Bare Soil	**75**	216	-	1	-	***292***
28-Herbaceous-Shrubby Vegetation/Tree Clumps	-	168	**30**	24	-	***222***
29-Herbaceous-Shrubby Vegetation/Tree Clumps/Agriculture/Bare Soil	-	1	-	-	-	**1**
30-Herbaceous-Shrubby Vegetation/Tree Clumps/Bare Soil	45	88	12	2	-	***147***
31-Herbaceous-Shrubby Vegetation/Water	-	1	-	-	-	**1**
32-Pasture	-	1	-	1	-	**2**
33-Savanna	-	-	-	1	-	**1**
34-Savanna/Herbaceous-Shrubby Vegetation	-		1	-	-	**1**
35-Savanna/Herbaceous-Shrubby Vegetation/Bare Soil	-	1	1	-	-	**2**
36-Savanna/Tree Clumps/Herbaceous-Shrubby Vegetation/Bare Soil	-	-	1	-	-	**1**
37-Tree Clumps	-	-	-	**30**	-	***30***
38-Tree Clumps/Agriculture/Water/Bare Soil	-	1	-	-	-	**1**
39-Tree Clumps/Bare Soil	63	40	25	23	-	***151***
Total	**187**	**857**	**94**	**110**	**210**	**1458**

*LVQ- Low Vegetation Quality; MVQ- Moderate Vegetation Quality; HVQ- High Vegetation Quality; VHVQ- Very High Vegetation Quality; NVP- No Vegetation Permeable

The unused lots of higher vegetation quality, that have in their composition percentages above 50% of trees, forest or savanna, accounted for a total of 204 lots or 13.99%. Of this total, 135 parcels or 66.18% were distributed in five administrative units: Venda Nova (30), South Center (28), North (26), Northeast (26), and West (25) (**App. 1.4**). Most of these lots were private, with only 11 lots (5.39%) publicly owned. The minimum, average and maximum areas of the highest quality vegetation lots were 61 m^2, 789 m^2 and 15214 m^2 respectively. Lots occupied over their entire surface by trees, forest or savanna occurred mainly in the administrative unit of Barreiro, highlighting 5 lots covered by forest advanced-intermediate stage, 5 parcels of tree clumps, 1 lot completely occupied by savanna and 1 by forest initial stage (**App. 1.5**). The highest vegetation quality land cover occurring in all administrative units were tree clumps (30 plots), tree clumps/bare soil (47) and herbaceous-shrubby vegetation/tree clumps (54).

The land cover of the used lots (1,370) encompassed ten types (same as unused ones by adding impermeable surfaces) distributed in 38 combinations (**Table 1.4)**. Of the total land cover arrangements five were present in more than 100 lots, totaling 1131 lots or 82.55%, comprising: impermeable surfaces (595 plots or 43.43%); impermeable surfaces/tree clumps (192 plots or 14.01%); impermeable surfaces/herbaceous-shrubby vegetation (133 plots or 9.71%); impermeable surfaces/tree clumps/herbaceous-shrubby vegetation (107 plots or 7.81%); impermeable surfaces/bare soil (104 plots or 7.59%). The total of 21 combinations presented native forests in their composition, distributed over 29 lots or 2.12% (from numbers 4 to 23, **Table 1.4**). Most of these lots (25 or 86.20%) belonged to the moderate (14) and low (11) vegetation quality categories. Only 3 lots were found in the high vegetation quality class and one lot in the very high vegetation quality.

Concerning the representation of the various land cover combinations in vegetation quality classes, in the very high vegetation quality class only 6 lots were represented, and the highest concentration or 4 lots was for the cover impermeable surfaces/tree clumps. As for unused lots, the high vegetation quality class was best represented, distributed in a total of 34 used lots or 2.48%. The most significant arboreal vegetation composition of these lots was tree clumps. While the class “No Vegetation Impermeable” was completely covered by surfaces such as cement, asphalt and buildings, the “No Vegetation Permeable” category was composed of bare soil and water, present mainly in the residential swimming pools. The low vegetation quality class had second significant representativeness in the used lots presenting two most frequent land cover combinations: impermeable surfaces/tree clumps (134 plots or 9.78%) and impermeable surfaces/herbaceous-shrubby vegetation (101 plots or 7.37%). Following was the moderate vegetation quality class with most of the lots concentrated in the land cover combinations impermeable surfaces/tree clumps (44 plots or 3.21%) and impermeable surfaces/herbaceous-shrubby vegetation (31 or 2.26%).

The land use presented by the used lots comprised nine types: commercial industrial; commercial institutional; commercial parking; commercial sheds; commercial sheds parking; housing building; housing courtyard; housing house; pavement asphalt (**App. 1.6**). Most of the lots have been used for housing (929 or 67.81%) especially for houses (675 lots or 49.27%) and on a smaller scale for buildings (254 lots or 18.54%). Commercial uses expressed through the presence of sheds (162-11.82%) and sheds coupled to parking (106 -7.74%) were observed in 268 lots (19.56%). Lots used entirely for parking accounted for a total of 65 (4.74%). Other apparently commercial uses, characterized as institutional (such as schools, stations, rotations, sports clubs, squares, parks, police station, power station, airport runway) occurred in 55 lots (4.01%). There were also uses of lots such as courtyards (39 or 2.85%), asphalt pavements (9 or 0.66%) and industrial structures (5 or 0.44%).

The distribution of the land uses of built lots by the administrative units of the city showed that although the use of lots for housing - especially houses - is common to all regions of the city two regions represented 38.51% of this use: Northeast (140 lots) and Venda Nova (120 lots) (**App. 1.7**). In the case of dwellings composed of buildings the South Center region held more lots of this use, which totaled 66 lots or 26.00%. This administrative region also concentrated the largest number of commercial institutional uses (12 plots) and courtyards (11 plots). In the case of commercial uses, the highlight was the presence of sheds that were found mainly distributed in the administrative units of Pampulha (31 lots), Northeast (28 lots), and West (24 lots). These last two also presented a greater number of lots occupied by sheds parking (19 each). Lots used exclusively as parking occurred more in the administrative regions of Pampulha (11 lots) and South Center (10 lots). The use marked by the presence of industrial structures was poorly represented with three occurrences in the North region and two in the Northeast. Likewise, asphalt paved surfaces occupied only a few lots, totaling nine, three of which occurring in the West administrative unit.

Table 1.4: Land cover combinations and its distribution by vegetation quality classes in used lots (N=1,370)

Land Cover*	**LVQ**	**MVQ**	**HVQ**	**VHVQ**	**NVP**	**NVI**	**Total**
1-Impermeable Surfaces	-	-	-	-	-	**595**	*595*

Land Cover*	LVQ	MVQ	HVQ	VHVQ	NVP	NVI	Total
2-Impermeable Surfaces/Bare Soil	-	-	-	-	**104**	-	***104***
3-Impermeable Surfaces/Forest Advanced-Intermediate Stage	-	1	-	-	-	-	**1**
4-Impermeable Surfaces/Forest Advanced-Intermediate Stage/Bare Soil	1	-	-	-	-	-	**1**
5-Impermeable Surfaces/Forest Advanced-Intermediate Stage/Forest Initial Stage	-	-	1	-	-	-	**1**
6-Impermeable Surfaces/Forest Advanced-Intermediate Stage/Forest Initial Stage/Herbaceous-Shrubby Vegetation/Bare Soil	1	-	-	-	-	-	**1**
7-Impermeable Surfaces /Forest Advanced-Intermediate Stage/Forest Initial Stage/Savanna/Tree Clumps/Herbaceous-Shrubby Vegetation	1	-	-	-	-	-	**1**
8-Impermeable Surfaces/Forest Advanced-Intermediate Stage/Forest Initial Stage/Tree Clumps/Herbaceous-Shrubby Vegetation/Bare Soil	-	1	-	-	-	-	**1**
9-Impermeable Surfaces/Forest Advanced-Intermediate Stage/Herbaceous-Shrubby Vegetation	1	2	1	-	-	-	**4**
10-Impermeable Surfaces/Forest Advanced-Intermediate Stage/Herbaceous-Shrubby Vegetation/Bare Soil	1	1	-	-	-	-	2
11-Impermeable Surfaces/Forest Advanced-Intermediate Stage/Tree Clumps	1	-	-	-	-	-	**1**
12-Impermeable Surfaces/Forest Advanced-Intermediate Stage/Tree Clumps/Herbaceous-Shrubby Vegetation	-	1	-	-	-	-	**1**
13-Impermeable Surfaces/Forest Advanced-Intermediate Stage/Tree Clumps/Herbaceous-Shrubby Vegetation/Bare Soil	-	1	-	-	-	-	**1**
14-Impermeable Surfaces/Forest Advanced-Intermediate Stage/Tree Clumps/Herbaceous-Shrubby Vegetation/Pasture	-	1	-	-	-	-	**1**
15-Impermeable Surfaces/Forest Initial Stage	-	-	1	1	-	-	**2**
16-Impermeable Surfaces/Forest Initial Stage/Bare Soil	2	-	-	-	-	-	**2**
17-Impermeable Surfaces/Forest Initial Stage/Herbaceous-Shrubby Vegetation	-	2	-	-	-	-	**2**
18-Impermeable Surfaces/Forest Initial Stage/Herbaceous-Shrubby Vegetation/Bare Soil	1	1	-	-	-	-	**2**
19-Impermeable Surfaces/Forest Initial Stage/Pasture/Bare Soil	-	1	-	-	-	-	**1**
20-Impermeable Surfaces/Forest Initial Stage/Savanna	-	1	-	-	-	-	**1**
21-Impermeable Surfaces/Forest Initial Stage/Tree Clumps	-	1	-	-	-	-	**1**
22-Impermeable Surfaces/Forest Initial Stage/Tree Clumps/Herbaceous-Shrubby Vegetation	1	-	-	-	-	-	**1**
23-Impermeable Surfaces/Forest Initial Stage/Tree Clumps/Herbaceous-Shrubby Vegetation/Water	1	-	-	-	-	-	1
24-Impermeable Surfaces/Herbaceous-Shrubby Vegetation	101	31	-	-	1	-	***133***
25-Impermeable Surfaces/Herbaceous-Shrubby Vegetation/Bare Soil	45	12	-	-	-	-	**57**
26-Impermeable Surfaces/Herbaceous-Shrubby Vegetation/Water	3	-	-	-	-	-	**3**
27-Impermeable Surfaces/Pasture/Bare Soil	-	1	-	-	-	-	**1**
28-Impermeable Surfaces/Savanna/Bare Soil	-	1		-	-	-	**1**
29-Impermeable Surfaces/Savanna/Tree Clumps/Herbaceous-Shrubby Vegetation	-	1	-	-	-	-	**1**
30-Impermeable Surfaces/Tree Clumps	**134**	**44**	**10**	**4**	-	-	***192***
31-Impermeable Surfaces/Tree Clumps/Bare Soil	44	14	**10**	-	1	-	**69**
32-Impermeable Surfaces/Tree Clumps/Bare Soil/Water	1	-	-	-	-	-	**1**
33-Impermeable Surfaces/Tree Clumps/Herbaceous-Shrubby Vegetation	72	25	**10**	-	-	-	***107***
34-Impermeable Surfaces/Tree Clumps/Herbaceous-Shrubby Vegetation/Bare Soil	37	18	1	-	-	-	**56**
35-Impermeable Surfaces/Tree Clumps/Herbaceous-Shrubby Vegetation/Bare Soil/Water	-	1	-	-	-	-	**1**
36-Impermeable Surfaces/Tree Clumps/Herbaceous-Shrubby Vegetation/Water	7	3	-	1	-	-	**11**
37-Impermeable Surfaces/Tree Clumps/Water	4	2	-	-	-	-	**6**
38-Impermeable Surfaces/Water	-	-	-	-	3	-	**3**
Total	**459**	**167**	**34**	**6**	**109**	**595**	**1370**

*LVQ- Low Vegetation Quality; MVQ- Moderate Vegetation Quality; HVQ- High Vegetation Quality; VHVQ- Very High Vegetation Quality; NVP- No Vegetation Permeable; NVI- No Vegetation Impermeable

1.4. Land Cover Clusters and Ecological Performance

Four land cover stood out as important components for the set of lots investigated, being present in all four clusters: bare soil, herbaceous-shrubby vegetation, tree clumps and built up areas (**Table 1.5**). Native forests only appeared in cluster 3 (6% forest advanced-intermediate stage, 6% forest initial stage) and cluster 4 (1% forest advanced-intermediate stage, 1% forest initial stage). Savanna stretches were represented in cluster 3 with 2% cover average. Pastures were represented by 1% in cluster 3. Of the ten land cover types of the sampled plots, agriculture and water were not represented in the clusters because they had very low average coverage, below 0. The four optimal clusters representing the land cover complexity of the sampled lots in Belo Horizonte, Brazil, can be summarized as: Cluster 1 was characterized by the predominance of impermeable surfaces or built up areas with an average coverage of 89%. This cluster had the lowest representation in the sample in terms of number of lots comprising 280 plots or 9.90%. Cluster 2 encompassed 477 plots or 16.87% being marked by the dominant presence of bare soil with an average coverage of 86%. Clusters 3 and 4 were predominantly occupied by tree clumps (49%) and herbaceous-shrubby vegetation (84%) respectively. Cluster 3 held the largest number of plots at 1193 or 42.18% followed by cluster 4 with 878 plots or 31.05% **(**for descriptive statistics see **App.1.8)**.

Table 1.5: Characteristics of land cover clusters of sampled lots in Belo Horizonte, Brazil (N=2,828)

Clusters Number	**Clusters Main Component**	**Definition**	**Number of Cases**
1	Cluster of built up areas	Cluster with an average land cover of 89% of built-up areas, 4% of tree clumps, 4% of herbaceous-shrubby vegetation, and 2% of bare soil	280
2	Cluster of bare soil	Cluster with an average land cover of 86% of bare soil, 5% of herbaceous-shrubby vegetation, 5% of built-up areas, and 4% of tree clumps	477
3	Cluster of trees	Cluster with an average land cover of 49% of tree clumps, 15% of herbaceous-shrubby vegetation, 12% of bare soil, 8% of built-up areas, 6% of forest advanced-intermediate stage of regeneration, 6% of forest initial stage of regeneration, 2% of savanna, and 1% of pasture	1193
4	Cluster of herbaceous-shrubby vegetation	Cluster with an average land cover of 84% of herbaceous-shrubby vegetation, 8% of bare soil, 5% of tree clumps, 3% of built-up areas, 1% of forest advanced-intermediate stage of regeneration, and 1% of forest initial stage of regeneration	878

The overall ecological performance showed differences between the four land cover clusters. The cluster of trees or cluster 3 - with the highest average land cover of tree clumps and native vegetation - had the highest achievement of 16.71, which can be classified as a high performance within the sampling parameters (Fig. 1.8). This cluster stood out with the highest values for all ecological regulation functions (water infiltration and storage, microclimate regulation, air purification and filtration, carbon sequestration and storage, soil conservation) and habitat functions (habitat provisioning, biodiversity conservation). Cluster 4 with the highest average land cover of herbaceous-shrubby vegetation stood out in the sequence with moderate ecological performance of 13.95. Next, the cluster 2 stood out with the highest average land cover of bare soil and low ecological performance of 5.44. Cluster 1 with predominance of built up areas had the lowest ecological importance of 1.68.

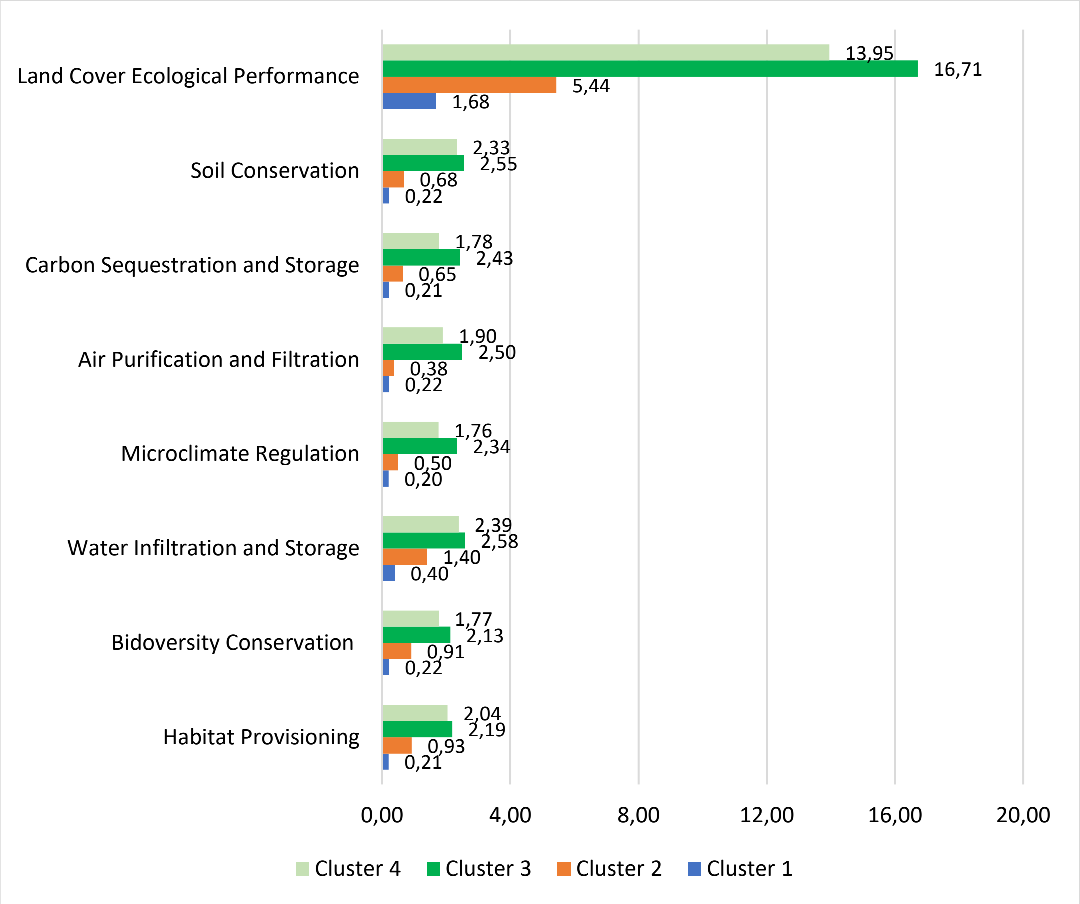

Figure 1.8: Land cover clusters, ecological functions and overall ecological performance (N=2,828)

1.5. Discussion

The set of vacant lots sampled in the city of Belo Horizonte proved to be diversified in land cover, which were reflected in the presence of various classes of vegetation quality. Despite this, there was a prevalence of lots under moderate conditions of vegetation quality, composed mainly of herbaceous-shrubby vegetation (between 50% and 100% of the lot), where trees or forests when present were represented in smaller proportion (up to the maximum of 50% of the lot). The largest lot area found in the sample, with an area of 38.33 ha was also a representative of this class. The predominance of these conditions in the sampled lots possibly reflects the norms of management of lots indicated by the legislation that foresees the maintenance of the vegetation low, in an herbaceous-shrubby phase, without the removal of stumps or roots (Belo Horizonte, 2012). Lots with moderate vegetation quality, together with those of low vegetation quality - predominantly composed of herbaceous-shrubby elements (> 0% to 50%) and trees or forests when present, represented to a lesser extent (> 0% to 25%) - and to lots without vegetation but permeable, composed of bare soil, made up the vast majority of the lots by covering about 70% of the sampled lots. This result agrees with the fact that in general urban areas comprise a considerable portion of land containing herbaceous-shrubby and spontaneous vegetation, whether in vacant lots, derelict land, buildings, brownfield, land currently in use, land in and around urban areas (Robinson and Lundholm, 2012).

Herbaceous-shrubby vegetation consists mainly of grasses, shrubs, managed lawns, also including spontaneous urban vegetation, which easily colonizes these plots. Although sites with those characteristics may be considered at first glance as devoid of economic and ecological value, or even presenting negative values for these features, recent research has suggested several ecological functions and ecosystem services provided by these environments (Robinson and Lundholm, 2012; McPhearson et al., 2013). Our study corroborates this claim, considering that the cluster of herbaceous-shrubby vegetation (cluster 4 composed of 84% of this vegetation type) stood out in the analysis in the second position in terms of ecological performance. This performance represented a measure of the cluster´s ability to fulfill selected ecological functions of regulation and habitat, through the sum of the ecological functions performed by each land cover grouping. It may be added that the analyzed ecological functions of water infiltration and storage, microclimate regulation, air purification and filtration, carbon sequestration and storage, soil conservation, habitat provisioning and biodiversity conservation can be translated as potential regulating services (for the first five ecological functions) and supporting ecosystem services (for the last two ecological functions). Related to this, Robinson and Lundholm (2012) obtained for urban areas composed of spontaneous herbaceous-shrubby vegetation important habitat provisioning values, expressed by the high diversity of invertebrate including butterflies, and plants, many of them non-native, but occurring various life forms, nitrogen fixing plants, and species with nectar producing flowers. The diverse community of invertebrates, in turn, encompassed pestcontrolling, detrivorous and pollinating species, gathering various ecological, economic and educational functions. The authors found also contributions of the herbaceous-shrubby vegetation and lawns habitats for the provision of regulating climate services with emphasis on urban microclimate regulation - through reflection and evapotranspirative cooling - and air pollution filter. In addition, lawns showed in the study standing biomass as an indicator of provisioning services, superior to those presented by the spontaneous urban vegetation. As pointed out by the authors the biomass of above ground vegetation together with an abundance of invertebrates can be considered ecological indicators for the provision of food or conversion of solar energy into plants and animals.

Despite having a low ecological performance, the cluster composed mainly of bare soil (86% - cluster 2) according to our analysis can contribute to various regulation and habitat ecological functions. In fact, bare soil cover represented in many lots of Belo Horizonte has various ecosystem functions and many potential ecosystem services in cities. This is due to the fact that soil is a component of urban ecosystems that functions as a foundation for many ecological processes, including the biogeochemical cycles and life cycle of many organisms (Effland and Pouyat, 1997; Picket et al., 2001). Among the ecosystem services presented by soils are the ability to function as a support for plant growth, sink for pollutants, substrate for built structures, habitat for microorganisms, physical and cultural support for human activities (transport, waste disposal, transport of energy, and water), flow path and storage for nutrients, water infiltration and storage (Lal, 2004; Morel et al., 2015). This last function related to the permeability enhancement in various areas of the city, expressed through the ability of soil material to transmit fluids, are especially important when observing that in the sampling of the vacant lots of Belo Horizonte, totally impermeable lots composed by impervious surfaces such as construction, asphalt, and cement are represented in about 21%, presenting no vegetation and without exposed soil. Soils can also contribute to carbon sequestration, and consequently to mitigate the effects of gas emissions and climate change (Lal, 2004). However, soil degradation by human activities negatively affects these functions in urban areas, reducing their mitigation capacity (Effland and Pouyat, 1997). This may be the case for many lots in the city of Belo Horizonte considering that the bare soil surface may have originated from burning in vacant lots, a common practice used for complete cleaning of the lot, but framed in the legislation as an environmental crime and subject to fines. This is a procedure that not only harms the potential for ecosystem services provision but also can cause damages, such as increased gas emissions and health impairment of the inhabitants.

The official dataset of vacant lots in the city does not present an update - usually dependent on inspection - that follows the dynamics of construction and occupation of the lots. This situation was echoed in the occurrence among the sampled lots of about 48% of built or used lots, covering an area of 306.12 ha, in contrast to the occurrence of 51% of unused lots, distributed in a total area of 131.98 ha. When comparing these two groups of lots, there is a difference in relation to the quality of vegetation that is absent and under impermeable conditions or presents mostly low quality of vegetation in used lots, while in the unused lots moderate conditions of vegetation quality and higher permeability are the usual ones. The absence and low quality of vegetation prevalent in most used lots is also reflected in the poor ecological performance found for cluster 1 where land cover averages of lots with dominance of built up areas (89%) are grouped. Among the similarities are that most of both groups of lots belonged to private owners and were grouped into size classes up to 1,000 square meters. Some deductions of greater interest related to the dynamics of occupation of these lots made possible by the characteristics of the dataset, can be translated for example in the situation of impermeability found for many lots and the types of use that have been given to these locations. Thus, one of the findings referred to the dynamics of occupation of vacant lots in the city, which has favored the maximum utilization of the plot for the establishment of constructions without leaving a permeability percentage for a large number of lots (43% of used lots) in densification zones where expected permeability stretches between 10 % to 20% (de Marco and de Assis, 2013). About the uses granted to these places, the highlight was housing (around 67%), given the raising demand for new homes - especially houses (49%) and buildings (18%) - and secondly for commercial use, expressed by the presence of sheds, sheds/parking and parking (about 24%). In the case of the predominance of the use of housing lots for the construction of houses, this result may be reflecting the city occupation zoning rules, which indicate the greater densification and verticalization of the buildings for the central and hypercentre regions of the city, less represented in the sample in relation to the areas of lower density (Belo Horizonte, 2010). Our study also pointed to a greater use of lots of the South Center region, which encompasses the central and hypercentre, for the construction of buildings, which agrees with the densification zoning rules established.

The nine land cover components of the unused lots (agriculture; bare soil; forest advanced-intermediate stage of regeneration; forest initial stage of regeneration; herbaceous-shrubby vegetation; pasture; savanna; tree clumps; water) were mixed so as to form 39 vegetation and land cover combinations, once again demonstrating the diverse nature of the vegetation types and ground cover that make up the city's vacant lots. Similarly, the used lots featured ten land cover types (same as used plus impermeable surfaces) arranged in 38 different combinations. This is consistent with the fact that urban areas are commonly characterized by a variety of small-scale man-made habitat mosaics, while under natural conditions heterogeneity is more controlled by factors such as topography, geology, and their interactions with past land use and land use at present (Gilbert, 1989). In the mosaic of the studied area stood out three land cover which are herbaceous-shrubby vegetation, tree clumps and bare soil, that made up the dominant combinations in most of the unused lots and in most of the predominant moderate vegetation quality lots. The same was true for the lots used especially for the high number of lots composed of herbaceous-shrubby vegetation and tree clumps, however belonging to the low vegetation quality category, with percentages of these vegetation types of at most 50% and 25% respectively.

Lots of higher vegetation quality that have in their composition percentages above 50% and 75% of trees, forest or savanna (high and very high vegetation quality), encompassed about 9% of total lots (204 lots in unused area and 40 used lots) and occupied area of 21.36 ha. The Venda Nova, South Center, North, and West administrative units concentrated greater number of higher quality vegetation lots and Barreiro presented higher quality lots forming pure stands of forest, savanna and tree clumps. Except for the administrative unit South Center, these are more peripheral administrative regions, which had a rural past with a predominance of farms and agricultural activities, and which were receiving inhabitants as the central regions of the city developed. In several of them, only from the 1990s onwards did the construction of buildings begin, but there was still a predominance of houses and low buildings in the landscape (Arreguy and Ribeiro, 2008). These lots of higher vegetation quality, predominantly composed by trees, forests and savannas, can cater for a range of differentiated ecosystem services especially considering that given their complex structure they can provide a wider variety of habitats, including nest sites, providing habitats, refuge and food for many plant and animal species, especially insects and birds (Robinson and Lundholm, 2012).

Lots with higher tree clumps average coverage (49%) along with native forests and savanna (2% to 6%) were grouped into cluster 3 which had the largest number of lots (ca. 42%) and a high ecological performance, superior to the other clusters. These lots therefore have the greatest potential for the provision of regulating ecosystem services (water infiltration and storage, microclimate regulation, air purification and filtration, carbon sequestration and storage, soil conservation) and supporting services (habitat provisioning, biodiversity conservation), evaluated in our study through expert opinion on related ecological functions. Among regulating ecosystem services, urban forests and trees are recognized for improving air quality by removing gaseous and particulate pollutants, with a positive impact on human health, reducing mortality (Manes and Salvatori, 2014). Urban trees are recognized to contribute to air purification and filtration and temperature regulation in cities (Bolund and Hunhammar, 1999). They also support nesting sites, provides food por pollinating species, and habitat for biological controlling species (Roshnath and Shinu, 2017).

Kim et al. (2015) found some important ecosystem services provided by urban forests and trees situated within vacant land, such as air pollution removal, carbon sequestration and storage, energy saving. The authors quantified the amount of carbon and air pollutants removed by trees and found relatively high values, especially when compared to other land uses in the target city of their research. McPhearson et al. (2013) also found a multiple provision of local and municipal scale ecosystem services formed by fine vegetation, coarse vegetation and bare soil spread over urban vacant lots, highlighting storm water mitigation, air pollution removal, carbon sequestration and storage, food production, space for recreation, and habitat for biodiversity. In general, vegetation is the largest provider of ecosystem services to urban landscapes, either through the natural remnants of forests and native vegetation, or through agricultural landscapes, vegetable gardens, gardens, backyard orchards, sidewalk planted trees and spontaneous urban vegetation (Breuste et al., 2013b). Lakes and water bodies also generate urban environmental services, especially microclimate regulation (Bolund and Hunhammar, 1999) but presented a low representation in the lots evaluated in the present study.

The whole set of findings found in the studies favor a fresh look at the vacant lots of the urban landscape investigated, which can be used in favor of the people. They are useful both to the municipality and local inhabitants for improvements to people's well-being and health through the benefits of ecosystem services. These aspects emerged in the studies through the verification of the importance of the land cover patterns of these sites for the provision of ecological functions within the urban landscapes' contexts offering opportunities for the insertion of various actions and the potential to host discussions related to urban planning. In Belo Horizonte, the vacant lots and their public value has remained invisible to urban communities because of their inactivity. One exception refers to a temporary intervention, which included the use of some vacant lots in the city, with the permission of the owners, for leisure activities, rest, meetings and small businesses (i.e. beauty salon) (Ganz, 2008). In this sense, the characterization, investigation of land cover patterns and detailed mapping of the vegetation of these lots undertaken in the present study can add to the existing research on the subject and at the same time enable their visibility providing insights and support for urban sustainability actions and policies.

Through the results of the study, we can also infer that the temporary occurrence of vacant lots itself has important ecological, welfare and quality of life consequences. This becomes more crucial when examining the dynamics of use of vacant lots deduced in the study, which denotes overuse of many lots, without preserving small permeability portions, thereby losing several benefits of interest to the city and its inhabitants. These benefits will obviously need to be balanced with socioeconomic issues and the need for housing in the city, indicating that actions aimed at the socio-ecological uses of vacant lots will be better addressed within the scope of participatory approaches. In addition, the fact that most lots are privately owned will require the establishment of conversations, agreements and negotiations with the owners. Therefore, the study paves the way for the continuation of research aimed at elucidating and measuring the ecosystem services available at these sites coupled with the use of participatory approaches to better understand the socioeconomic context in the various administrative units of the city. This can contribute to the benefits of urban vegetation being better reflected in planning decisions.

1.6. Conclusion

The characterization of a representative portion of the vacant lots of Belo Horizonte indicated the occurrence of a diverse land cover and a large percentage of lots with the capability to provide ecological functions. These functions can be translated into various ecological processes and multiple potential ecosystem services, especially those of regulating and supporting. The greatest potential lies in the lots where arboreal elements and native vegetation of forests and savannas occur such as in the cluster of trees (cluster 3), which gathered almost half of the investigated lots. The predominant herbaceous-shrubby vegetation cover (cluster 4) occurring in 31% of the lots, presented moderate potential for ecological functions and the provision of regulating and supporting ecosystem services. All the diversity of land cover and the predominance of moderate vegetation quality situations in the investigated lots lead to the interpretation that the temporary occurrence of the vacant lots impacts positively the environmental quality of the city. The study also showed that the regulation of land use has not contained the excessive use of lots indicating a trend towards the valorization of concrete and impermeable structures, to the detriment of the adoption of ecological solutions that are minimally based on permeability, not respecting even those required in the regions of lots, of at least 10% to 20%. Both the invisibility of vacant lots as a public value, neglecting their potential for improving quality of life in the city and the full use of lots without leaving permeable fractions denote the need for vacant lots, as well as urban vegetation and its benefits to be better considered in the city urban planning. Our recommendations for the socio-ecological use of vacant lots in the city can be summarized as:

- create and apply governance instruments for the use of vacant lots;
- better understand the neighborhood of the lots in terms of the equipment and green areas that exist around them and the socioeconomic aspects;
- listen to the residents and their demands, as well as the owners of the lots;
- adopt actions that are guided by the concept of multifunctionality aiming to cover the multiple socio-ecological functions coming from the lots, including scientific research itself, such as that related to ecosystem services;
- consider as a starting point the uses indicated in the city development plan (UFMG, 2011a; UFMG, 2011b) which covers various public uses, among which social uses - including fairs, soccer fields, sports centers, playgrounds or places of walking, places for parties – ecological and agricultural uses - including community gardens, cultivation of medicinal plants, flowers,

orchards, trees for other purposes, poultry, goats and other livestock, environmental preservation.

1.7. References

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SUPPLEMENTARY MATERIAL

Appendix 1.1: Land cover and use types definitions

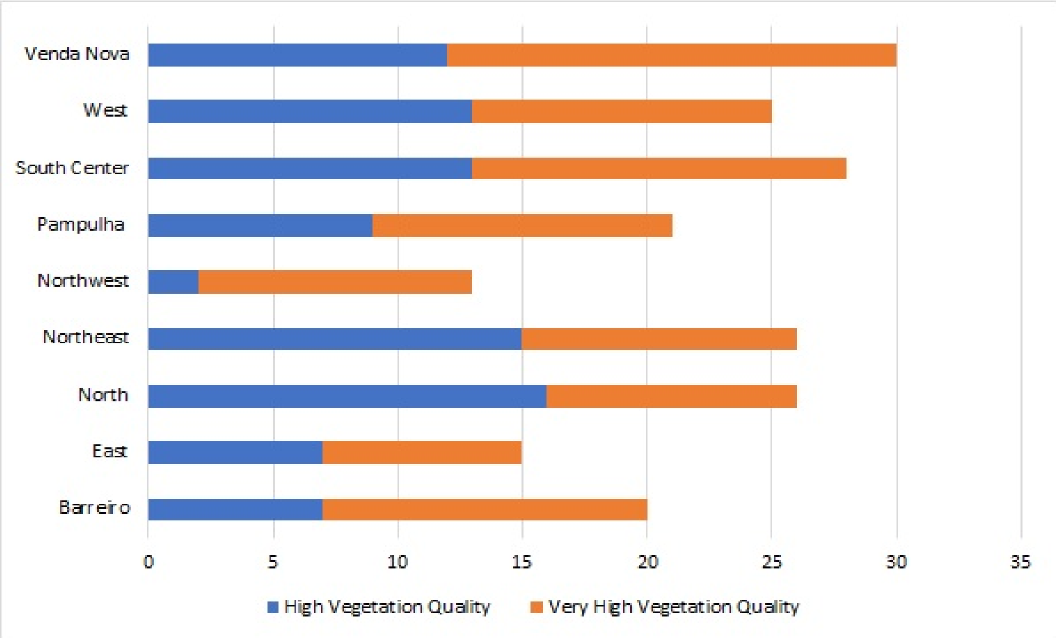
Land Cover and Use Types	Definition
Agriculture	Areas of agricultural cultivation, especially vegetable gardens
Bare Soil	Soil without plant cover
Forest Advanced-Intermediate Stage of Regeneration	Forests in more advanced or middle stages of regeneration with taller or more developed trees
Forest Initial Stage of Regeneration	Younger forests in the early stages of regeneration with smaller trees and development
Herbaceous-shrubby vegetation	Vegetation with predominance of grasses and/or shrubs, including lawns and spontaneous vegetation
Impermeable Surfaces	Surfaces composed by asphalt, cement and/or constructions resistant to water penetration
Pasture	Grasslands interrupted by sparse trees
Savanna	Vegetation composed of spaced trees, shrubs and native grasses
Tree Clumps	Groupings of trees of various species, including native and exotic (such as a tree yard)
Water	Small ponds or pools
Commercial Industrial	Industrial units and support infrastructure
Commercial Institutional	Areas composed of schools, clubs, sports courts, squares, power lines, airports
Commercial Parking	Parking places with presence of several vehicles
Commercial Sheds	Sheds for various purposes, including warehouses
Commercial Sheds Parking	Sheds associated with parking areas
Housing Building	Residences composed of buildings
Housing Courtyard	Patios and yards covered by asphalt, cement or exposed soil
Housing House	Residences composed of houses
Pavement Asphalt	Surfaces covered by asphalt of unknown use

Appendix 1.2**:** Average weight given by experts for the ecological functions of the various land cover. Values ranged from 0 to 4 meaning: 0 (no importance or contribution to the ecological function considered); 1 (low importance or contribution to the ecological function considered); 2 (medium importance or contribution to the ecological function considered); 3 (high importance or contribution to the ecological function considered); 4 (very high importance or contribution to the ecological function considered)

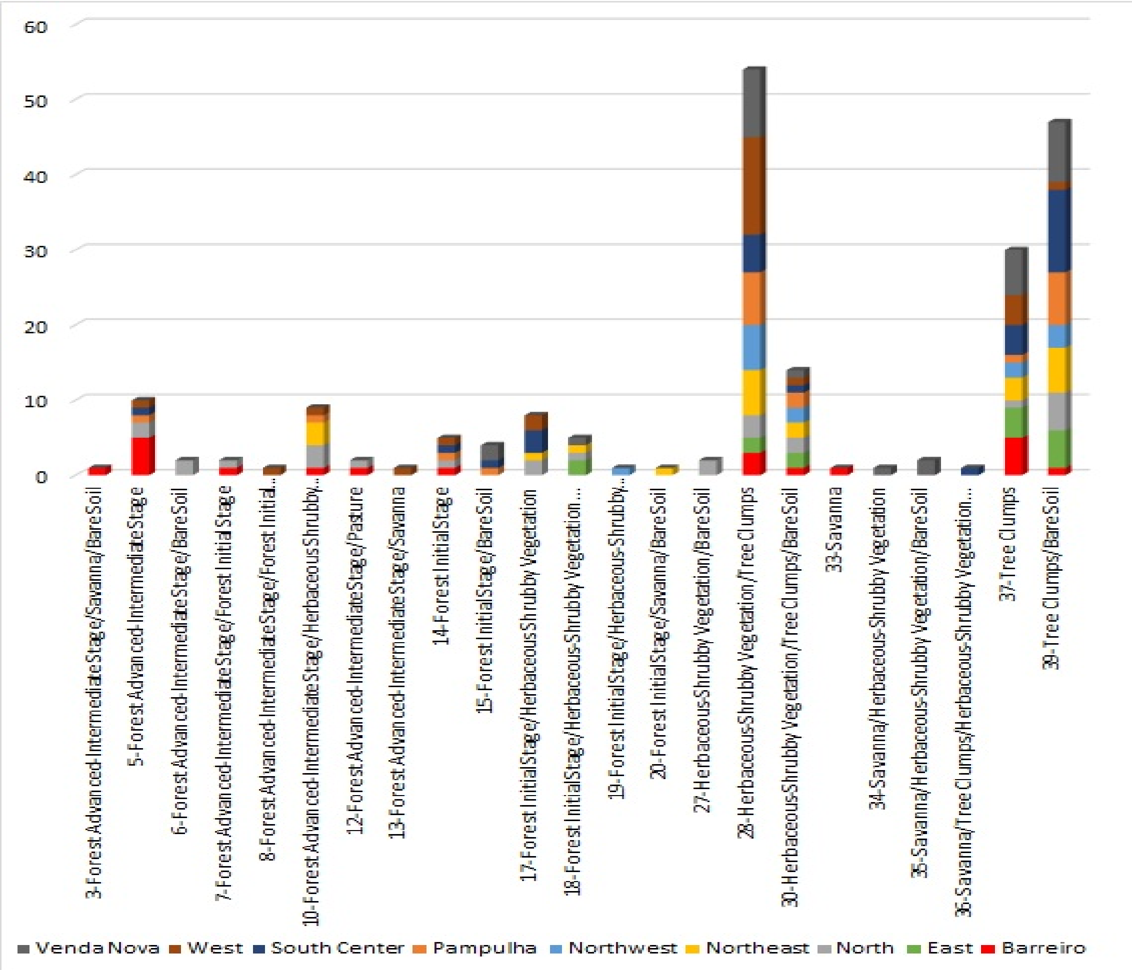
Land Cover	**Habitat Provisioning**	**Biodiversity Conservation**	**Water Infiltration and Storage**	**Microclimate Regulation**	**Air Purification and Filtration**	**Carbon Sequestration and Storae**	**Soil Conservation**
Forest Advanced-Intermediate Stage	4	4	4	4	4	4	4
Forest Initial Stage	3	3	4	4	3	3	4
Savanna	3	3	3	3	3	3	3
Tree Clumps	3	3	3	3	3	3	3
Herbaceous-Shrubby Vegetation	2	2	3	2	2	2	3
Pasture	2	2	2	2	2	2	2
Agriculture	2	2	2	2	2	2	2
Bare Soil	1	1	1	0	0	1	1
Water	1	1	2	2	1	1	1
Impermeable Surfaces	0	0	0	0	0	0	0

Appendix 1.3**:** Distribution of vegetation quality classes between used and unused, public and private lots

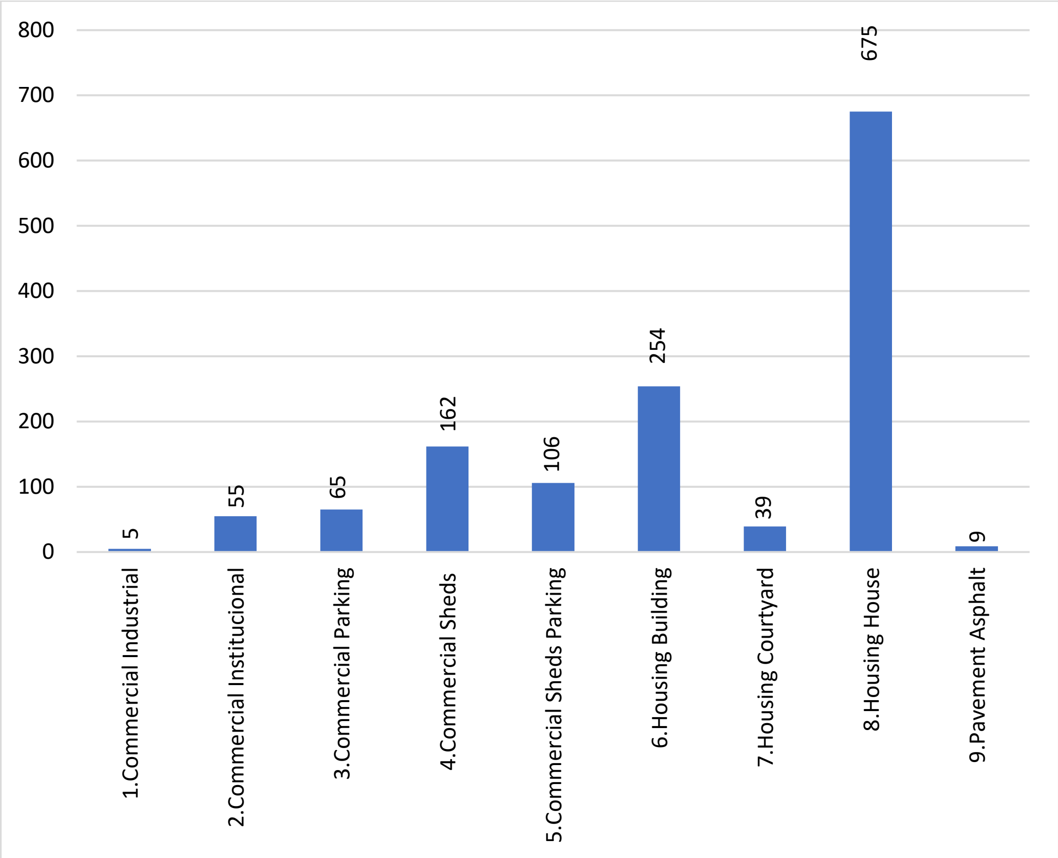
Vegetation Quality Classes	**Used Public**	**Used Private**	**Unused Public**	**Unused Private**	**Total Public**	**Total Private**	**Overall Total**
Low Vegetation Quality	55	404	10	177	65	581	646
Moderate Vegetation Quality	11	156	36	821	47	977	1024
High Vegetation Quality	1	33	3	91	4	124	128
Very High Vegetation Quality	0	6	8	102	8	108	116
No Vegetation Permeable	10	99	11	199	21	298	319
No Vegetation Impermeable	36	559	0	0	36	559	595



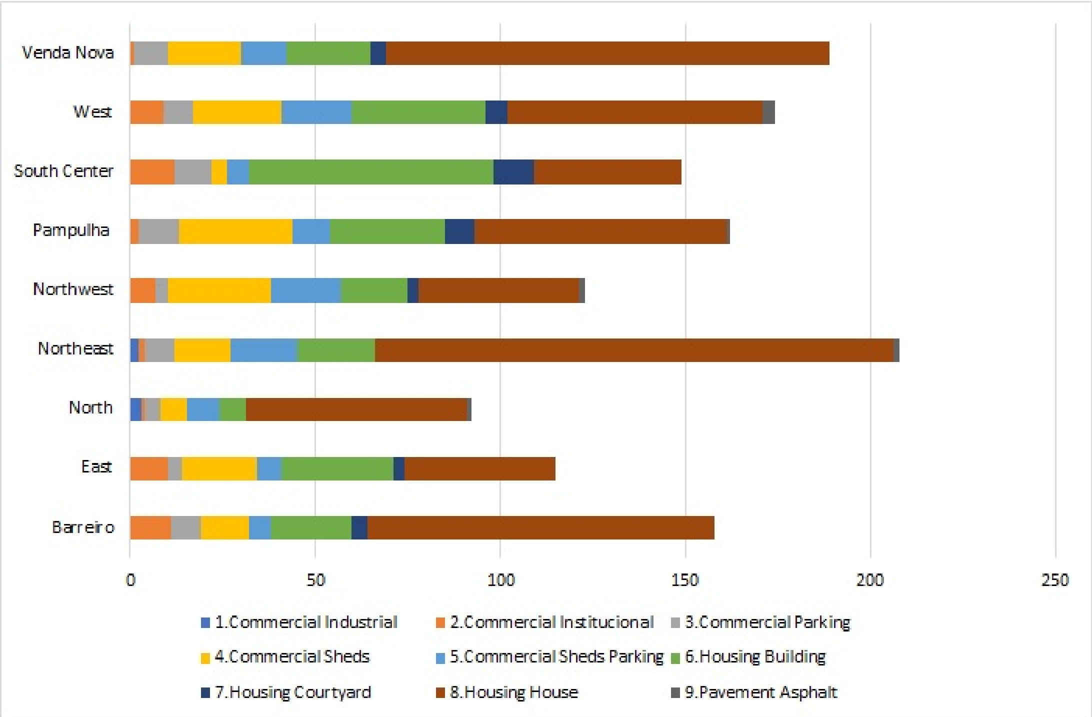
Appendix 1.4**:** Distribution of lots with higher vegetation quality in administrative units (N=1,458)



Appendix 1.5**:** Distribution of lots with higher vegetation quality in land cover classes in the administrative units (N=1,458)



Appendix 1.6**:** Detailed land use of used lots (N=1,370)



Appendix 1.7**:** Land use of built lots in the nine administrative units (N=1,370)

Appendix 1.8**:** Descriptive statistics of the land cover clusters

Clusters		**Tree Clumps**	**Herbaceous-Shrubby Vegetation**	**Forest Advanced-Intermediate Stage**	**Forest Initial Stage**	**Savanna**	**Pasture**	**Agriculture**	**Water**	**Bare Soil**	**Impermeable Surfaces**
1	Mean	4.08	3.95	0.22	0.13	0.10	0.00	0.00	0.21	2.42	88.88
Median		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00
Range		40.00	45.00	50.00	40.00	50.00	0.00	0.00	55.00	45.00	60.00
Standard Deviation		8.47	9.23	2.99	1.90	2.00	0.00	0.00	2.13	7.46	15.71
% of total Sum		14.70	4.90	7.40	4.00	14.20	0.00	0.00	69.30	4.80	92.20
2	Mean	4.19	4.65	0.00	0.16	0.00	0.02	0.00	0.00	85.88	5.10
Median		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	95.00	0.00
Range		40.00	45.00	0.00	40.00	0.00	10.00	0.00	0.00	60.00	50.00
Standard Deviation		8.80	10.19	0.00	2.17	0.00	0.46	0.00	0.00	16.51	12.28
% of total Sum		6.60	2.50	0.00	2.10	0.00	3.20	0.00	0.00	74.30	2.30
3	Mean	49.34	15.23	6.42	6.09	1.65	0.77	0.20	0.19	11.84	8.25
Median		50.00	10.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Range		100.00	55.00	100.00	100.00	100.00	100.00	80.00	20.00	55.00	55.00
Standard Deviation		31.51	17.37	21.46	20.54	10.38	7.40	4.02	1.47	16.35	15.05
% of total Sum		65.10	7.00	78.60	68.70	83.90	96.80	80.00	23.00	8.60	3.10
4	Mean	4.59	83.52	0.51	1.00	0.02	0.00	0.02	0.03	7.50	2.82
Median		0.00	85.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Range		40.00	60.00	60.00	60.00	15.00	0.00	20.00	15.00	50.00	50.00
Standard Deviation		8.82	16.53	4.75	5.67	0.50	0.00	0.67	0.55	12.11	9.48
% of total Sum		13.60	85.60	14.00	25.10	1.90	0.00	20.00	7.70	12.20	2.40
Total	Mean	10.58	30.51	1.14	1.24	0.27	0.11	0.04	0.12	19.17	36.82
Median		0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Range		100.00	100.00	100.00	100.00	100.00	100.00	80.00	55.00	100.00	100.00
Standard Deviation		21.14	38.32	8.90	8.66	4.11	2.78	1.55	1.46	32.33	43.09
% of total Sum		100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

CHAPTER 2

EXPLORING LANDSCAPE PATTERNS AND SOCIOECONOMIC ATTRIBUTES OF VACANT LOTS TO FOSTER URBAN PLANNING POLICIES

Abstract:

The socioeconomic components of urban landscapes can function as driving forces of their features' arrangements. Among these features vacant lots have been the subject of several studies without addressing, however, potential associations between landscape patterns and socioeconomic factors, that may reveal ecological processes and driving forces on urban systems. In this study we used regression models and regression trees to explore the association between landscape metrics of the vacant lots and socioeconomic factors of their neighborhoods, in the city of Belo Horizonte, southeastern Brazil. The landscape patterns evidenced are notably influenced by the socioeconomic factor population density, which determined the occurrence in densely populated neighborhoods of denser lots with smaller total core areas. Lots with different types of land cover located in sites with a larger number of protected areas were more likely to be interconnected with each other and with protected areas, which is an ecologically friendly configuration as it reinforces structural connectivity, that can benefit the local flora and fauna. Lots of very high vegetation quality, with characteristics of interest for environmental conservation, tended to be distributed at closer distances, but in neighborhoods with low number of protected areas, which may emphasize the importance of these lots in terms of expansion of preserved green areas. The configuration and composition of the vacant lots found in the studies can contribute to increasing the availability of green infrastructure in the city and to establishing urban planning measures that address those lots, especially with regard to environmental conservation.

Keywords: human-related factors, landscape metrics, regression trees, urban ecology, urban landscapes

2.1. Introduction

Vacant lots have been the subject of several studies worldwide regarding their socio-ecological attributes or qualities that connect the intersection between human and wildlife needs (Kremer et al., 2013; McPhearson et al., 2013; Kim, 2016; Anderson and Minor, 2017). These studies have been mainly aimed at understanding the public value of vacant lots in terms of their potential economic, social and ecological benefits (Kim, 2016). The uniqueness of vacant lots, in terms of their composition which includes vegetation and other natural elements, in the often densely populated urban environment, makes them also suitable for investigations within the principles of landscape ecology. This science is a consolidative interdisciplinary branch of knowledge where human activities are considered part of ecosystems encompassing, therefore, both natural and cultural aspects of the landscape (Botequilha Leitão et al., 2006). Landscape ecology has also perceptible affinities with environmental planning as it explicitly addresses the spatial and temporal dimensions of the phenomena under observation (Botequilha Leitão, 2001; Botequilha Leitão et al., 2006). It centers on the three characteristics of the landscape that are structure, function, and change (Forman and Godron, 1986). The spatial structure of the landscape involves two main aspects, the first one referring to its composition, in terms of the types of land cover or landscape elements. The second concerns the landscape configuration or the spatial arrangement, position, distribution and interrelation between the various patches or elements of the area under investigation (Turner, 1989; Griffith et al., 2000).

As a science of integration between ecological and human aspects, landscape ecology provides important tools for the discernment of the human-nature interactions and can endow a basis for characterizing the various elements of the ecosystem, both in terms of descriptive aspects, and to the functioning of ecosystems (Turner and Gardner, 1990). One of the methodologies used for the characterization of the spatial structure - including the measurement of the relative position and distribution of the landscape elements - is the calculation of the landscape metrics (Botequilha Leitão et al., 2006). These metrics can be considered as indicators that relate spatial patterns to ecological processes generated by them (Rocchini, 2005). As such, the landscape metrics-based approach is especially suitable when we want to investigate relationships between structural elements of the landscape and ecological processes and functions, fundamental for landscape planning and management (Botequilha Leitão et al., 2006). For urban environments all features expressed in the metrics, such as land cover and landscape configuration, are fundamental contributors to the quality of life in cities even influencing the price of properties (Geoghegan et al., 1997). The latter is due to the fact that people value not only man-made and ecological features of the parcels in the cities but also the patterns of use of the surrounding areas (Geoghegan et al., 1997).

While the metrics help to describe land use patterns and its associated ecological processes, in general, the socioeconomic components capture what lies behind, functioning as the driving forces of the landscape arrangements (Ribeiro and Lovett, 2009). In the case of urban areas there is little knowledge on the landscape patterns of the vegetation at the global scale and the factors driving these patterns (Dobbs et al., 2017). However, some inferences about the influence of socioeconomic factors on the urban landscape were presented by Dobbs et al. (2017), which obtained the most fragmented landscape structure in economically unequal cities, characterized as emerging economies. The socioeconomic arrangements also influence urban vegetation patterns, biodiversity and green infrastructure (Szlavecz et al., 2011; Dobbs et al., 2017; Ferguson et al., 2018). Thus, human activities in cities are translated as driving forces and limiting factors that act on urban ecosystems, and not only as sources of disturbances (Grim et al., 2000). Investigating the relationships between socioeconomic factors and ecological attributes of urban areas is therefore of utmost importance both to shed light and to enable predictions of the impacts of urban growth in an increasingly urbanized world (Mennis, 2006). Such an approach can promote the design of sustainable urban planning policies, as it becomes clearer from what point urban growth is putting pressure on the environment by forcing the scarcity of natural features or undermining the ability of natural resources to deliver benefits (Mennis, 2006).

One of the primary social aspects influencing vegetation and biodiversity patterns is the control over land ownership (Swam et al., 2011). Some studies carried out in rural landscapes have resulted in significantly higher values of biodiversity for sites belonging to the public power in relation to the private ones, possibly due to different management and adoption of conservation measures (Lovett-Doust and Kunst, 2001; Spies et al., 2007). In urban landscapes, other social determinants of vegetation and biodiversity patterns refer to the access and control of the resources of areas required for conservation; the dynamics of financial or social resources that foster actions relevant to conservation and the basis of the perception of the owners and residents, used in the management and design of urban land use (Swam et al., 2011).

Socioeconomic variables such as family income and dwelling time can also influence patterns of plant diversity in urban landscapes. A study conducted by Hope et al. (2003) resulted in positive correlations between those two socioeconomic variables (family income; dwelling time) and plant diversity. Another example is the association of density of dwellings, educational level and immigration status with variations in vegetation cover in urban ecosystems: negatively correlated in the case of density of dwellings and positively in relation to the others (educational level; immigration status) (Alberti et al., 2003; Luck et al., 2009).

The acquisition of knowledge about the occurrence of vegetation in urban areas as well as of its characteristics, the way in which it is distributed in the city and interacts with other attributes, can provide answers and practical applications focused on people's quality of life and urban sustainability (Muratet et al., 2008). Considering that in densely urbanized cities the availability of vegetation and residual spaces of natural resource concentration are usually low, vacant lots presence is crucial to providing prospects for transformations in urban land use that contribute to community development and to the provision of ecosystem services, making up a social and ecological infrastructure in cities (Susca et al., 2011; Kremer et. al., 2013). In this sense, studies addressing vacant lots have been the focus of attention of urban land use planners and ecologists in various locations around the globe (Kremer et al., 2013). They have been contextualized in global studies as important components for communities, economies and environment, being a source of ecosystem services that support the health and well-being of local populations (McPhearson et al., 2013; Anderson and Minor, 2017; Kim et al. 2018). Vacant lots have been characterized in relation to their composition, shape, size, location, distribution, greenness, land cover, land use, neighborhood context, ecosystem services, socio-economic conditions, below ground biocontrol activity, quality as a habitat resource, among others (Pearsall and Christman, 2012; Yadav et al., 2012; Kremer et al., 2013; McPhearson et al., 2013; Rega-Brodsky and Nilon, 2016). In Brazil, however, the information on the occurrence, composition and socio-ecological attributes of these plots in cities is scarce, despite having 86.6% of its population inhabiting cities, with approximately 15 of them with a population of more than one million inhabitants (Horta et al., 2018a; Plecher, 2019). Most of the time the existing information on vacant lots in Brazilian cities is related to municipal taxes, since the ecological and environmental enhancement of green areas in the city has been neglected, even though environmental preservation has been incorporated into urban planning the last three decades (Costa, 2008; Herzog, 2013). In any case, general investigations of the associations between landscape patterns and socioeconomic factors are rare, although that may reveal ecological processes and driving forces on urban systems (Ghafouri et al., 2016).

In order to start filling this gap, our study refers to the investigation of the occurrence of landscape patterns through the calculation of landscape metrics of vacant lots of the city of Belo Horizonte, capital of Minas Gerais state, Brazil. Furthermore, we intended to elucidate if the human component represented by socioeconomic factors influences the arrangement and spatial patterns of the lots land cover expressed through measures of vegetation quality. The socio-ecological attributes are thus represented by the biological component vegetation, as well as by the configuration and composition of the vacant lots expressed through landscape metrics and socioeconomic factors. We explored in this study, therefore, the potential relationships between landscape patterns and socioeconomic factors, a topic of lesser attention in both urban vacant lots research and landscape ecology studies (Ghafouri et al., 2016). The hypothesis of our work is that there is a pattern in the distribution of vacant lots and their composition in terms of vegetation quality and neighborhood location, reflected in the landscape metrics analysis. Further, socioeconomic factors (such as neighborhood population density, income, education, protected areas number, vacant lots price) may influence those patterns both at the class level (metrics integrate patches into a class) as well as at the patch level (metrics of the individual context of each patch). We therefore quantified the ecological metrics to represent the landscape patterns and tested through regression models and regression trees the relationships between socioeconomic factors and landscape metrics to understand the human forces acting in this landscape.

2.2. Materials and Methods

2.2.1. Study Area

Belo Horizonte is a Brazilian city located in the southeast region, in the state of Minas Gerais. It has a total area of about 33,100 hectares, with an average elevation of 900 m, average temperatures between 15ºC - 28ºC and vegetation represented by components of the Atlantic Forest and Cerrado or Savanna-like vegetation formation (Grandi et al., 1992; IBGE, 2005). The city has an estimated population of 2.6 million and has nine administrative regions delimited from its location and occupation history namely: Barreiro, East, North, Northeast, Northwest, Pampulha, South Center, West and Venda Nova (**Fig. 2.1**). Belo Horizonte is a planned city created in 1897 to host the state capital. This situation has given relevance to the actions of the government, which has always had an active influence on the processes of urbanization, space structuring and urban expansion of the municipality (Costa, 2006).

Although socio-ecological and economic alternatives initiatives are rare for the city's vacant lots, the study contained in the Integrated Development Master Plan of the Metropolitan Region of Belo Horizonte (UFMG, 2011a; UFMG, 2011b) pointed out some proposals for territorial reorganization and use of these lots in order to reduce socio-spatial inequalities and their large stock. These proposals were guided by the principles of the social function of the property and the attention to the housing deficit of social interest through the availability to the owners of options to be evaluated by the city halls. The report also indicated the need to create instruments to regulate and guide the use of vacant lots, which obliges property owners to undertake some use of the lots within a stipulated period of one year, in areas with vacancy of lots above 50%. Among the uses indicated by the project are social spaces (fairs, soccer fields, poly-sports courts, playgrounds or places of walking, environmental preservation areas or places for parties, etc.) to be appropriated by the population, through the residents' association, without the need for an institutionalization of certain fixed uses. The other proposed uses would be for urban agriculture (community gardens, cultivation of medicinal plants, flowers, orchards, trees for other purposes, poultry, goats and other livestock) to contribute to income generation, food security, self-management and sustainability of local people.

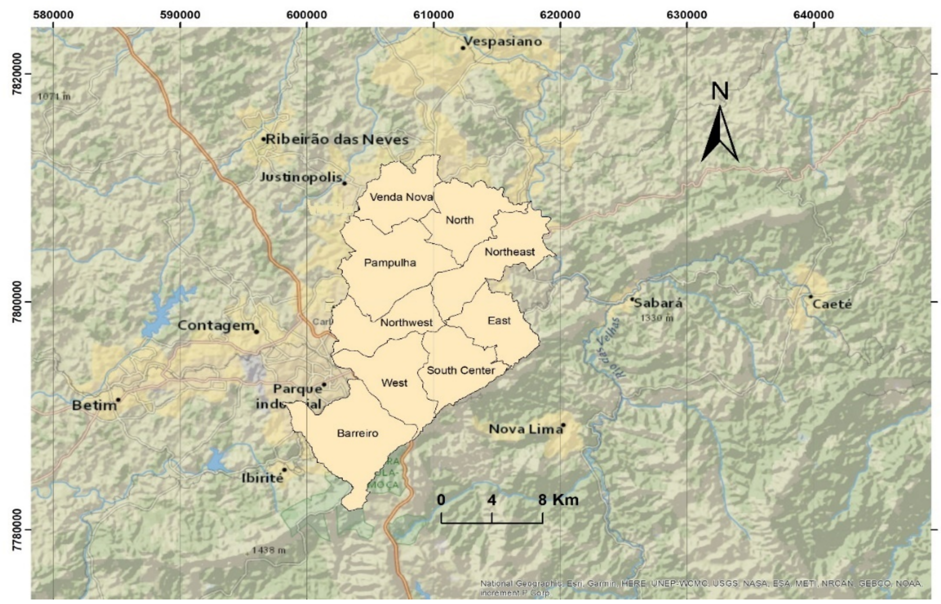


Figure 2.1: The city of Belo Horizonte, Brazil, and its nine administrative units (Basemap: National Geographic Worldmap)

2.2.2. Dataset, Land Cover and Vegetation Quality

The dataset utilized comprised a polygon map of the vacant lots of Belo Horizonte, year 2017 (**Fig. 2.2**) and a polygon map of the administrative units of the city, provided by the city hall (Prodabel/PBH). The total of 26,906 vacant lots available in the dataset underwent a representative sampling evaluation procedure for a 95% confidence interval, using the sample size calculation equation (Cochran, 1997). Thus, a representative sample of 2,828 vacant lots or 11% of total lots (**Fig. 2.3**) were distributed in the city nine administrative units as follows: Barreiro - 311 lots (sampled from a total of 2,670 or 12%); East - 207 lots (sampled from 1,384 or 15%); North - 277 lots (sampled from 2,126 or 13%); Northeast - 349 lots (sampled from 4,922 or 7%); Northwest - 208 lots (sampled from 3,441 or 6%); Pampulha - 407 lots (sampled from 4,266 or 10%); South Center – 355 lots (sampled from 2,082 or 17%); West - 346 lots (sampled from 3,307 or 10%); Venda Nova – 368 lots (sampled from 2,708 or 14%). In this sample 2,647 plots or 93.60% comprised private lots and 181 or 6.40% public lots. There were also 1,458 unused lots (51.55%) and 1,370 plots (48.44%) in use, with impermeable surfaces such as construction, asphalt, and cement.

It was also used the database generated for a previous study for the evaluation of land cover patterns and vegetation quality of the vacant lots. The land cover was synthesized through vegetation quality classes, including the ten land cover types that were: agriculture; bare soil; forest advanced-intermediate stage of regeneration; forest initial stage of regeneration; herbaceous-shrubby vegetation; impermeable surfaces (asphalt, cement, construction); pasture; savanna; tree clumps; water. What defined belonging to a certain category of vegetation quality was the land cover with the highest percentage of occurrence. Six classes of vegetation quality were established that included from lower quality situations (where there was a predominance of soil cover by vegetation of lower structural complexity with predominance of herbaceous or shrubby elements), going through situations of higher structural complexity and consequently higher quality (with predominance of arboreal elements or native formations), and up to conditions of vegetation-free lots with or without permeable surfaces. These classes of vegetation quality - which are defined and grouped by number of lots belonging to each one in **Table 2.1** – are: LVQ- Low Vegetation Quality; MVQ- Moderate Vegetation Quality; HVQ- High Vegetation Quality; VHVQ- Very High Vegetation Quality; NVP- No Vegetation Permeable; NVI-No Vegetation Impermeable.

Tabela 2.1: Land cover classes of the lots sampled in Belo Horizonte, Brazil (N=2,828)

Vegetation Quality Classes	**Definition**	**Number of Lots**
Low Vegetation Quality (LVQ)	Lots with up to 50% of structurally simplified vegetation (herbaceous-shrubby vegetation, pasture, agriculture) or with a low occurrence of arboreal vegetation and native remnants up to 25% (tree clumps, savanna, forest advanced-intermediate stage of regeneration, forest initial stage of regeneration)	646
Moderate Vegetation Quality (MVQ)	Lots with more than 50% to 100% of structurally simplified vegetation (herbaceous-shrubby vegetation, pasture, agriculture) or with occurrence of arboreal vegetation and native remnants with more than 25% to 50% (tree clumps, savanna, forest advanced-intermediate stage of regeneration, forest initial stage of regeneration)	1,024
High Vegetation Quality (HVQ)	Lots with more than 50% to 75% of occurrence of arboreal vegetation and native remnants (tree clumps, savanna, forest advanced-intermediate stage of regeneration, forest initial stage of regeneration)	128
Very High Vegetation Quality (VHVQ	Lots with more than 75% to 100% of occurrence of arboreal vegetation and native remnants (tree clumps, savanna, forest advanced-intermediate stage of regeneration, forest initial stage of regeneration)	116
No Vegetation Permeable (NVP)	Lots with no vegetation composed of bare soil	319
No Vegetation Impermeable (NVI)	Lots with no vegetation fully occupied by impermeable surfaces (asphalt, cement, constructions)	595

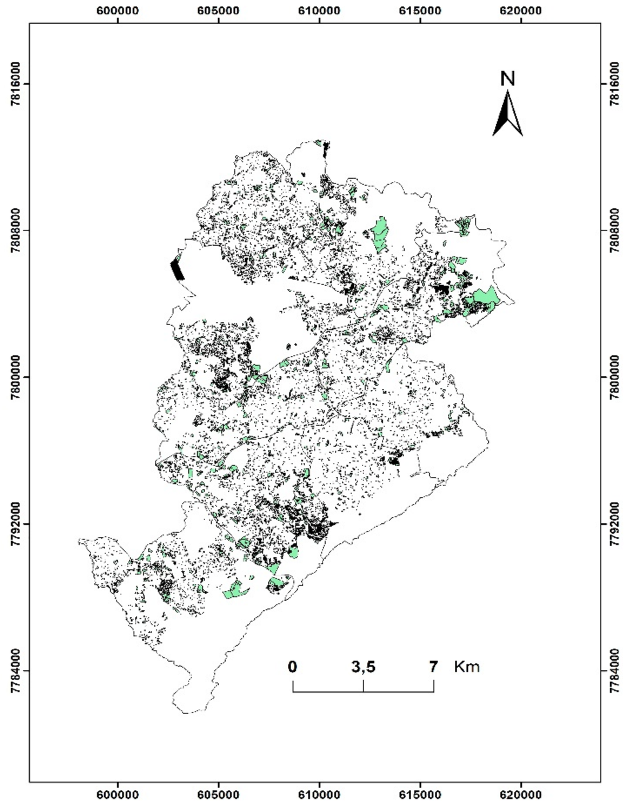


Figure 2.2: Total vacant lots from Belo Horizonte dataset, year 2017 (Prodabel/PBH)

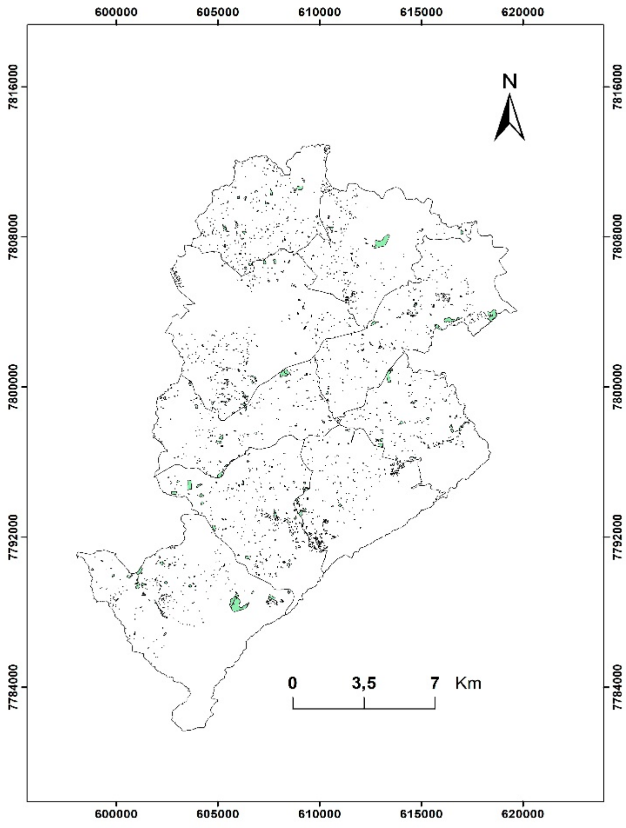


Figure 2.3: Vacant lots sampled from Belo Horizonte dataset, year 2017 (Prodabel/PBH)

2.2.3. Landscape Metrics and Socioeconomics Factors

Landscape metrics are algorithms that quantify spatial characteristics of patches, classes of patches or entire landscapes (de Smith et al., 2018). They include a wide array of indices of landscape patterns obtained from categorical maps (de Smith et al., 2018; Zaragosi et al., 2012) which aim to characterize the composition (e.g. number of land cover types) and spatial configuration (e.g. spatial arrangement of land cover types in a landscape) of the patch mosaic (Frank et al., 2013). The quantification of the spatial pattern from the ecological perspective refers mainly to that related to the complex distribution of resources in the landscape (McGarical, 2015). Thus, this measurement of landscape patterns is basically concerned with the characterization of spatial heterogeneity (McGarical, 2015). There are various software packages used for calculating landscape metrics (e.g.Fragstats for raster based maps) with some integrated into existing Geographic Information System - GIS (Patch Analyst – raster and vector based maps; Polyfrag – vector based maps, V-LATE – vector based maps) (McGarical and Marks, 1995; Ueema et al., 2009; Rempel et al., 2012; MacLean and Congalton, 2013; Tiede, 2016). We utilized in this study the R program (R Core Team, 2018) for the landscape metrics calculations, particularly the packages raster (Hijmans, 2017), simple features for R (Pebesma, 2018) and landscapemetrics (Hesselbarth et al., 2019). In order to compute the patch metrics, polygons of the lots were rasterized using cell sizes of 0.1 m, 0.5 m and 1 m depending on the size of the polygon (below 5000 m^2, between 5000 m^2 and 50000 m^2 and above 50000 m^2). This was done because even though the metrics do not depend on the cell size, the package used is based on raster format. Thus, it is important that the resolution be sufficient to obtain an accurate representation of the size and shape of the patches.

We investigated the patch mosaic formed by the vacant lots and their respective land cover, synthesized as vegetation quality classes (each lot with its own land cover is considered a patch). Considering our intention to verify the patterns closest to the possibilities of the vacant lots functioning as habitat and source of resources for organisms in the landscape, we selected a set of landscape metrics at the class and patch level mentioned ahead (**App. 2.1).** Patches can be defined as discrete areas characterized by their abrupt discontinuities and the patch level metrics are calculated for each patch individually characterizing its context (de Smith, 2018; McGarical, 2015). At patch level we used the following metrics: CAI-Core Area Index – edge depth of 5 m; CORE-Core Area; PARA-Perimeter-Area Ratio; SHAPE-Shape Index, PROX-

Proximity Index - with distance threshold used of 3000 m, considering previous studies of connectivity in urban landscapes (Ueema et al., 2009; Horta et al., 2018b) (**App. 2.2**). The patch metrics calculated for each lot were also organized into vegetation quality classes and by the city administrative units. In order to characterize the studied landscape broadly speaking and to verify association with socioeconomic factors at the class level the metrics used comprised: CAI_MN-Core Area Index Distribution – edge depth of 5 m; ENN_MN-Euclidean Nearest Neighbor Distance Distribution; SHAPE_MN-Shape Index Distribution; PD-Patch Density; TCA-Total Core Area; ED-Edge Density; MPS-Mean Patch Size; SHEI-Shannon's Evenness Index (**App. 2.3**). The class level metrics are calculated to integrate all the patches of a given type or class (de Smith, 2018) and in our study we grouped them into administrative units' classes. All these landscape metrics at class and patch level were used as dependent variables to verify their association with the explanatory variables composed by the selected socioeconomic factors.

The socioeconomic factors were used both to characterize the landscape of the city administrative units and as explanatory variables investigated to verify potential associations with the landscape metrics. The following socioeconomic variables were selected for the study: average income (AI), population density (PDE), higher education percentage (HE), number of protected areas in 500 m, 1500 m, 3000 m perimeters (NPA, NPB, NPC), median lots price within 2000 m and 5000 m (MPA, MPB). Average income, population density and higher education were obtained from the official government census and demographic data of the municipality of Belo Horizonte for the year 2010 (Brasil, 2010). First, it was verified the neighborhood of vacant lots, considering that each lot was characterized with the value of the variable corresponding to the neighborhood where it was inserted. The average income was obtained from the calculation by neighborhood of the average of the sum of the values of the mean monthly nominal income of the persons responsible for permanent private households. Likewise, population density values per lot originated from the calculation of the average inhabitants per square kilometer of each neighborhood where the vacant lots were located. In the case of the higher education variable, the weighting data came from official interviews (Brasil, 2010) totaling 67 surveyed points, distributed sparsely throughout the city, so that not all neighborhoods were represented. Thus, for each lot was assigned the value referring to the location closest to the lot and with similar visual characteristics observed in high resolution images (Google Earth images; GeoEye image) for dwellings and constructions. The values of the higher education variable were obtained by calculating the percentage of the number of persons consulted with higher education in relation to the total number of interviewees. At the class level grouped in administrative units', the socioeconomic factors were calculated through the average of the sum of each patch value, except for the variable population density, which was obtained from official records by region.

The independent variable number of protected areas in three different distances (500 m, 1500 m and 3000 m) was obtained using a map of protected areas of Belo Horizonte (Prodabel/PBH), coupled with conservation areas count by neighborhood and verification of the neighborhood of the vacant lot. This variable was used in the studies because it is understood that the initiatives of management and creation of protected areas in the city depend on socioeconomic and political actions that may vary between the different regions of the city (UFMG, 2011a). The number of protected areas surrounding each plot was computed using distances of 500 m, 1500 m and 3000 m. The maximum distance of 3000 m had as reference the greatest flight distance of a connectivity indicator pointed to the city, the bird species *Ramphastos toco* (Horta et al., 2018b).The median price variable was obtained from the elaboration of a map of land value (lots square meter prices) using real estate advertisements collected in the internet in June 2017. The coordinates, area and price of the lots in sale were used to generate a GIS points layer representing lots for sale centroids along with their attributes. In order to associate a likely price to each vacant lot, the median price of the lots for sale around each vacant plot from our sampling was computed using buffers around the of 2000 m and 5000 m. In both cases the QGIS, ArcView GIS (ESRI, Redlands, California, USA) softwares and R program were used. For descriptive statistics of the dependent (landscape metrics) and independent variables (socioeconomic factors) both at the class and patch level SPSS statistics software was used (**App. 2.2, 2.3**). At the class level regression models were performed using the R program (R Core Team, 2018) to test the relationships between socioeconomic factors and landscape metrics. Prior to this, correlation tests were conducted between the independent variables, with elimination of those with higher correlations from the model.

Considering the complexity of the relationships between landscape metrics and socioeconomic factors at patch level, which gathers a robust set of data, we chose the method of statistical analysis of regression trees, which is used to continuous variables. The regression trees are particularly applicable for the analysis of complex ecological data, since they can deal with nonlinear relationships, missing values and high-order interactions (De´ath and Fabricius, 2000). A regression tree is constructed through binary partitioning that splits the data into branches through an algorithm that selects the division that minimizes the sum of the squared deviations from the mean, in the two separated parts (van Echelpoel et al., 2015). This process ends when a node reaches a minimum node size and becomes a terminal one. The regression tree therefore comprises models that relate the response to its predictors by recursive binary splits (Elith et al., 2008). The root node of the tree congregates the entire dataset while the terminal node is no longer subject to partitions. This whole process aims to determine which division best explains the variability in the dependent variable in terms of the independent variables, deciding if a node should be terminal or target of new splits (Andersen et al., 2000). The best split is defined by the algorithm by minimizing the variance due to split at this node. The regression trees are represented graphically which helps in the exploration, understanding and interpretation of results (De´ath and Fabricius, 2000; van Echelpoel et al., 2015). They can be used to identify which factors are important in a model in relation to explanatory power and variance. A measure of explanatory variable importance can be obtained considering the goodness of split measures. In the regression trees used in the present study it was not necessary to eliminate socioeconomic (independent) variables through correlations since the tree itself does. For the development of the regression trees we used the R program (R Core Team, 2018) environment particularly the rpart (Therneau and Atkinson, 2019). The trees referring to the regression models that best explained the variance were selected for presentation in the results.

3.3. Results

The investigation of the relationship between the landscape metrics, which express the configuration and composition of the lots in the landscape, and the socioeconomic characteristics of the lots´ neighborhoods was carried out at the class level, initially, by checking the correlation between the explanatory variables, that resulted in the removal of the redundant variables. Population density (PDE), number of protected areas in 1500 m perimeter (NPB) and the median lots price within 5000 m (MPB) remained in the analysis. Eight landscape metrics at class level were used in the regression models. The resulting models show different significance for the associations between the dependent variables (landscape metrics) and the socio-economic factors (**Table 2.2**). The TCA (Total Core Area) landscape metric, which represents an aggregation or sum of all core areas of the patches (lots) of each land cover type, presented a regression model of high significance ($p \leq 0.001$). In this model 76% of the variation in number of the total aggregate core area for each patch type is explained by the socioeconomic factor population density. The model indicates that there is a negative relationship of the population density with changes of the total core area of the patches or lots, so that as the population density decreases, the total central areas of the lots in the landscape increases.

Two other regression models were significant at the level $p \leq 0.01$, concerning the dependent variables ENN_MN (Euclidean Nearest Neighbor Distance Distribution) and ED (Edge Density). In the case of the regression model of the ENN-MN - defined as the mean of the sum of the straight-line distances between patches or lots and their closest neighbor of the same type - two variables account for 72% of variation of the model. The coefficients obtained showed that the role of the independent variable number of protected areas in 1500 m perimeter from the lots (NPB) is more important than the population density (PDE) in explaining changes in Euclidean nearest neighbor distance distribution. The model also revealed that while there is a positive relationship between changes in PDE values and ENN_MN, for the shifts in NPB values with changes in ENN_MN there is a negative association. Thus, as the number of protected areas in 1500 m perimeter increases, a reduction of the ENN_MN occurs. Similarly, in the regression model of the edge density (ED) metric - which is the sum of the lengths of all edge segments in the landscape, divided by the total landscape area - the socioeconomic factors NPB and PDE are important, but with the latter playing a more significant role. These two significant variables explain 72% of the variance of the model and both have a positive relationship with the changes in the edge density (ED).

The regression model of patch density (PD) presented a significant result at $p \leq 0.05$, with 68% of the variation explained by population density (PDE), number of protected areas in 1500 m perimeter (NPB) and the median lots price within 5000 m (MPB). The role of PDE and NPB are more important than that of MPB variable in explaining the changes in patch density (PD). The model indicated that there is a positive relationship between changes in PDE and NPB values with changes in patch density. In the case of changes in MPB values with those in patch density, the relationship is negative, meaning that there is a decrease of the median lots price within 5000 m with the increase of patch density. The other regression models for the landscape metrics CAI-MN (Core Area Index Distribution), SHAPE_MN (Shape Index Distribution), MPS (Mean Patch Size) and SHEI (Shannon's Evenness Index) presented low significance (**Table 2.2**). The core area index is a metric that quantifies core area as a percentage of patch area or the percentage of the patch that is comprised of core area (MacGarical, 2015). For the CAI_MN model, the socioeconomic variables NPB (negative) and MPB (positive relationship) explained 42% of the core area index variations. Shape index is the measure of overall shape complexity that when equal to 1 the patch is a square or almost and increases without limit as patch shape becomes more irregular (MacGarical and Marks, 1995). In the case of SHAPE_MN, the MPB variable explained 34% of the model variation showing a positive relationship with the changes in shape values. Mean patch size at the class level is a function of the number of patches in the class (administrative units) and total class area. For MPS the variable NPB (negative relationship) accounts for 24% of the variances. The SHEI variable represents the diversity of patches types (land cover or vegetation quality classes) in the landscape so as an even distribution of area among patch types results in maximum evenness ((MacGarical, 2015). According to the regression model 15% of the variations in SHEI are explained by the population density (PDE) of the neighborhoods.

Tabela 2.2: Results for the regression models for landscape metrics and socioeconomic factors at class level

Dependent Variables	**Regression Models**	**Significance of F**	**Adjusted R^2**
CAI_MN	0.3549278 – 0.0826273NPB + 0.0003847MPB	0.081	0.42
SHAPE_MN	1.240e+00 + 7.112e-05MPB	0.059	0.34
ENN_MN	267.249189 + 0.009274PDE - 18.665182NPB	0.009**	0.72
PD	6.0889451 + 0.0007749PDE + 0.6587649NPB - 0.0044590MPB	0.034*	0.68
TCA	6618.27029 - 0.45194PDE	0.001***	0.76
ED	4.5991144 + 0.0009608PDE + 0.4652323NPB	0.009**	0.72
MPS	2390.43 - 172.82NPB	0.100	0.24
SHEI	3.061e-02 + 2.373e-06PDE	0.160	0.15

*Results are significant at $p \leq 0.05$ **Results are significant at $p \leq 0.01$ ***Results are significant at $p \leq 0.001$

The data used to generate the class-level regression models we just presented is shown in **App. 2.4**. It also shows information on the percentage of lots constructed or used in relation to the sampling of lots throughout the city (BLT) and in relation to the total lots of each administrative unit (BLA). The administrative unit Northeast presented the highest values of percentage of total constructed lots (15.81%) and lots constructed by administrative unit (59.60%). Subsequently, the following stand out: Venda Nova (BLT-13.80%, BLA-51.36%), West (BLT- 12.50%, BLA-50.29%), Pampulha (BLT-11.82%, BLA- 11.53%, BLA-50.80%). The Northwest and East regional units presented high percentages of constructed lots in relation to the total of lots sampled in these regions, respectively 59.13% and 55.56%. Regarding the landscape metrics, the Northwest administrative unit stood out with the highest values of CAI-MN (0.97), SHAPE_MN (1.38) and ENN-MN (358.94). The other highlights in relation to the highest values of the metrics were: Venda Nova (PD-12.52); Barreiro (TCA-4809.41); Venda Nova (ED-16.77); Barreiro (MPS-2876.97); West (SHEI-0.06). The South Center administrative unit concentrated all the highest socioeconomic factors that characterize each neighborhood, except for population density (PDE) that was higher in the Venda Nova regional unit (9109.40), South Center in third place (8698.80). The highest socioeconomic factors at South Center included: AI/Average Income- 5799.45; HE/Higher Education percentage-34.87; NPA/Number of Protected Areas in 500 m perimeter -1.84; NPB/ Number of Protected Areas in 1500 m perimeter- 8.07; NPC Number of Protected Areas in 3000 m perimeter-18.88;

MPA/ Median lots Price within 2000 m- 2267.69; MPB/ Median lots Price within 5000 m- 1694.77.

The modeling through regression trees of the relationship between landscape metrics at the patch level and socioeconomic factors resulted in models that explain slightly the variance of the dependent variables. Four landscape metrics (CAI -Core Area Index, CORE- Core Area, PARA- Perimeter-Area Ratio, SHAPE- Shape Index, PROX-Proximity Index) and eight socioeconomic variables (AI-Average Income; PDE- Population Density; HE-Higher Education percentage; NPA/NPB/NPC-Number of Protected Areas in 500/1500/3000 m perimeter; MPA/MPB- Median lots Price within 2000 m/5000 m) were used in the models, which were explored in terms of the entire metropolitan area and for each administrative units and vegetation quality classes. For the whole city the best model is that of the PROX variable, which nevertheless explained only 13.35% of the variance (**Table 2.3**). The regression tree model of the proximity index - that represents distances between patches of the same type considering the size and proximity of all patches whose edges are within a specified search radius of the focal patch – is shown in **Fig. 2.4**. The tree has eight terminal nodes and of the eight explanatory variables used, four remained in the model comprising: population density (PDE), average income (AI), number of protected areas in 1500 m perimeter (NPB) and median lots price within 2000 m (MPA). The lowest values of the proximity index (nodes 2,4,10,6) are found in plots in which 82% of the population density (PDE) observations are greater than or equal to 3512, while 48% of the plots have a number of conservation units in the neighborhood up to 1500 m (NPB) less than 3.5, and 25% of the plots show average income (AI) greater than or equal to 1034. Therefore, low values of PROX tend to be associated with both high population density and low values of NPB. The effect of AI and MPA is more complex and depends on the combination of both variables.

Table 2.3: Regression results concerning the percentage of variance explained by the model generated for landscape metrics patch level and socioeconomic factors for the whole city (CAI-Core Area Index Mean; CORE-Core Area; PARA-Perimeter-Area Ratio; SHAPE-Shape Index, PROX-Proximity Index)

Regression Model	**Dependent Variables**	**CAI**	**CORE**	**PARA**	**SHAPE**	**PROX**
Percentage of Variance Explained by the Model		5.93	10.05	3.83	4.09	**13.35**

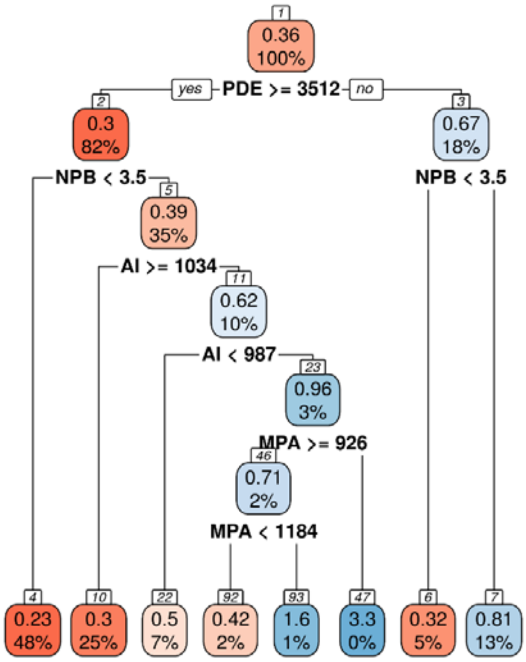


Figure 2.4: Regression tree concerning the dependent variable Proximity Index and explanatory variables that explain the greater variance of the model performed at the patch level for the whole city (AI-Average Income; PDE-Population Density per Square Kilometer; NPB- Number of Protected Areas in perimeter of 1500 m; MPA-Median Price within 2000 m)azul valores amais altos vermelhos valorees mais baixos da variável depenedente

The regression tree model for the landscape metrics data grouped into administrative units had the best model of the dependent variable CAI (Core Area Index), for the Northeast administrative unit, which explained 46.33% of the variance (**Table 2.4**). From the total of eight independent variables used, five remained in the model comprising: population density (PDE), average income (AI), number of protected areas in 1500 m perimeter (NPB), median lots price within 2000 m (MPA) and median price within 5000 m (MPB). The tree has eight terminal nodes and larger percentages of observations for the plots distributed among the lower values of core area index or the percentage of the patch that is comprised of the core area (**Fig. 2.5**). The lowest CAI values are concentrated mainly in three nodes (2, 10, 5) and three terminal ones (4, 20, 21). In nodes 2, 20 and 21 with a low value of core index area, 55%, 25% and 9% of plots show a median lots price within 5000 m (MPB) smaller than respectively 866 and 615. There is, therefore, a tendency to find smaller values of core area index in plots placed in neighborhoods with prices within 5000 m smaller. There is also a tendency to have lower values of the core are index for the plots distributed in neighborhoods with greater population density (PDE- nodes 4, 5), considering that 55% (18% + 37%) of plots present population density greater or equal to 13e+3 in nodes with low core area index. In the case of the variable number of protected areas in 1500 m perimeter (NPB – node 10), the effect is more complex since 34% of plots show values greater than or equal to 1.5 in a low CAI node (indicating propensity to find lots with low CAI values in neighborhoods where NPB are higher) but 3% show those values in a high CAI value node. For the variables AI and MPA the effect is also not very clear and depends on the combination of both variables.

Table 2.4: Regression results concerning the percentage of variance explained by the model generated for landscape metrics patch level and socioeconomic factors for each Administrative Unit (CAI-Core Area Index; CORE-Core Area; PARA-Perimeter-Area Ratio; SHAPE-Shape Index, PROX-Proximity Index)

Regression Model	**Administrative Units**	**Dependent Variables**	**CAI**	**CORE**	**PARA**	**SHAPE**	**PROX**
Percentage of Variance Explained by the Model	Barreiro		32.66	32.82	32.06	28.04	34.41
Percentage of Variance Explained by the Model	East		31.30	14.91	14.62	30.81	19.72
Percentage of Variance Explained by the Model	North		38.02	16.67	33.91	21.20	40.70
Percentage of Variance Explained by the Model	Northeast		**46.33**	7.28	28.95	24.40	24.28
Percentage of Variance Explained by the Model	Northwest		34.75	14.52	26.63	22.46	19.13
Percentage of Variance Explained by the Model	Pampulha		32.48	18.48	14.49	19.49	31.07
Percentage of Variance Explained by the Model	South Center		21.55	29.29	30.67	14.24	28.26
Percentage of Variance Explained by the Model	West		24.68	11.04	26.46	28.38	28.07
Percentage of Variance Explained by the Model	Venda Nova		24.92	21.87	18.76	28.37	23.24

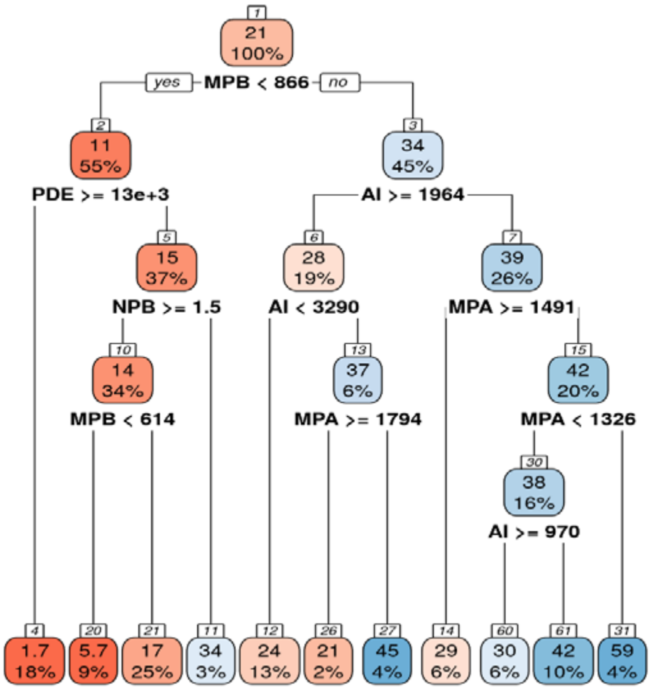


Figure 2.5: Regression tree concerning the dependent variable Core Area Index and explanatory variables that explain the greater variance of the model performed at the patch level for the Northeast Administrative Unit (AI- Average Income; PDE-Population Density per Square Kilometer; NPB- Number of Protected Areas in perimeter of 1500 m; MPA/MPB- Median Price within 2000/5000 m) (Red High Values; Blue Low Values)

In the case of the data grouped in vegetation quality, the best regression tree model was for the PROX (Proximity Index) variable, class of very high vegetation quality (VHVQ), which explains 44.61% of the variance (**Table 2.5**). It is noteworthy that the very high vegetation quality category is composed of 116 lots distributed among the various administrative units as follows: Venda Nova (19); South Center (16); Pampulha (14); Barreiro (13); North (12); West (12); Northeast (11); Northwest (11); East (8). Of the eight explanatory variables used two remained in the model: higher education percentage (HE) and number of protected areas in 1500 m perimeter (NPB). The regression tree has three terminal nodes, with a larger representation of the low proximity index values (**Fig. 2.6**). The lowest values of the proximity index are found in two nodes (4, 2) in which 85% of plots of very high quality of vegetation present higher education percentage greater than or equal to 9.7 and in 78% of the plots that present number of protected areas in 1500 m perimeter (NPB) of less than 10. Here there is a tendency, therefore, to find lots of very high vegetation quality with a lower proximity index, in neighborhoods with higher education percentage, and in places with lower number of conservation units in a perimeter of 1500 m.

Table 2.5: Regression results concerning the percentage of variance explained by the model generated for landscape metrics patch level and socioeconomic factors for each Vegetation Quality Class (CAI-Core Area Index Mean; CORE- Core Area; PARA-Perimeter-Area Ratio; SHAPE-Shape Index, PROX-Proximity Index)

Regression Model	Vegetation Quality	Dependent Variables	CAI	CORE	PARA	SHAPE	PROX
Percentage of Variance Explained by the Model	HVQ		37.81	12.59	40.23	26.37	26..03
Percentage of Variance Explained by the Model	LVQ		24.64	10.96	19.00	12.12	32.28
Percentage of Variance Explained by the Model	MVQ		14.44	3.90	8.50	13.36	31.04
Percentage of Variance Explained by the Model	VHVQ		23.86	19.98	26.35	27.96	**44.61**
Percentage of Variance Explained by the Model	NVI		24.94	17.12	17.88	24.61	23.08
Percentage of Variance Explained by the Model	NVP		33.60	13.06	11.38	26.50	32.85

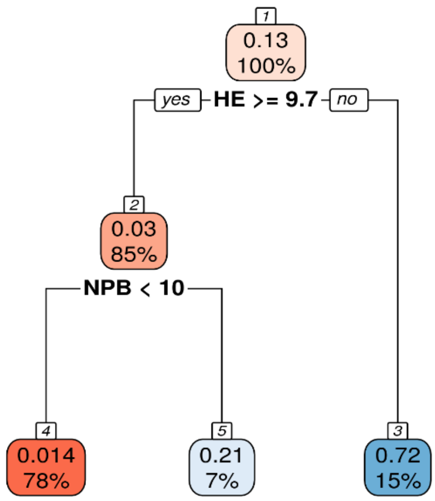


Figure 2.6: Regression tree concerning the dependent variable Proximity Index and explanatory variables that explain the greater variance of the model performed at the patch level for the class Very High Vegetation Quality (VHVQ) (HE-Higher Education Percentage; NPB- Number of Protected Areas in perimeter of 1500 m)

2.4. Discussion

The results of the regression models for the class-level landscape metrics - grouped into administrative units - showed that lot size, expressed by its core areas (TCA), distance between patches or lots of the same land cover type (ENN_MN) and patch density (PD) are significantly influenced by the socioeconomic factors population density (PDE), number of protected areas in 1500 m perimeter (NPB) and median lots prices within 5000 m (MPB). These are landscape metrics related directly to area and distances, which were also important in relationships to socioeconomic factors, especially the demographic ones, in an Asian urban landscape (Ghafouri et al., 2016). The socioeconomic factor population density (PDE) was a strong predictor for the total core area (TCA) in the present study, and the values of this metric tend to reduce in more densely populated areas. On the other hand, patch density (PD) increased with increasing population density. This denotes a pattern of landscape configuration where the patches tend to cluster on areas of higher population density, however, they have smaller areas in these locations. The sum of the edges of all lots or patches edge density (ED) consequently also increased with increasing population density, as showed in the regression model. The Euclidean nearest neighbor distance mean (ENN_MN) responded relevantly and negatively to the socioeconomic variable number of protected areas in 1500 m perimeter (NPB) and thus the distance between patches tended to reduce where the number of conservation areas present within a radius of 1500 m was greater. In practical terms we can interpret that lots located in places with larger number of protected areas are more likely to interconnect with each other and with protected areas, which is a landscape configuration favorable for animals, plants, biodiversity and hence to the increase of ecosystem services. The most favored administrative units of Belo Horizonte in this regard were South Center and West, which had higher NPB values (8.07; 5.74) and lower average patch distance values (200.60; 252.69). The socioeconomic factor median lots prices within 5000 m of the lots (MPB) was only more important in the patch density metric model, indicating a tendency for lower lots prices in neighborhoods with high patch density.

In the regression tree models, the socioeconomic factors population density (PDE), number of protected areas in 1500 m perimeter (NPB), median lots prices within 5000 m of the plots (MPB) and percentage of higher education (HE) were the most important predictor of landscape metrics proximity index (PROX) and core area index (CAI) at patch level. For the landscape as whole, the regression tree model poorly explains variance and showed a trend for patches with shorter distances in neighborhoods with higher population density. This result somewhat agrees with the previously presented regression models for the case of patch density (PD) but disagrees with tendencies for the Euclidean nearest neighbor distance mean (ENN_MN). Hence the use of the tree model for evaluations at patch level of the whole city is limited due to its poor predicting performance. The regression tree model that best explained variance in the case of patch groupings in administrative units was that for the Northeast region. In this case we found a tendency for lower core area index of lots to occur in neighborhoods with a median price within 5000 m (MPB) smaller. The relationship between core area index and population density followed the linear regression model for administrative units as a whole, with a tendency to reduce the core area in areas with higher population density. As the results showed, the Northeast administrative unit presented one of the highest percentages of built lots, with high transformation dynamics, and at the same time, consisted of the region with the lowest median lot prices. In this context, it is likely that the variation of the lots core areas will follow their prices. For the grouping of vegetation quality patches, the most important predictors of proximity index were higher education percentage (HE) and number of protected areas in 1500 m perimeter (NPB), with a tendency of occurrence of lots of very high vegetation quality with lower proximity index, in neighborhoods with greater higher education percentage, and in places with lower number of protected areas in 1500 m perimeter (NPB). This means that although lots of high vegetation quality were closer and interconnected, this occurred in neighborhoods with low number of protected areas, which can emphasize the importance of these lots in terms of expanding the city's preserved green areas. The result of the regression tree model for very high vegetation quality lots and their configuration therefore differs from that found for the linear regression model of the administrative unit classes and their lots of various vegetation quality classes, in which the chance of interconnection occurs not only between the lots but also between these and the protected areas in a perimeter of 1500 m.

The regression models and regression trees of our study have similarities among the predictors´ socioeconomic factors and in the greater importance of landscape metric responses for areas and distances but denote variations in the strength and nature of relationships between variables. Research into relationships between city dwellers and their management of the surrounding environmental conditions indicates more localized associations, which can vary widely within and between cities, making it difficult to generalize trends (Pearsall and Christman, 2012). However, some variables present a vast literature indicating relationships between socioeconomic factors and the urban environment, such as the relationship between wealth and land cover, being a strong predictor of urban vegetation vigor in many studies (Lo and Faber, 1997; Mennis, 2006; Pearsall and Christman, 2012). In our study, although the average income variable was included in the evaluations, it was excluded from the models due to its high correlation with other variables (regression model), or poor relationship with landscape metrics (regression trees). This weak influence can be noticed by noting that among the administrative units that hold the largest number of lots with high vegetation quality there are those with high average income and others with low income. For example for the very high vegetation quality category was found a total of 116 plots, and Venda Nova administrative unit had the largest number of lots (19) but the lowest average income (1194,43), while the regional South Center stood out in sequence with 16 lots and the highest average income throughout the city (5799,45). In the case of vacant lots and house prices, location is usually considered to be determinant in variations, but there are situations where the presence of a landscape with trees may be associated with higher land prices (Geoghegan et al., 1997; Anderson and Cordell, 1988). However, housing and lot price is not always a significant value in relation to vegetation quality, which in many studies is expressed through the Normalized Difference Vegetation Index (NDVI) which is a general measure of vegetation intensity or greenness (Mennis, 2006). The median parcel or lot price variable in our studies tended to lower values in high density patch neighborhoods and for lots with lower core area index, located in the Northeast administrative unit, which appear to be reasonable but not related to vegetation quality, instead to lots area itself.

The socioeconomic factor population density is usually negatively associated with either vegetation cover or vegetation vigor in urban areas in several studies, given the impact of people on its surroundings (Pozzi and Small, 2005; Mennis, 2006). In our study the socioeconomic factor population density was a strong predictor and has a marked influence being negatively associated with the total core area of the lots. Thus, the greatest impact exerted by population density is on the areas of the lots which tends to be smaller in densely populated places. Education is also a factor pointed in the literature as positively associated with high values of vegetation intensity or greenness (Lo and Faber, 1997; Mennins, 2006). In our study, this variable stood out only in the model of the very high vegetation quality class, with a tendency of greater proximity between lots of this class in sites with higher education percentage (HE). In the case of lot distance and protected green areas, parks and open spaces Kremer et al. (2013) found distance to green areas negatively correlated with population density. In the present study, generally, the distance between patches or lots tended to reduce in neighborhoods with a larger number of protected areas present within a radius of 1500 m.

2.5. Conclusion

The elucidation of the vacant lots´ configuration obtained in the present study, its landscape patterns and relationships with socioeconomic factors have potential policy ramifications indicating that the configuration of vacant lots can provide subsidies to planning design focused on urban sustainability. We found evidence of landscape patterns related to configuration and composition, which are influenced by some socioeconomic factors, notably population density, which determines the occurrence in densely populated neighborhoods of denser lots with smaller total core areas. Vacant lots therefore tend to cluster more in areas with higher population density, but with smaller areas and consequently with a smaller total core area. This indicates – for the unused lots - that the most populated neighborhoods of the city still have available lots, but with much smaller areas. Furthermore, lots of diverse vegetation quality classes located in sites with a larger number of protected areas are more likely to be interconnected with each other and with protected areas. This is an ecological friendly configuration that positively affects structural connectivity - benefiting urban biodiversity - and increases the relevance of the vacant lots distributed throughout the city. Of great potential in terms of ramifications of environmental conservation policies is the fact that the very high vegetation quality plots, with characteristics of interest for environmental conservation, tend to be distributed in closer distances, but in neighborhoods with low number of conservation units. This type of configuration may emphasize the importance of the lots investigated in terms of expansion of conserved green areas of the city.

2.6. References

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SUPPLEMENTARY MATERIAL

Appendix 2.1: Landscape metrics used in the study (MacGarical and Marks 1995, 2002, MacGarical, 2015)

Landscape Metrics	Equation
Patch Level Metrics - Dependent Variables	
CAI – Core Area Index	CAI=(a_{ij}^{c}/a_{ij}) *100 where a_{ij}^{c} =core area (m^2) of patch ij based on specified edge depths (5 m); a_{ij} =area (m^2) of patch ij
CORE - Core Area	CORE= a_{ij}^{c} *(1/10,000) where aij^{c} =core area (m^2) of patch ij based on specified edge depths (5 m)
PARA – Perimeter-Area Ratio	PARA= p_{ij}/ a_{ij} where p_{ij} =perimeter (m) of patch ij; a_{ij} =area (m^2) of patch ij
SHAPE-Shape Index	SHAPE= p_{ij} / min p_{ij} where p_{ij} =perimeter (m) of patch ij in terms of number of cells surfaces; min $p_{ij=}$ minimum perimeter (m) of patch ij in terms of number of cells surfaces
PROX-Proximity Index	PROX= Σ (a_{ij}/ h_{ij}^{2}) where a_{ij} =area (m^2) of patch ij; h_{ij}^{2} distance (m) between patches ij, based on patch edge to edge distance, computer from cell center to cell center (search radius 3000 m)
Class Level Metrics – Dependent Variables	
CAI_MN- Core Area Index Distribution	CAI_MN= [Σ(a_{ij}^{c}/a_{ij}) /ni]*100 where a_{ij}^{c} =core area (m^2) of patch ij based on specified edge depths (5 m); a_{ij} =area (m^2) of patch ij; ni= number of patches in the landscape of the patch type (class) i
SHAPE_MN- Shape Index Distribution	SHAPE= p_{ij} / min p_{ij} where p_{ij} =perimeter (m) of patch ij in terms of number of cells surfaces; min $p_{ij=}$ minimum perimeter (m) of patch ij in terms of number of cells surfaces; MN= or mean, equals the sum, across all patches of the corresponding patch type, of the corresponding patch metric values, divided by the number of patches of the same type
ENN_MN- Euclidean Nearest Neighbor Distance Distribution	ENN_MN= h_{ij} where $h_{ij=}$ distance (m) from patch ij to nearest neighboring patch of the same type (class), based on patch edge-to-edge distance, computed from cell center to cell center; MN= or mean, equals the sum, across all patches of the corresponding patch type, of the corresponding patch metric values, divided by the number of patches of the same type
PD- Patch Density	PD=ni/ A where ni= number of patches in the landscape of the patch type (class) i; A= total landscape area (m^2)
TCA- Total Core Area	TCA= Σ a_{ij}^{c} *(1/10,000) where a_{ij}^{c} =core area (m^2) of patch ij based on specified edge depths (5 m)

Landscape Metrics	Equation
ED- Edge Density	ED= (E/A)*10,000 where E= total length (m) of edge in the landscape; A= total landscape area (m^2)
MPS- Mean Patch Size	MPS= $\Sigma (a_{ij} / ni)*(1/10,000)$ where a_{ij} =area (m^2) of patch ij; ni= number of patches in the landscape of the patch type (class) i
SHEI- Shannon's Evenness Index	SHEI= $-\Sigma (P_i * \ln P_i) / \ln m$ where P_i= proportion of the landscape occupied by patch type (class) I; m= number of patches types (classes) present in the landscape, excluding the landscape border, if present

Appendix 2.2: Descriptive statistics of the dependent and independent variables for the class level analysis

Variables	Mean	Median	Range	Standard Deviation
Dependent Variables				
CAI_MN– Core Area Index Distribution	0.54	0.57	0.73	0.22
SHAPE_MN – Shape Index Distribution	1.33	1.33	0.09	0.29
ENN_MN- Euclidean Nearest Neighbor Distance Distribution	269.86	256.73	158.34	45.32
PD- Patch Density	8.71	7.98	6.29	2.01
TCA- Total Core Area	3,229.36	2,872.53	2,397.42	889.87
ED- Edge Density	13.47	12.81	5.81	2.36
MPS- Mean Patch Size	1,770.73	1,726.32	1,798.33	635.25
SHEI- Shannon's Evenness Index	0.05	0.05	0.03	0.01
Independent Variables				
AI- Average Income (R$ - Brazilian Currency)	2,248.65	1,778.09	4,605.02	1,936.86
PDE- Population Density (km^2)	7,498.53	8,473.70	38,332.28	1,746..68
HE- Higher Education Percentage (%)	22.13	22.29	19.81	6.57
NPA- Number of Protected Areas in 500 m Perimeter	0.72	0.56	1.70	0.50
NPB- Number of Protected Areas in 1500 m Perimeter	3.58	3.07	7.07	2.14
NPC- Number of Protected Areas in 3000 m Perimeter	9.93	9.03	13.53	4.35
MPA-Median Lots Price within 2000 m (R$ - Brazilian Currency)	1,249.57	1,124.00	1,374.29	411.57
MPB-Median Lots Price within 5000 m (R$ - Brazilian Currency)	1,243.89	1,115.69	740.98	268.87

Appendix 2.3: Descriptive statistics of the dependent and independent variables for the patch level analysis

Variables	**Mean**	**Median**	**Range**	**Standard Deviation**
Dependent Variables				
CAI- Core Area Index	27.70	23.51	95.44	20.96
CORE- Core Area	0.10	0.00	23.54	0.67
PARA- Perimeter-Area Ratio	0.26	0.26	8.06	0.20
SHAPE- Shape Index	1.37	1.36	4.02	0.21
PROX- Proximity Index	0.36	0.09	9.00	0.70
Independent Variables				
AI- Average Income (R$ - Brazilian Currency)	2,325.13	1,565.51	8,006.27	1,936.86
PDE- Population Density (km^2)	8,346.64	8,282.48	38,332.28	4,685.48
HE- Higher Education Percentage (%)	22.02	22.75	44.08	10.44
NPA- Number of Protected Areas in 500 m Perimeter	0.78	0.00	5.00	1.03
NPB- Number of Protected Areas in 1500 m Perimeter	3.83	3.00	18.00	3.34
NPC- Number of Protected Areas in 3000 m Perimeter	10.41	9.00	28.00	5.95
MPA-Median Lots Price within 2000 m (R$ - Brazilian Currency)	1,249.46	1,141.00	7,538.00	663.64
MPB-Median Lots Price within 5000 m (R$ - Brazilian Currency)	1,220.93	1,179.00	1,583.00	330.95

Appendix 2.4: Landscape metrics class level and socioeconomic factors found for each administrative unit (AU-Administrative Units; 1-Barreiro, 2-East, 3- North, 4-Northeast, 5-Northwest, 6-Pampulha, 7- South Center, 8-West, 9-Venda Nova; BLT%-Built Lot Total Percentage; BLA%-Built Lot Percentage per Administrative Unit; CAI_MN-Core Area Index Distribution; ENN_MN-Euclidean Nearest Neighbor Distance Distribution; PD-Patch Density; TCA-Total Core Area; ED-Edge Density; MPS-Mean Patch Size; SHEI-Shannon´s Evenness Index; AI-Average Income; PDE-Population Density per Square Kilometer; HE-Higher Education Percentage; NPA/NPB/NPC- Number of Protected Areas in perimeters of 500/1500/3000 m; MPA/MPB- Median Price within 2000/5000 m)

AU	**BLT %**	**BLA %**	**CAI_MN**	**SHAPE_MN**	**ENN_MN**	**PD**	**TCA**	**ED**	**MPS**	**SHEI**	**AI**	**PDE**	**HE**	**NPA**	**NPB**	**NPC**	**MPA**	**MPB**
1	11.53	50.80	0.64	1.34	256.73	6.23	**4809.41**	11.10	**2876.97**	0.05	1370,95	5242,30	18,12	0,42	2,17	5,55	1124,00	1115,69
2	8.39	55.56	0.65	1.32	305.80	7.49	2411.99	13.54	2260.93	0.05	1954,44	8473,60	27,10	0,38	2,07	6,92	1352,62	1627,48

3	6.72	33.21	0.58	1.33	294.00	7.99	2872.53	10.96	1606.70	0.04	1309,31	6468,90	15,06	0,53	2,82	9,04	1012,66	1104,06
4	**15.18**	**59.60**	0.54	1.29	237.80	8.67	3444.00	12.31	1726.32	0.05	1353,57	7347,00	15,76	0,65	3,52	8,87	893,40	984,34
5	8.98	59.13	**0.97**	**1.38**	**358.94**	6.92	2629.99	12.81	2334.74	0.05	1778,09	8953,70	24,93	0,13	1,00	5,34	1247,07	1333,33
6	11.82	39.80	0.24	1.30	251.68	7.94	4578.67	11.34	1085.99	0.03	2394,08	4416,80	24,93	0,88	3,81	10,40	1107,78	1075,14
7	10.88	41.97	0.32	1.36	200.60	10.84	2782.77	15.86	1078.64	0.04	**5799,45**	8698,80	**34,87**	**1,84**	**8,07**	**18,88**	**2267,69**	**1694,77**
8	12.70	50.29	0.57	1.33	252.69	9.85	3076.39	16.57	1873.03	**0.06**	3083,48	8776,30	22,29	1,09	5,74	14,43	1287,40	1306,44
9	13.80	51.36	0.32	1.29	270.47	**12.52**	2458.52	**16.77**	1093.23	0.05	1194,43	**9109,40**	16,12	0,56	3,07	9,97	953,51	953,79

CHAPTER 3

FUNCTIONAL CONNECTIVITY IN URBAN LANDSCAPES PROMOTED BY *RAMPHASTOS TOCO* (TOCO TOUCAN) AND ITS IMPLICATIONS FOR POLICY MAKING

Abstract:

The scarcity of green areas in urban landscapes hinders connectivity among sites reducing the flux of organisms and seed dispersal. *Ramphastos toco* is an effective plant disperser in tropical landscapes, playing an important role in conserving plant connectivity. In this study we combined two methods of landscape connectivity analysis, in a way not yet explored, to assess the potential contribution of *Ramphastos toco* to enhancing connectivity among urban vegetation patches. We used spatial modeling techniques to evaluate least cost routes, or those that facilitate bird movement through green urban areas, in Belo Horizonte, a city in Southeast Brazil. We also assessed the relative importance of forest patches for conserving both bird and seed dispersal fluxes using the integral index of connectivity. The resulting least cost route of greater accessibility for the species included in its course an important forest patch under environmental licensing for the construction of a residential condominium. The number of green urban areas covered by forest, of highest habitat quality for the species, summed to 155 patches. Of this total only 5.2% were relevant for regional connectivity, while the four most important patches are targeted by the city's expansion plans. *Ramphastos toco* is an effective connector for tropical green urban areas given its adaptability, wide range of movement and seed dispersal effectiveness. We emphasize the need for incorporating ecological knowledge and the prioritization of green areas into city planning, since current expansion projects jeopardize forest patches that are crucial to the functional connectivity of the urban landscape.

Keywords: environmental planning; least cost routes; seed dispersal; urban ecology

3.1. Introduction

The alarming rate of urbanization and future estimates of urban sprawl in the major cities of the world place urban land use as one of the most expansive causes of landscape alteration, with impacts often exceeding city limits (Woolley, 2005; Brantz and Dümpelmann, 2011; Faeth et al., 2011; Elmqvist et al., 2013). This situation calls for measures that include the increasing relevance of cities as repositories of a portion of the world's biodiversity (Faeth et al., 2011). The recognition of this issue has led to a very diverse set of initiatives and social movements for creating urban parks, urban gardens and nature reserves aiming at incorporating nature and biodiversity conservation into cities throughout the world (Antrop, 2004; Goddard et al., 2010; Kowarik, 2011). In fact, in urban landscapes, natural habitats and protected green areas can function as biodiversity repositories; however, the maintenance of such sites alone is not enough for guaranteeing species protection since there is also a need for promoting landscape connectivity among areas (Zipperer and Pickett, 2012; Pena et al., 2017). Thus, urban planning and other strategies aiming at improving, as far as possible, animal flux and plant dispersal in the landscape matrix can reduce the risk of population extinction (Chardon et al., 2003).

The process of urbanization is even more alarming and rapid in developing countries in the tropics, where initiatives to include urban biodiversity and ecosystem services, and enhance forest connectivity, are in their infancy (Arifin and Nakagoshi, 2011; Herzog, 2013). Implementing biodiversity conservation and restoring forest connectivity in tropical cities is very challenging for a number of reasons; while scientific knowledge on biodiversity and ecosystem services exists, it is rarely incorporated into urban land use planning and management (Horta et al., 2018). Particularly lacking is the exchange of knowledge and tools among science, society and land use planning bodies in cities for developing applied research on environmental indicators (Niemelä, 1999). There is also a need for biological and ecosystem indicators to address some of the most prominent environmental problems — habitat fragmentation, habitat isolation and connectivity loss.

Connectivity is an important ecological phenomenon, especially considering the growing impacts to natural ecosystems arising mainly from human population growth and land use intensification (Mühlner et al., 2010; Rayfield et al., 2011). These impacts threaten ecosystem functioning and biodiversity conservation by modifying the landscape and increasing habitat fragmentation (Fischer and Lindenmayer, 2007). Fragmentation results in habitat isolation, which reduces the connections between patches by disrupting the movement and flow of animals, plants and genes between areas and populations (Rayfield et al., 2011). Fragmentation directly affects the process of seed dispersal, which is of paramount importance to ecosystem functioning and the structural design of tropical communities (Dennis and Westcott 2006) because it comprises an intrinsic functional relationship between frugivores and the plants dispersed by them (Böhning-Gaese, 2007).

In fragmented landscapes seed dispersal depends on the behavior and local abundance of frugivores (Dennis et al., 2005). The loss of connectivity due to fragmentation influences the capabilities of dispersal agents by restricting movement among patches, and thus selects species with dispersal strategies that can overcome the isolation of patches (Purschke et al., 2014). This means that seed dispersal between patches may not occur if appropriate dispersal agents are absent and/or if the behavior of the disperser (frugivore) does not allow passing through certain anthropogenic components of the matrix (i.e. areas of pasture, cultivation, construction, etc.) (Wright, 2007).

Reduced connectivity may also lessen functional diversity by filtering plant dispersal traits from the species pool (i.e. seed production, seed buoyancy, seed mass), favoring those with better-adapted trait values (i.e. reduced connectivity can promote a broader distribution of plant species with greater efficiency) (Favre-Bac et al., 2017). In this context, several plant species are now threatened with extinction because of the threats to the animals that disperse them. An example of this is the increased risks for plant extinctions due to lost mutualisms with avian dispersers in tropical humid forests, in face of the accelerated bird population reductions and extinctions (Sekercioglu et al., 2004). This situation requires the adoption of solid and long-lasting measures for the restoration of fragmented habitats and, especially (as in the case of cities), the facilitation of seed dispersal through corridors in order to maintain natural ecological processes in the long-term (Wright, 2007).

Connectivity is, therefore, a critical concept in ecology considering that connections between habitats are fundamental for the survival, dispersal and persistence of individuals, populations and communities (Dawson, 1997; Auffret et al., 2015). There are two major components of connectivity: structural and functional (Tischendorf and Fahrig, 2000). Structural connectivity refers to spatial relationships among landscape elements and concerns the physical attributes of the landscape (Taylor et al., 2006; Ayram et al., 2016). This component is measured through landscape metrics that use distance among patches (such as mean nearest neighbor distance) (Taylor et al., 2006; Mühlner et al., 2010). Functional connectivity, on the other hand, considers the movement behaviors of species as determined by resistance from the landscape matrix through the presence of land cover that hinders flow (e.g. roads, buildings) or by landscape features that facilitate flux (e.g. forest patches, hedgerows, trees) (Graham, 2001a; Chardon et al., 2003).

The importance of functional connectivity stems from theoretical advances that recognize functional traits as central to the functioning of ecosystems. Diversity and composition of functional traits have been highlighted in recent research as some of the main drivers of ecological processes, more so than species richness (Hooper et al., 2005). More than the species (or taxon) itself, the functional identity of a species (i.e. specific trait such as beak size) and the functional divergence between species, have been recognized as largely responsible for facilitating ecosystem multifunctionality (Mouillot et al., 2011). In this sense, functional connectivity per se is concerned specifically with the connection of traits and services provided by common guilds, rather than individual species or taxa.

Among groups of fauna, vertebrates are recognized as important contributors to plant seed dispersal in the Neotropics, with birds standing out due to their greater impact on plant diversity patterns and genetics (Karubian et al., 2012). Moreover, birds have outstanding abilities to disperse urban plant species (Noss, 1991). The occurrence of birds in urban environments is highly influenced by the presence and size of vegetation patches, as well as by the structural and floristic attributes of green urban areas, to which they respond directly (Chace and Walsh 2006). Avian occurrence is also facilitated by trees along streets and vegetation remnants resulting from urbanization (Barth et al., 2015; Pena et al., 2017). At the same time, bird species increase the probability of seed survival, as long as they regurgitate them far from the tree where it was collected, thus avoiding damage and mortality caused by predation and pathogens (Janzen, 1980; Howe, 1990).

Although there have been only a few studies addressing the effectiveness of tropical plant dispersal agents, some have highlighted the importance of various species of the avian family

Ramphastidae, or toucans, for tropical plant dispersal (Howe, 1990; Holbrook and Loiselle, 2007; Holbrook, 2011). Among the characteristics of toucans that endow Ramphastidae with efficacy at tropical plant dispersal are: their adaptability to, and ability to move across, different habitat types (e.g. forests, fragmented forests, degraded areas, isolated trees, agroforestry systems); their large home-ranges and endurance for long distance movements, which play important roles in seed dispersal, plant genic flux, plant genetic diversity and forest regeneration; their primarily frugivorous diet; their brief and rapid feeding visits to fruit trees, which facilitates the dispersal of seeds far from the parental plant thus beneficiating plant performance (e.g. through reduced mortality caused by density-dependent processes and increased recruitment probabilities, due to the distribution of seeds across different habitats); and their large gape, which allows seeds of different sizes to be swallowed (Howe, 1990; Graham, 2001b; Holbrook and Loiselle, 2007; Goulart et al., 2011; Holbrook, 2011).

The aim of our work is to develop a tool for incorporating scientific knowledge into land use planning in a rapidly developing region of the city of Belo Horizonte, Brazil. We propose *Ramphastos toco* (Toco Toucan) as an indicator species along with a methodological approach that combines least cost routes and forest connectedness, in order to identify areas for which long-term permanence is essential, or where connectivity needs to be restored or conserved. Therefore, the main goal of our study is to evaluate the functional connectivity of *R. toco* and the plants it disperses between a source area where the species has been recorded and the most relevant urban vegetation patches that occur in northern Belo Horizonte. We also discuss the pertinent sociopolitical and governance issues that might influence connectivity in the region. We do this by considering that tropical cities usually possess marked socio-spatial inequalities and center to periphery population growth (Pasternak and Bogus, 2004), with ecosystem protection usually occurring through mechanisms of green area protection, but often without considering ecological criteria, such as connectivity, for long-term sustainability planning.

We hypothesize that patches that are larger and have greater connectivity are more important for maintaining the movement of *R. toco* and the plants it disperses. In addition, tree clumps and orchards can facilitate species movement, and least cost routes can help decision makers protect or restore the quality of the urban matrix in order to maintain and conserve toucans and the trees on which they depend for feeding. Conversely, these tree species will also benefit from the toucans on which they depend for dispersal. This type of modeling, therefore, can help land-use planning for the conservation of both birds and plants. In the city of Belo Horizonte, the presence of *R. toco* has been recorded for the Fazenda Lagoa do Nado Municipal Park, a green urban area located in the northern region of the city (Mafia et al., 2012). This region is characterized by a low incidence of protected green areas within its perimeter and of conservation units in the immediate peri-urban areas (PDDI, 2011). Hence, the area possesses precarious conditions for landscape connectivity that call for further evaluation. Of the large frugivorous birds that inhabited the forest-savanna habitats of the region of Belo Horizonte prior to its establishment (other species of toucans, trogons and guans) (Rodrigues and Goulart, 2005), R. toco is one of the few that remain. Enhancement of the functional connectivity of this urban landscape may allow *R. toco* to increase plant dispersal, recruitment and genetic flux, and favor the conservation of tree populations inhabiting the urban matrix and forest patches. Considering all the previously-mentioned benefits that toucans bring to plant seed dispersal, we assume, in this study, that the movement of *R. toco* among several green urban areas will enhance functional connectivity among vegetation patches by facilitating tree species dispersal, increased genetic flux and diversity among sites.

3.2. Materials and Methods

We utilized spatial modeling techniques to generate least cost routes based on matrix resistance to species movements. To add more information to our model we also evaluated, through a complementary approach, the relative importance of forest patches to functional connectivity based on information regarding the species flight and travel distances. Thus, functional connectivity among urban green areas was examined in terms of the potential plant seed dispersal and genic flux that *R. toco* may facilitate using both least cost path routes and the index of integral connectivity

3.2.1. Study area

The study took place in the city of Belo Horizonte, state of Minas Gerais, Brazil, which encompasses a total area of 33,100 ha, with a mean elevation of around 900 m (Felix, 2009). The human population of Belo Horizonte is estimated at 2.6 million. The climate is tropical, with mean annual temperatures varying from 15ºC to 28ºC. The city is situated in the extreme west of the Atlantic Forest biome were it meets the Cerrado biome, and so possesses plant species from both regions (Brina, 1992; Grandi et al., 1992; IBGE, 2005). Protected green municipal areas sum to around 890 ha (PDDI, 2011). Our study area is located in the northern region of Belo Horizonte and comprises a total area of 17,998.58 ha (**Fig. 3.1**). Of this total, 1,376.05 ha correspond to forest patches in more advanced stages of regeneration. The mean and maximum nearest neighbor distance for the forest fragments of the landscape are 580 m and 10,220 m, respectively, reflecting an important physical discontinuity among patches. In order to evaluate the possible routes followed by *R. toco,* a source area, where *R. toco* was previously recorded (Mafia et al., 2012), and four destinations comprising the most conspicuous green areas of the studied area, were identified.

The green urban area defined as the source for the evaluation of connectivity routes was the Fazenda Lagoa do Nado Municipal Park (FLNMP), with a total area of 30 ha. The vegetation cover includes semi-deciduous seasonal forest, savanna and exotic eucalyptus plantations (Mafia et al., 2012). The green urban areas defined as destinations in the northern region of Belo Horizonte were the Museum of Natural History and Botanical Garden of the Federal University of Minas Gerais (MHNJB), Ursulina de Andrade Mello Municipal Park (UAMMP), Serra Verde State Park (SVP) and Isidoro Forest (IF) or Granja Werneck spot (Fig. 1). MHNJB encompasses a total area of 60 ha, most of which is covered by remnants of seasonal semi-deciduous forest in different stages of succession (Pereira et al., 2010). UAMMP has a total area of 32 ha composed of forest in advanced stages of regeneration interspersed with plots in initial regeneration (PBH 2015). SVP has a total area of 142 ha and IF is approximately 940 ha. These destinations correspond to the last significant green frontier in northern Belo Horizonte and comprise an ecotone of semi-deciduous seasonal forest patches mixed with savanna (Brandão and Araújo, 1992; Duarte et al., 2014).

IF is currently occupied by around 30,000 people of which about 19,000 are descendants of enslaved Africans known as Quilombolas. The area has abundant water courses and remnants of natural vegetation (Duarte et al., 2014). The Isidoro region was originally occupied by landless families. There have been many attempts of repossession by the ownership given the various interests in the site, including land speculation and conversion of the area into a middle class residential community for 300,000 people, structured with apartment buildings, schools and health care centers, among other infrastructure (Duarte, 2014; Bairros de Belo Horizonte, 2015). These attempts have ignited many environmental, social and legal conflicts, which remain unresolved. The northern region is part of a large urban sprawl project in Belo Horizonte aligned with the implementation of a new administrative city hall, campus, including the construction of bus system lines, as well as commercial and industrial expansion towards the region of Confins airport, which is the main airport of Minas Gerais State.

3.2.2. Focal Species

The bird species *Ramphastos toco*, also known as Toco Toucan or Tucanuçu, is native to South America and distributed throughout the Neotropical Region. The species is widely distributed throughout Brazil and occurs well beyond the eastern coastal region. It is the largest of all toucans with a body of approximately 56 cm and weight of about 540 g, and is easily recognized by its huge orange beak (Sick, 1997). Toucans are omnivorous, but preferably frugivorous, and are among the largest seed dispersers, regurgitating lumps and pellets with numerous uninjured seeds (Sick, 1997; Galetti et al., 2000). *Ramphastos toco* exhibits diverse food and feeding patterns in urban areas, feeding on fruits of both native and exotic plant species (dos Santos and Ragusa-Netto, 2013). It forages largely on fleshy fruit, being driven by the availability of abundant resources (Ragusa-Netto, 2006), and occurs both in areas of semi-open vegetation and sites of dense forest (França et al., 2009).

The average home range of the genus *Ramphastos* is of about 86 ha, with the maximum distance traveled in 30 minutes being approximately 3,027 m. The estimated distance for medium-sized seed dispersal is between 269 m and 449 m. The large home range and long-distance movements indicate that toucans disperse seeds on a scale of hundreds of meters (Holbrook, 2011). Most toucans avoid flying over extensive water bodies, with the except for *R. toco*, which sustains flights across grasslands and water bodies over 5 km wide (Sick, 1997; Short and Horne, 2001).

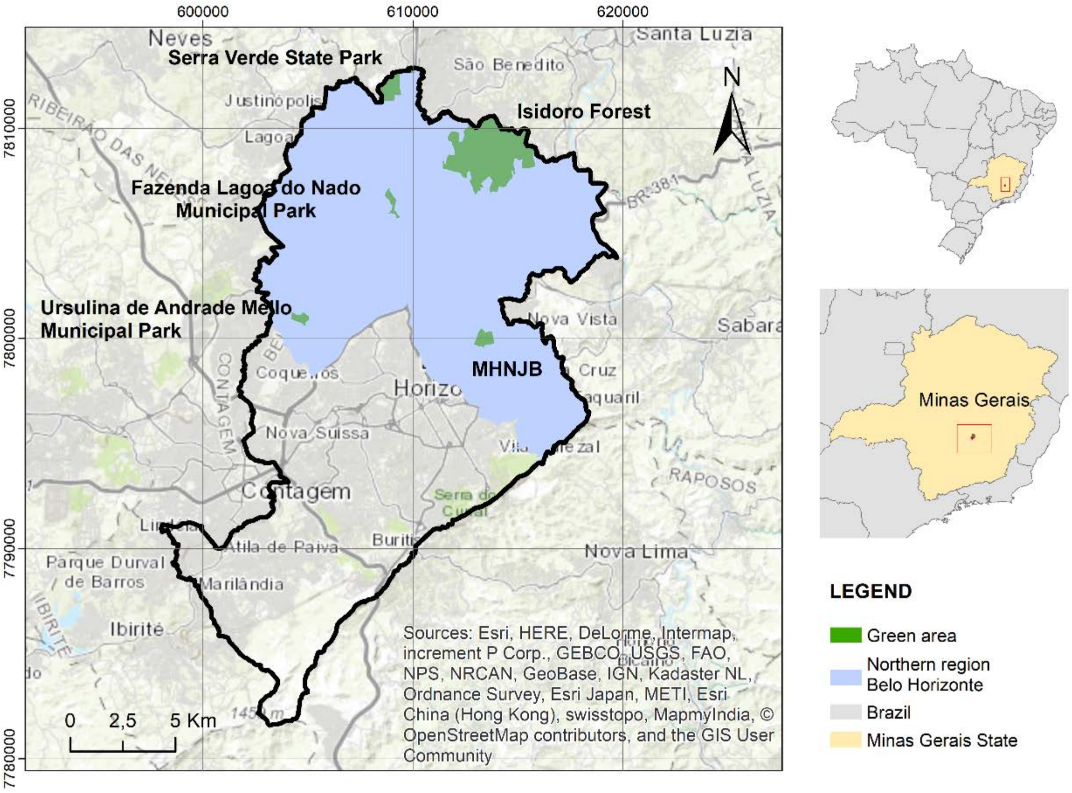

Figure 3.1: Study area containing the municipal parks of Fazenda Lagoa do Nado and Ursulina de Andrade Mello, the Serra Verde State Park, Museum of Natural History and Botanical Garden of the Federal University of Minas Gerais (MHNJB) and Isidoro Forest, in Belo Horizonte

3.2.3 Distance-Cost Method: Least Cost Routes between Green Areas

The distance-cost method is based on the analysis of least cost routes, taking into account the behavior of the organism of interest, through the designation of weights or cost values according to the characteristics of the habitats in the landscape. The generated model, thus, expresses the best dispersal corridor, defined by cost values (Mühlner et al., 2010). The routes delineated by this method reflect those that are most likely to be taken by a particular species from a source towards another habitat patch, connected by links. The itinerary is influenced by land cover and use types within the matrix that can offer resistance or facilitate an organisms´ movements (Chardon et al., 2003; Watts et al., 2010).

The spatial dataset used in the present study includes official maps from the municipal database, provided by Belo Horizonte City Hall (PBH). The vegetation map of Belo Horizonte (**Fig. 3.2**) was generated from aerial photos taken in 2007 and 2008 (South American Coordinates System Projection 1969, UTM Zone 23s), and comprise the following classes of cover/use: forest; secondary forest; woods; grove; reforestation; orchard; plantation; scrub; agriculture; pasture; and other (**Table 3.1**). We assumed that the 2007/2008 maps were still adequate for assessing the characteristics of the current landscape since the region has experienced a low rate of deforestation, as shown by 2000-2016 wood loss/gain maps (http://earthenginepartners.appspot.com/science-2013-global-forest). We also accept that there is a delay in the response of species to fragmentation (Metzger et al., 2009), especially for the toucan/plant system.

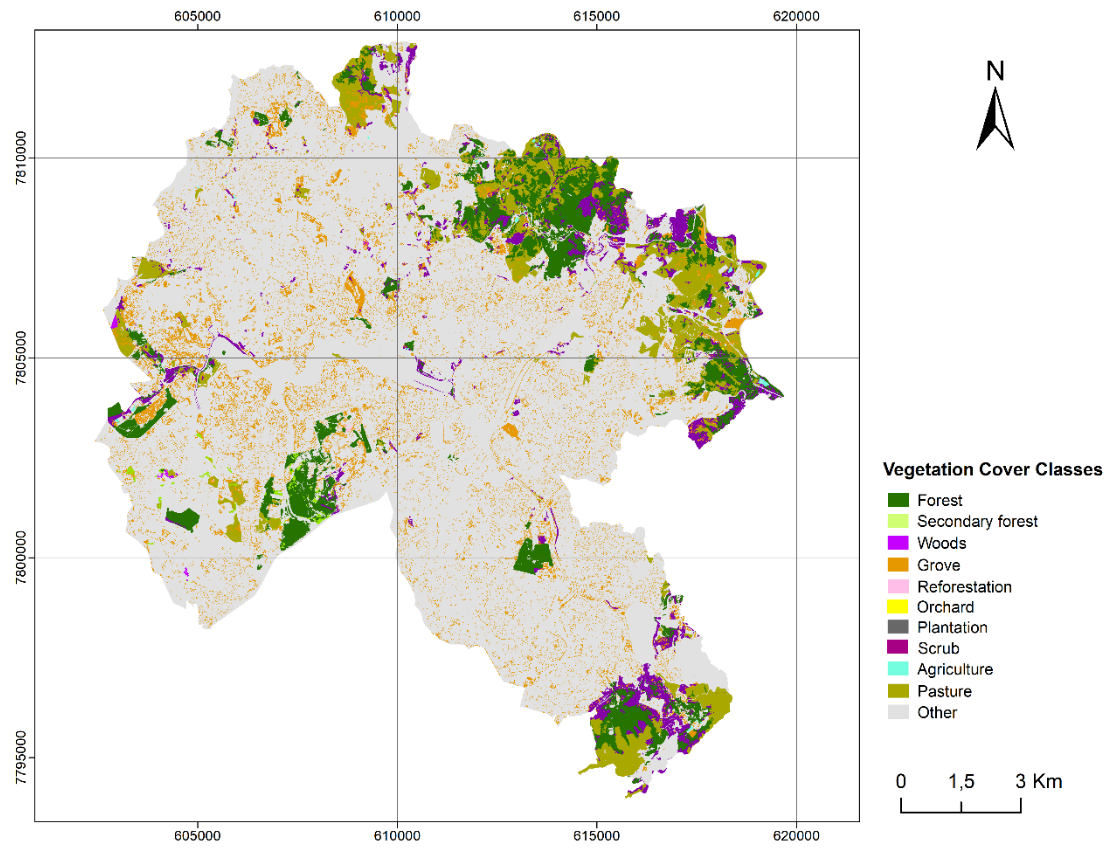

Figure 3.2: Vegetation map of Belo Horizonte (Source: PRODABEL/PBH)

Table 3.1: Land cover and use classes used in the mapping of vegetation

Land Cover and Use Classes	Definition
Forest	Forests at advanced stages of regeneration
Secondary Forest	Forests at middle and early stages of regeneration
Woods	Vegetation resulting from less dense forests, composed of spaced trees and shrubs, including savannahs
Grove	Tree clumps, including lines of trees planted along streets
Orchard	Fruit trees grown in yards
Plantation	Banana plantations
Reforestation	Plantations with exotic tree species such as eucalyptus
Scrub	Initial regeneration with abundance of invasive species and weeds, forming a dense tangled vegetation
Agriculture	Agricultural areas
Pastures	Diverse lawns and areas used for grazing, composed of grasses
Other	Urban infrastructures and water bodies

The ArcGIS 10.0 - Patch Analyst software package and its extensions (spatial analyst; cost distance) were used to design the least cost routes among the selected green urban areas related to the movement of the *R. toco*. The input data, a map of cost values, was based on a vegetation map of the northern region of Belo Horizonte (total area of 17,998.58 ha) and the designation of weights (cost/values) to each class according to a cost grid (**Table 3.2**). These values were determined based on the knowledge of some of the authors regarding the species' behavior and the literature (Perera et al. 2012).

Table 3.2: Grid used to represent the cost values of the various classes of land cover and use

Land Cover and Use Classes	Area (ha)	Cost Values
Forest	1376.05	1
Secondary Forest	0.34	2
Woods	8.67	3
Grove	1446.36	3
Orchard	0.51	3
Plantation	1.81	3
Reforestation	1.60	4

Land Cover and Use Classes	Area (ha)	Cost Values
Scrub	684.82	5
Agriculture	15.31	5
Pastures	1241.26	5
Other (Structures and Water Bodies)	13221.85	8

The composition of the grid and the relative preferences of the focal species were established based on previous studies with toucan species (Graham, 2001b, a; Santos and Ragusa-Netto, 2013). These studies indicated a predilection for arboreal habitats with wide availability of forage resources, notably larger vegetation patches. Modified landscapes composed of isolated trees had also been reported as used for displacement and foraging. Toucans also nest in hollow trunks of large trees, which is directly associated with forest cover. The established gradient of the route cost values according to the structural complexity of vegetation cover is similar to that used by Graham (2001a) in an analysis of least cost routes for another species of Ramphastidae (*R. sulfurarus*), in a region with lesser land cover classes: forest (cost 1); secondary forest/living fence (cost 2); and pasture/agriculture/water bodies (cost 3). According to this author, fruit abundance, proximity of patches and the presence of connector elements influenced the movement patterns of this toucan in the rural areas assessed.

The cost values were thus inserted based on the habitat preference of the studied species according to potential availability of food resources, presence of nesting sites and perches, predator exposure and human interference, such as poaching, noise and pollution. We considered higher quality habitats to be those exhibiting greater structural complexity of vegetation in terms of tree elements and their densities and heights, as well as the presence of fruit trees. As such, the best habitat quality, or the most structurally complex, was considered to provide a greater range of resources and less risk to the focal species, and consequently be more attractive for their breeding, foraging and dispersal. The procedures included converting the vegetation map (polygon) into a raster format, with spatial resolution of 3 meters to capture the spatial pattern of landscape elements. The cost distances map was then generated and the minimum distance between points (Euclidean distance, which is commonly used to measure structural connectivity) and between the source area and destinations, and route sinuosity, total cost and cost per kilometer, were calculated.

3.2.4. The Graph Theory Method: Relative Importance of Forest Patches for Landscape Maintenance

In recent years, several studies have addressed issues regarding functional connectivity of natural habitats and its implications for populations according to graph-theoretical approaches (Chardon et al., 2003; Urban et al., 2009; Teng et al., 2011; Kupfer, 2012). The graph generated from these concepts comprises a set of nodes, equivalent to habitat patches, connected by links, indicating the dispersal potential among habitats (Urban et al., 2009). Quantification of the functional connectivity and relative importance of green patches in the studied urban landscape was done using the public domain software CONEFOR 2.6 (Saura and Torné, 2012), with calculations based on graph theory mathematics (Urban et al., 2009; Teng et al., 2011; Kupfer, 2012). This approach relies on using graph-based metrics that measure habitat availability and accessibility at the landscape level (Luque et al., 2012).

We used the integral connectivity index (IIC) and the delta of the integral connectivity index (dIIC). The former (IIC) ranges from 0 to 1 and increases with the improved connectivity (Pascual-Hortal and Saura, 2006). With this index, general landscape connectivity is calculated from the connections within and between patches, and from the dispersion flow between habitats (García-Feced et al. 2011). The latter (dIIC) is generated for each patch and provides a representation of the most critical elements for the maintenance of landscape connectivity, without which there would be a large decrease of integral connectivity (Saura and Pascual-Hortal, 2007), thus linking the biological response of the target species to landscape structure (Baguette and Van Dyck, 2007). The vegetation map of the study region was used as input data, considering only the forest class, which consists of habitats of higher quality for *R. toco*. The distance of dispersion adopted for *R. toco* was 3,000 m, as suggested by Holbrook (2011) for species of this genus. Fragments smaller than 1 ha were excluded because of the preference of toucans for larger (5 ha to 10 ha) patches (Graham, 2001b).

3.3. Results

3.3.1. Least Cost Routes between Green Urban Areas

The resulting least cost route of greater accessibility for *R. toco* movement from the defined source (Fazenda Lagoa do Nado Municipal Park - FLNMP) towards the four different green areas located in the northern region of Belo Horizonte was the route to Isidoro Forest (IF) (**Table 3.3**). The total cost and cost per kilometer of this route were, respectively, 2.87 and 17,661. **Fig. 3.3** shows the distance cost map generated for the region. Routes to the Serra Verde State Park (SVP) and Ursulina de Andrade Mello Municipal Park (UAMMP) had similar total costs, corresponding to 29,675 and 30,258, respectively. The distance of the route found between the source area and the two parks was, however, reasonably larger for UAMMP (8,912 m as opposed to 6,239 m), but the cost per kilometer for SVP (4.76) was higher than the others.

Table 3.3: Least Cost Routes between Fazenda Lagoa do Nado Municipal Park and the four defined Destinations

Destination	Route Distance (m)	Euclidean Distance (m)	Sinuosity	Number of Cells (3x3m)	Total Cost	Cost per Kilometer
Ursulina de Andrade Mello Municipal Park	8912	7069	1.26	2602	30258	3.40
MHNJB	9855	7907	1.25	2802	37919	3.85
Isidoro Forest	6194	5336	1.16	1713	17761	2.87
Serra Verde State Park	6239	5413	1.15	1838	29675	4.76

The most costly trajectory was the one directed to the Museum of Natural History and Botanical Garden of the Federal University of Minas Gerais (MHNJB), which had a total cost of 37,919, covering the largest distance between points (9,855 m) and the second largest cost per kilometer, of 3.85. Route sinuosity varied from 1.15 (SVP) to 1.26 (UAMMP). The variables total cost and Euclidean distance, the latter a commonly used to measure structural connectivity, varied in lockstep, but cost per kilometer did not. The cost per kilometer depended upon vegetation cover and habitat distribution along the routes. Thus, the resultant functional corridors (**Fig. 3.4a**) followed pixels with higher permeability for *R. toco*, which are associated with vegetation cover and human interferences. The landscape matrix of Belo Horizonte is dominated by residential, commercial and industrial buildings, which represent the most resistant land-use type for *R. toco* flux given its dearth of natural resources.

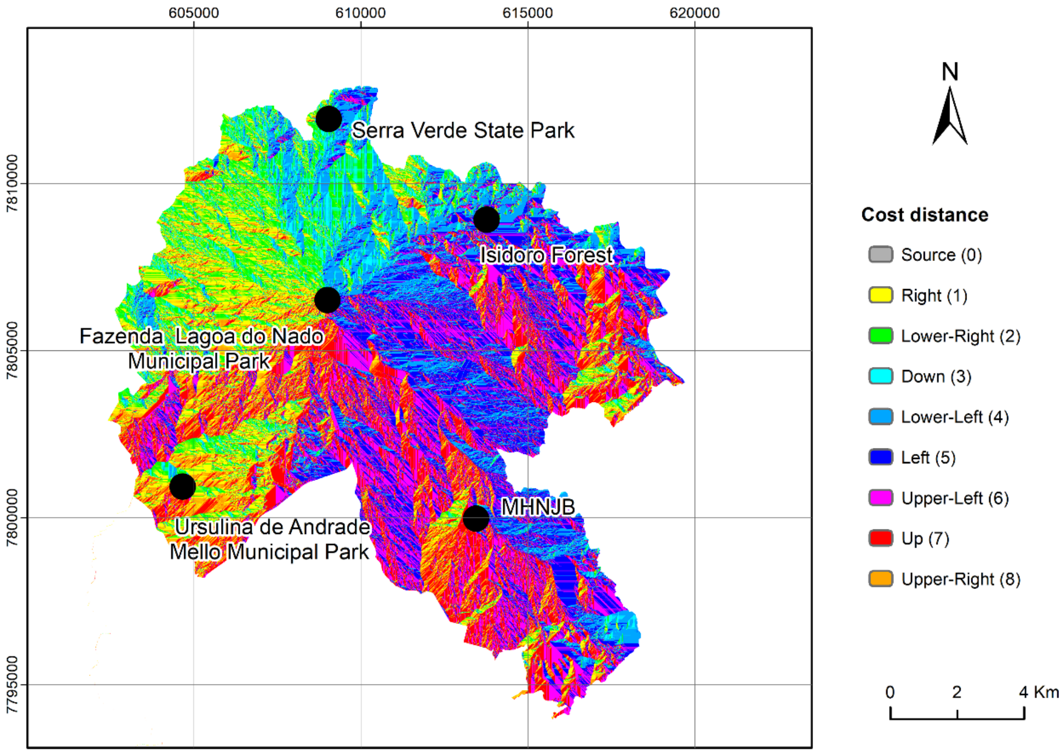

Figure 3.3**:** Map of cost distances

The initial portion of the IF route, close to the FLNMP, contained an important forest patch for the city: the 20 ha Planalto Forest (PF) (**Fig. 3.4b**). Small fragments of tree clumps (or groves that include lines of trees planted along streets), woods, orchards and pastures also occur along this route. Tree clumps were commonly distributed as small isolated patches along all routes. Forest patches were absent from the SVP route, which had a similar length to that of IF, but a higher cost per kilometer (**Fig. 3.4c**). The long route to UAMMP included the large (around 114 ha) forest patch of the Ecological Station of the Federal University of Minas Gerais (ESUFMG) (Fig. 4d). In contrast, the furthest route from the source, MHNJB, included only three minor forest patches along its extension (**Fig. 3.4e**).

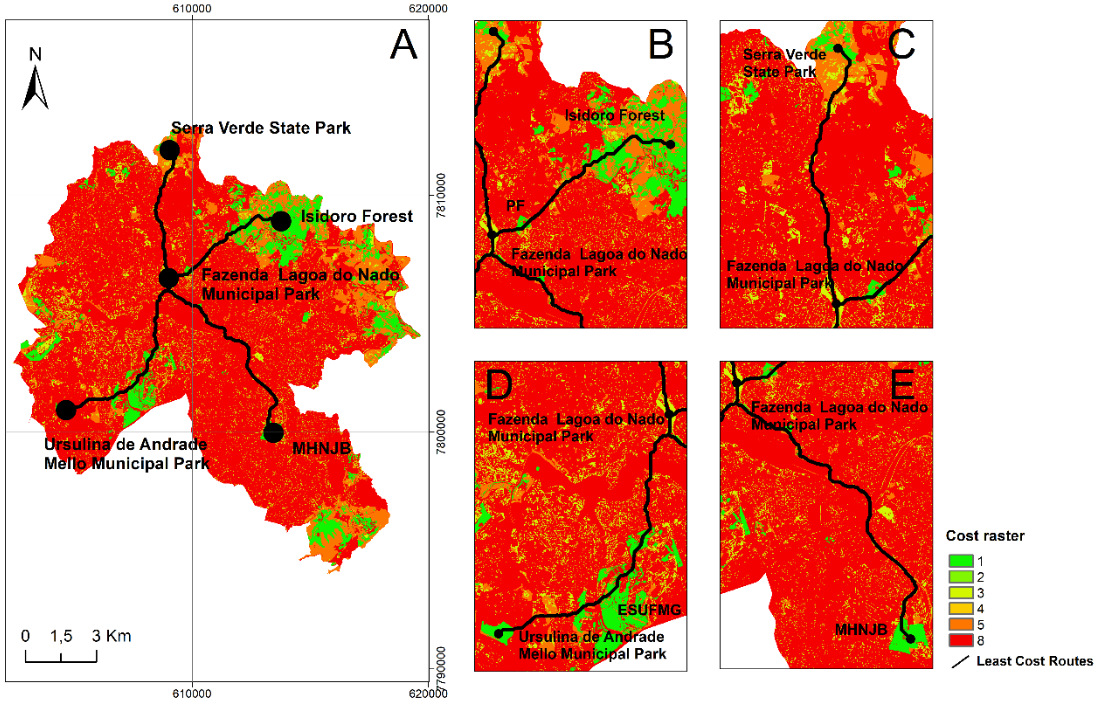

Figure 3.4**:** Least cost routes among Fazenda Lagoa do Nado Municipal Park and the four destinations in northern Belo Horizonte (A). Detail of the least cost route between Fazenda Lagoa do Nado Municipal Park and Isidoro Forest (B). Detail of the least cost route between the source and Serra Verde State Park (C). Detail of the least cost route directed to Ursulina de Andrade Mello Municipal Park (D). Detail of the least cost route directed towards the Museum of Natural History and Botanical Garden of the Federal University of Minas Gerais (MHNJB) (E)

3.3.2. Relative Importance of Forest Patches to the Maintenance of Landscape Connectivity

The IIC obtained for the urban landscape studied was 0.00 (1,18491E-11). Of all 155 forest patches in the northern region of Belo Horizonte, 131, or 84.5%, were smaller than 10 ha (**Fig. 3.5**) and 111, or 71.6%, presented areas less than 5 ha. A total of 103 forest patches (66.5%) made only a small contribution to landscape functional connectivity (dIIC varying from 0.04 to 0.66). Only eight patches, or 5.2%, stood out in terms of their contribution to landscape functional connectivity for *R. toco*, with four of them having dIIC values between 3.95 to 9.56, while the remaining patches had values ranging from >9.56 to 25.52 (**Fig. 3.6**). These patches presented areas greater than 25 ha.

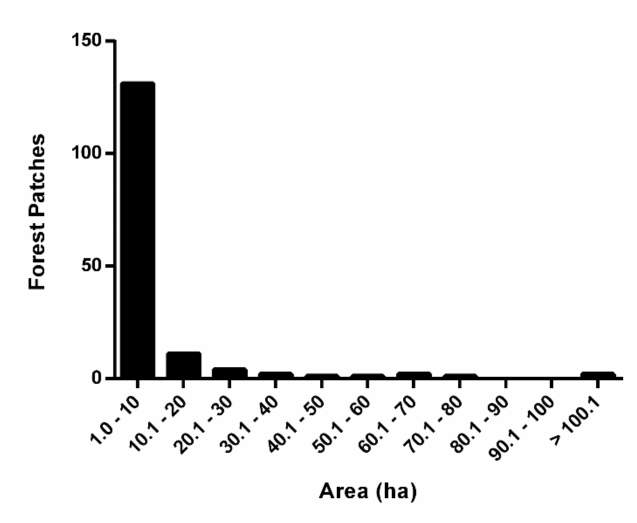

Figure 3.5**:** Size-class distribution of forest patch area (ha)

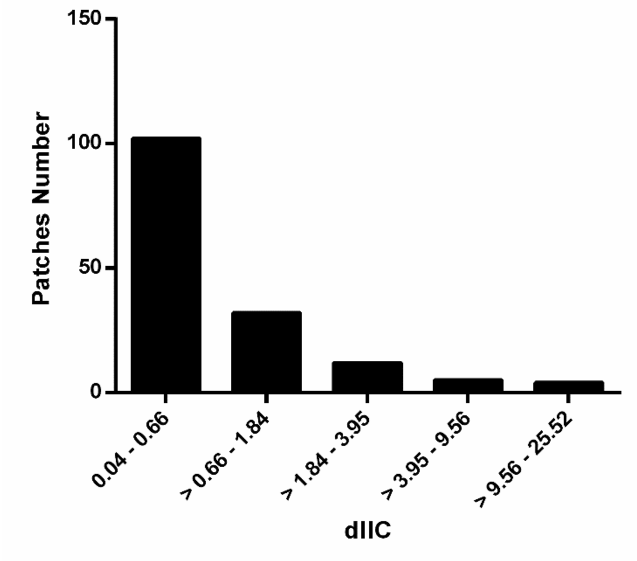

Figure 3.6**:** Class distribution of delta Integral Index of Connectivity (dIIC) values for forest patches

The patches of very high importance for connectivity maintenance (>9.56 to 25.52) were those with areas greater than 60 ha, which included four patches: three patches belonging to Isidoro Forest (with areas of 61 ha, 69 ha, and 127 ha), which had the highest dIIC values, and one patch (79 ha) pertaining to the Environmental Protection Area Fazenda Capitão Eduardo (EPACE) (**Fig. 3.7**). There was not a perfect correspondence between dIIC and patch sizes since some larger fragments had lower dIIC scores **(Fig. 3.8)**. Thus, although an area can be very important for the conservation of birds and of the plants they disperse, isolation is also a constraint, especially within such a degraded landscape.

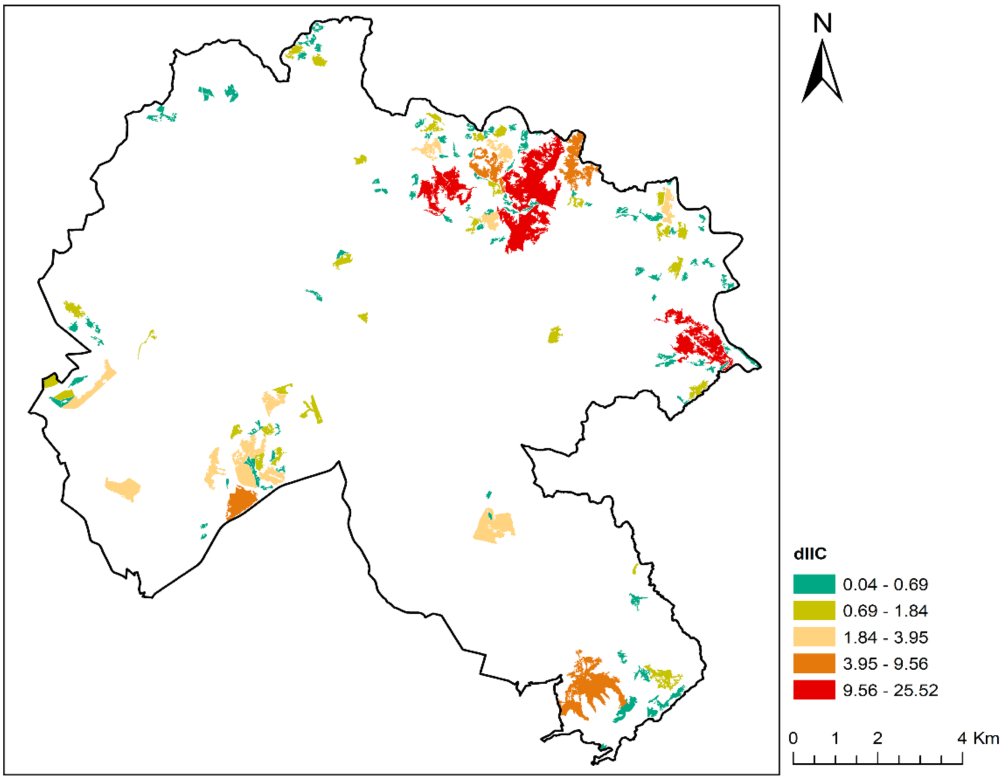

Figure 3.7**:** Spatial representation of the relative importance of forest patches for landscape connectivity. Note that in the upper portion there are three highly important (red) patches of the Isidoro Forest and to the right, one relevant (red) patch corresponding to the Environmental Protection Area Capitão Eduardo

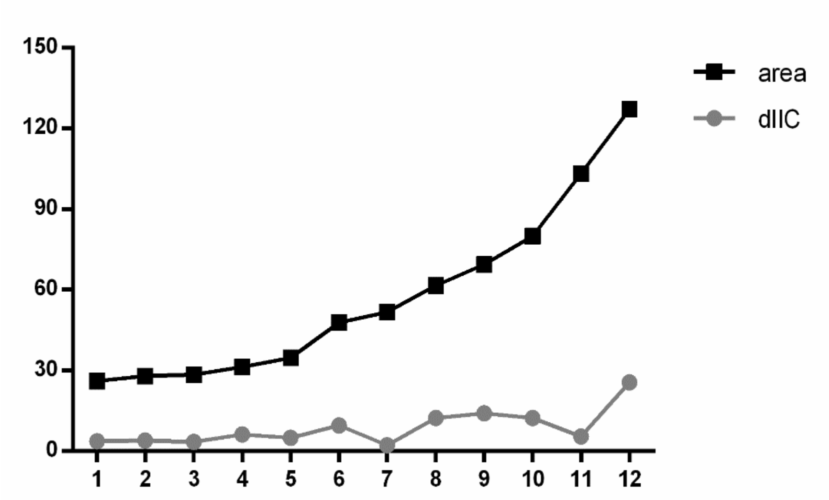

Figure 3.8**:** Variation in Delta Integral Index of Connectivity (dIIC) with area of patches larger than 25 ha (dIIC maximum = 25.52, minimum = 2.24 and average = 8.64; area maximum = 127.07, minimum = 26.03 and average = 57.42)

3.4. Discussion

3.4.1. Least Cost Routes between Green Urban Areas

Despite the uneven and sparse distribution of green urban areas in the northern region of Belo Horizonte, which is typical of Brazilian urban landscapes (Sperandelli et al., 2013), it was feasible to identify routes or functional connectivity corridors that could be used by *R. toco*. Variation in the costs of routes reflected the presence or absence of components permeable to the species' movement through the landscape. The permeability of forests was identified as greater than that of other land cover typologies which, in order of decreasing permeability, comprised: secondary forest; woodland/ grove/ orchard/ plantation; reforestation; scrub/agriculture/pasture; and structures/water bodies. This sequence of habitat permeability reflects habitat quality and the availability of food resources, as indicated mainly by the potential occurrence of fruit trees, perches and nesting sites. These parameters are typically attractive for the movements of species of Ramphastidae and are of low energetic cost and reduced predation risk (Graham, 2001a, b; Holbrook, 2011).

Feeding activity of *R. toco* in an urban area in central Brazil was found to be influenced by the abundance and the diversity of fruit species (Santos and Ragusa-Netto, 2013). These authors found that the presence of *R. toco* populations at urban sites was related to the permanent food supply provided by a variety of patches in the urban landscape and to the different fruiting patterns distributed throughout the year, since the species forages on both native and exotic species. The availability of a permanent food supply within urban areas attracts avian species and corroborates the prioritization of food resources (expressed by potential tree fruit availability and accessibility) and vegetation structure as indicators for *R. toco* movement along the least cost routes generated for the studied urban landscape.

Ramphastos toco has a variable diet (including cicadas, arthropods, young birds), but preferentially eats a diversity of fruits including both native and exotic species (Short and Horne, 2001; Goulart et al., 2011; Santos and Ragusa-Netto, 2013). A study undertaken in a Brazilian urban landscape (Santos and Ragusa-Netto, 2013), found a diet with a higher proportion of fruits of native species, especially *Cecropia pachystachia* (45%), *Inga laurina* (23%) and *Copaifera langsdorffii* (19%). Although most exotic species had fruits that were used in low proportion by *R. toco* (such as *Melia azedarach* 7%, *Morus nigra* 6%, *Carica papaya* 6%, *Schefflera* sp. 5%, *Coccothrinax barbadensis* 4% and *Levistonia* sp. 2%), two palms represented a prominent proportion of the diet: *Royostenia oleracea* (17%) and *Elaeis guineensis* (12%).

The fact that *R. toco* consumes exotic species does not confirm the dispersal of these plants, since it is necessary to test the effects of gut passage on the seeds of these species, as well as verify if there is indeed propagation and establishment of plants (Bartuszevige and Gorchov, 2006). In any case, if it is presumed that *R. toco* promotes efficient dispersal of exotic species, it is necessary that potential damage be evaluated. Among the most damaging possibilities is that *R. toco*, given its ability to travel great distances, promotes the dispersal of seeds of exotic species to forest fragments located in the peri-urban and rural regions of the city´s surroundings. In this way, *R. toco* could potentially accelerate the process of invasion and its negative implications for biodiversity conservation (i.e. decreased diversity of native species in invaded sites) and evolutionary diversification (Vilà et al., 2011).

Therefore, one problematic aspect of conserving connectivity for *R. toco* is increasing connectivity for invasive species. In the Pontal of Paranapanema, a southern landscape of Brazil, *R. toco* feeds on many exotic plants, of which *Meliza azedarach* (Goulart et al., 2011) is particularly significant because of its invasive potential, due to its fast growth being a risk to native species. Despite the significance of the risk of spreading exotic and invasive species across a landscape, we understand that the studied ecosystem is highly modified with an abundance of exotic tree species along city streets (Bueno et al., 2012; Pena et al., 2016), and in orchards, yards and gardens. Hence, the benefits of providing ecosystems services could outweigh the problems related to biological invasion, which is already underway. Otherwise, more care should be taken in conserving toucans in more native and less modified environments.

In the case of the exotic species *Royostenia oleracea*, for instance, there are consequences of its presence other than the negative points previously discussed. This species, popularly called the imperial palm tree, was brought to Brazil in 1809 by the Portuguese court and planted in the Botanical Garden of Rio de Janeiro (Oliveira et al., 2009). From this, all Brazilian imperial palms have since descended, and are widely used in urban afforestation and gardening in

Brazilian cities. In Belo Horizonte, for example, the most beautiful and privileged touristic places employ this exotic palm tree as ornamentation. Thus, other aspects of the presence of exotic species need to be considered when making decisions regarding planting specimens of exotic species in cities. Although the prioritization of native species is ideal, cultural, aesthetic and other services provided by introduced species should be taken into account. For example, Zipperer (2002) discusses the importance of exotic species in urban landscapes, including promoting many benefits and ecosystem services such as aesthetic beauty, recreational opportunities, carbon sequestration, air purification and improvement of water quality, among others. Since colonization by invasive species and the planting of exotic species are common features of urban landscapes (Niemelä, 1999), research aimed at assessing the invasive potential of species according to their demographic characteristics in areas surrounding cities and in natural sites may also help.

Another aspect to consider is the role that smaller patches play in providing connectivity as "stepping stones", which is crucial for several groups of birds (Saura et al., 2014; Herrera et al., 2017). While larger patches may be population sources and contain a greater diversity and higher abundance of resources, smaller patches play a similarly vital role in facilitating dispersal and connectivity. In this way, the landscape as a whole should be considered, including not only isolation distance and patch size, but also the amount of other habitat patches surrounding each individual patch (Fahrig, 2013). In our study area, the most common landscape feature in the routes generated was tree clumps, which, coupled with woods, orchards and pastures, compose small fragments that can be used by *R. toco* as connector elements. For urban landscapes, the availability of food resources, as previously mentioned, is known to be a major driver of the occurrence of birds (Santos and Ragusa-Netto, 2013; Tryjanowski et al., 2015). This is certainly the case for *R. toco*, which is characterized as the only toucan to prefer open areas, occupying habitats ranging from savannas, gallery forests, secondary forests, forest edges, clearings and open woodlands to scrub, plantations, groves, orchards and street trees. The species feeds singly or in small groups by exploring mainly the canopy, but also reaching fallen fruit on the ground in orchards and plantations (Short and Horne, 2001).

The functional connectivity provided by *R. toco*, due to its feeding activity and dispersal ability, to various trees species is easily achieved in our studied landscape through the route to Isidoro Forest (IF), which has the shortest distance from the source (Fazenda Lagoa do Nado Municipal

Park) and the lowest total and per kilometer costs due to the presence of relevant forest patches along its course. Although the IF route was very important for *R. toco* movement, social and legal problems and development plans of the city highlight the need for much more debate, hopefully with scientific arguments. This route encompasses areas that are involved in various land ownership conflicts plus a forest patch of 20 ha covered with forest and housing springs and streams (Planalto Forest - PF). This site is under environmental licensing for the construction of a residential condominium, and despite obtaining the preliminary license from the Municipal Environmental Council, it has remained preserved to date solely because of societal engagement with the issue (Hoje em Dia 2015a, b).

The importance of the IF route for landscape connectivity, coupled with the constant threats to its conservation and permanence, highlights the urgent need for policy reformulation and reevaluation of the city's urban plan. The regulation of use is necessary to ensure sanitary and healthy conditions for the inhabitants of the region, while establishing conservation areas based on social and ecological criteria. It is becoming increasingly necessary to adopt urban planning and management actions that take into consideration biodiversity and connectivity among green urban areas. This is further supported by the low number of notable green areas in the northern region of Belo Horizonte, which include just a few protected areas (PDDI, 2011). Furthermore, the protected areas highlighted in the present work, such as the Serra Verde State Park, possess routes with high costs per kilometer. This can also determine the selection of routes taken by *R. toco* in the southern parts of Belo Horizonte and the reduction of possibilities for establishing functional connectivity for northern locations.

Other studies of least cost routes for birds in Belo Horizonte have stressed the need for conserving and planting street trees, as well as for increasing the amount of native vegetation, thus corroborating the importance of better urban planning aimed at the conservation of urban biodiversity (Pena et al., 2017). It is evident from our results that an increase in vegetation, especially trees (involving the awareness of city planners and managers), will improve the dispersal scenario for *R. toco*. According to our results, increased and maintained focus on the use of native tree species related to local birds is imperative for urban afforestation in the city, since this measure can improve the flow between source areas, especially when there is no directed planting along public streets. However, cultural, aesthetic and other ecosystem services, as well as the invasive potential of exotic species, must be discussed, considered and inserted in decisions regarding the species to be used.

3.4.2. Relative Importance of Forest Patches to the Maintenance of Landscape Connectivity

The integral index of connectivity (IIC) was very low for the landscape considering the expected limits of 0 and 1 (Saura and Torné, 2012). In calculating the index we assumed a maximum dispersal distance of 3000 m (Holbrook, 2011). The overall low connectivity of the studied landscape indicates high inter-patch isolation, even considering the strong dispersion ability (expressed through dispersal distance) of *R. toco*. Moreover, the dominance of smaller patches (less than 5 ha), further indicates weak intra-patch connectivity that contributes to the low index.

The relative contribution of forest patches to the connectivity of the studied urban landscape was uneven, with low dIIC values for the majority of the patches and, consequently, low relative importance. The prominence of some patches indicates the need for adopting special conservation measures for them. Although larger patches possessed dIIC values, not all of them followed the same trend, which means that larger areas are not always the most suitable for conservation, whereas configuration and isolation are of utmost importance.

In the studied landscape, the Environmental Protection Area Fazenda Capitão Eduardo (EPACE) comprised a forest patch with major importance for functional connectivity. The area, however, is also under conflict of interests, with the city hall recently repealing legislation concerning the creation of the protection area through law project 2152/15. The goal now is to transform the area into a residential development for low income people, as part of the federal program "My House, My Life" (Hoje em Dia, 2015c; ALMG, 2016). In a contradictory manner, the project would displace to this site the already vulnerable population living at the Isidoro Forest (IF) settlement.

The major importance of IF to landscape connectivity, as shown by it having one of the highest dIIC values, reiterates the need for a reevaluation of the expansion projects foreseen for the northern region of Belo Horizonte with the incorporation of ecological knowledge coupled with social evaluation for the establishment of conservation measures for vegetation remnants.

Although the importance of public policies that stimulate biodiversity protection and prioritize education and citizenship awareness is acknowledged, such initiatives are scarce in developing countries, resulting in a continued absence of environmental awareness (Pauchard et al. 2006). The occurrence of various development projects that threaten biodiversity protection by overlapping with areas of high importance for the conservation of connectivity in northern Belo Horizonte agrees with Herzog (2013), who emphasized the neglect of natural ecosystems in the Brazilian urban context. The city's overall sustainability — considering the consumption and loss of ecosystems, equal access to resources, a diverse economy based on solidarity, incentive for the wellbeing of people, among others — has thereby been postponed (Shen et al., 2011). Still, the urban sustainability that is so desired will only be reached with the proper placement of natural biological components, coupled with human and social issues, in the urban planning decision making process.

We selected an avian species that is extremely vagile, and thus is far less constrained by inter-patch distance than many other species with lower dispersal ability. For instance, forest interior passerines are incapable of crossing several hundred meters of open habitats (Stratford and Stouffer, 1999; Hansbauer et al., 2008; Marini, 2010). Our model cannot be applied to such specialist and fragile species. Nevertheless, most of these species have disappeared and been absent from most of the forest patches, and especially from regions of the urban matrix, for decades or centuries (Christiansen and Pitter, 1997; Rodrigues and Goulart, 2005). Therefore, we chose to focus on a more generalist species that inhabits the landscape at a density that can effectively provide ecosystem functioning.

3.5. Conclusion

The study of functional connectivity among green urban areas using *R. toco* as a focal species generated information on least cost routes and the relative importance of forest patches for connectivity in a city in southeastern Brazil. Our findings can contribute to improved urban planning that takes into consideration the maintenance of biodiversity through the feasibility of functional connectivity among green areas.

Our study area exhibited low overall integral connectivity with the occurrence of just a few patches relevant to connectivity, which emphasizes the value of some areas subjected to land use and planning conflicts. The purposes behind various development projects in the region aimed at urban sprawl and residential development need to be reevaluated, and consideration given to the prioritization of green areas and their incorporation into city policies, given the fragility of sites and the potential for significant losses to connectivity, biodiversity and quality of life.

Although an approach that contemplates multiple species is more attractive to the purposes of planning rural landscapes, the species *R. toco*, given its adaptive characteristics, extensive plasticity, wide range of movement and effective dispersal of tree species, is an important indicator species of functional connectivity of urban environments, where not all species of fauna are welcome. The combination of the two landscape connectivity methods (least cost routes plus relative importance of forest sites for functional connectivity) proved to be a powerful tool and approach for environmental planning in cities where development and expansion are a constant part of the dynamics.

3.6. References

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FINAL CONCLUSION

1. Conclusion

The governance of urban areas, particularly in South America, has strong impacts on human well-being and public health, on key issues such as greenhouse gas emissions, disease transmission and epidemics (such as dengue, zika) and on the use of resources at the global level. Once built, it becomes difficult to change a city in a substantial way. In many developing countries around the globe, cities run the risk of being restricted for many decades in urban development models that consume a large amount of energy and resources, putting at risk the sustainability of the planet. Recognizing the scale of the problem in an increasingly urbanized world, countless institutions are leading globally initiatives to create transitions to sustainable cities. In Belo Horizonte, a large city of southeastern Brazil, efforts have been made to enhance aspects of urban sustainability through the city's participation in movements and councils. One of these global initiative group is the New York-based International Council for Local Environmental Initiatives (ICLEI). ICLEI develops programs and campaigns that address local sustainability issues and protect common local assets such as air quality, climate and water. However, several important urban features and characteristics for improving the availability of green infrastructure and ecosystem services have not yet been included in this scope, such as vacant lots and the scarcity of conserved areas in regions under pressure to expand.

In this sense, the research topics presented in this thesis intended to reduce these gaps. These topics shared the same purpose of proposing appropriate methodologies for the assessment of vacant lots and green infrastructure of the city of Belo Horizonte and of subsidizing urban planning policies aimed at sustainability. In Chapter 2 we combined land cover mapping of vacant lots using vegetation quality categories that made it possible to verify a diverse land cover and the predominance of moderate vegetation quality lots, mainly composed of herbaceous-shrubby vegetation. In the case of the clusters of the land cover patterns, the results generated in Chapter 2 indicated also an expressive representativeness of lots composed of tree clumps and native vegetation able of benefiting the city population by providing ecological functions and regulating and supporting ecosystem services such as: water infiltration and storage, microclimate regulation, air purification and filtration, carbon sequestration and storage, soil conservation, habitat provisioning, biodiversity conservation. All this information generated can contribute to the formulation of actions and public policies aimed at urban sustainability. The studies presented in Chapter 3, based on the use of a methodological combination including regression statistical models and regression trees, showed that the landscape patterns of vacant lots are mainly defined by the area and distance related metrics of the vacant lots. These metrics in turn respond mainly to the socioeconomic factors population density and number of protected areas in the 1500 m perimeter. We unveiled that there are vacant lots of different vegetation qualities with shorter distances - between them and between lots and protected areas - in neighborhoods with larger number of protection areas. This condition denotes a positive configuration regarding the structural connectivity, which may benefit elements of urban biodiversity. In addition, lots of high vegetation quality tended to be distributed at closer distances, but in neighborhoods with low number of protected areas, which may emphasize the importance of these parcels in terms of expansion of preserved green areas in the city. There was also an indication that vacant lots tend to cluster more in areas with higher population density, but with smaller areas and consequently with a smaller total core area. Thus, Chapter 3 also presented a research with policy ramifications as some vacant lots spatial configurations - resulting from associations between landscape patterns and socioeconomic factors in the neighborhoods of the plots - showed to be of relevance to the design of sustainability-focused urban planning.

Chapter 4 focused on the least-cost routes or those preferred and most likely to be used by the bird touco toucan or tucanuçu (*Ramphastos toco*) to move and disperse in the northern region of Belo Horizonte, through the most expressive fragments of vegetation in this region. The bird species was chosen as an indicator because of its effectiveness in the dispersal of tropical plant seeds and its adaptive and highly plastic characteristics, with a wide range of displacement, thus facilitating its movement in urban areas. Therefore, the study considered that the movement of tucanuçu through several green areas of the city may increase functional connectivity between patches of vegetation, providing dispersal of tree plant species and increasing gene flow and genetic diversity between areas. The results can be summarized as: low integral connectivity in the studied region; the occurrence of few forest patches relevant to connectivity; areas of importance for ecological connectivity in the northern region - such as Mata do Isidoro, Mata do Planalto and Capitão Eduardo's Environmental Protection Area - under threat of deforestation and disappearance. Therefore, given the various development projects for this region - aimed at urban expansion, the establishment of allotments and residential buildings - the studies point to the need to reassess these purposes and define the protection of areas of ecological relevance, considering the fragility of the region and future impacts and significant losses in terms of connectivity, biodiversity and quality of life. All this information, as well as the methodological combination used (least-cost routes plus importance of forest patches in the region for functional connectivity) can contribute to improvements in public policy and urban planning that consider the maintenance of biodiversity by enabling connectivity between areas.

The studies fulfilled both the objectives specific to each topic, focused on landscape patterns and spatial assessments of vacant lots and vulnerable green areas of the northern region of Belo Horizonte, as well as the proposition of using different methodological combinations of assessment. Different spatial tools and methodological approaches were used in the studies to allow the characterization of urban vacant lots and green areas in their ecological and socioeconomic dimensions. An integration of the ecological and socioeconomic aspects of the vacant lots coupled with the evaluation of green vulnerable areas and ecological indicators were performed. All information generated in this process is made available here for the incorporation of vacant lots and ecological indicators into the governance strategies for the sustainability of the municipality. In addition, the whole framework of methodological combinations adds diverse possibilities of approaches to the existing research universe in the topics covered. The study can thus support the establishment of pilot plots in the city for various purposes, which may include, among others, educational, research, economic, and socio-ecological actions. Deciding on the best actions to be implemented will certainly require conversation and prior understanding with the locals through participatory approaches, to understand how they envision the uses of these sites and to engage them. The fact that most lots are privately owned will require the establishment of conversations, agreements and negotiations with the owners. Although the characteristics of the lots indicate that a socio-ecological approach can bring many benefits to the city and its inhabitants, the economic aspects associated with diverse uses and housing needs are of great importance in many regions of the city. This importance can be corroborated by the study done by Horta et al. (2018) relative to variations of people´s views on vacant lots, their characteristics and multiple uses, in two different economic contexts in the city of Belo Horizonte: in an upper-middle-class neighborhood with higher income family and in a popular middle-class neighborhood of lower income. Although many similarities were observed in the views of respondents in the two neighborhoods, in the lower income neighborhood there seemed to be an interest in the immediate use of the vacant lots and choices of multiple uses such as “build something commercial” and “build house” appeared among the first preferred in the answers. For the wealthier neighborhood more ecological uses replaced those choices in the first positions, such as “build a vegetable garden” or “plant a garden”. Thus, the present study and further research that integrates ecological, political and socioeconomic issues can assist in outlining urban planning guidelines and decisions that include the benefits of transforming vacant lots and urban vegetation. In general terms, what has been evidenced is that the combined use of ecological data, socioeconomic information, as well as the spatial analysis and modeling of ecological processes can help to understand processes of loss and gain of ecological services and help in sustainable policy design.

2. Contributions from the Thesis

The publications generated during the doctorate and the preparation of the thesis are cited below.

Article

Horta MB, Bhakti T, Cordeiro PF et al (2018) Functional connectivity in urban landscapes promoted by Ramphastos toco (Toco Toucan) and its implications for policy making. Urban Ecosystems 21:1097-1111. https://doi.org/10.1007/s11252-018-0789-z

Book Chapter

Horta MB, Cabral MI, Pires I et al (2018a) Assessing urban ecosystem services: different methodological approaches applied in Brazil, Germany, and Portugal. 8 In: Rosa IS, Lopes JC, Ribeiro R, Mendes A (eds) Handbook of Research on Methods and Tools for Assessing Cultural Landscape Adaptation. Engineering Science Reference pp183-220

Book

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Lecture

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3. References

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