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ECOSYSTEM SERVICES AND URBAN VEGETATION COVERAGE IN BELÉM:
the influence on noise pollution, air pollution and climate regulation

Belém – Pará
2013

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Dissertação apresentada para obtenção do grau de Mestre em *Gestão dos Recursos Naturais e Desenvolvimento Local na Amazônia*. Núcleo de Meio Ambiente. Universidade Federal do Pará.
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“A maior criação da humanidade foi suas cidades. Elas representam a extrema realização de nossa imaginação enquanto espécie, atestando nossa capacidade de reformar o ambiente natural das maneiras mais profundas e duradouras”.

Joel Kotkin

ABSTRACT

The ties between urban areas and environmental issues are growing as strong as the global awareness of the need to conserve, improve and valorize the ecosystem services provided by nature, in order to ensure the sustainability of life in and outside cities. Green vegetation coverage (or green areas) is one of the major sources of such services. Considering that there is no turning back on urbanization process, and the urban environmental problems are on the rise, the urban green areas should be among the elements that influence urban life quality. As a result of the urbanization process, the city of Belém has lost a great percentage of its natural ecosystems. This work focused at analyzing ecosystem services (air quality, air pollution and climate regulation) provided by local vegetation coverage quality and quantity, considering the spatial distribution and temporal changes on three administrative districts. A theoretical framework was built and assessed while vegetation coverage was calculated using NDVI and Fractional Vegetation Coverage on LANDSAT 5 imagery over a 23-year period. Owing to a more detailed scale, NDVI enabled conducting the quantitative and qualitative analyses of vegetation coverage, which showed significant loss of very dense, dense and moderate vegetation coverage and an increase in poor vegetation and bare soil areas. In addition, the study findings revealed increased noise pollution, decrease in air quality and increase in temperature, all resulting from changes in natural coverage. The significant lack of environmental data leaves no doubt about the urgency of investing on vegetation coverage for the urban sustainability in Belém, given that both actual and forecast scenarios indicate drastic green area losses. Hence, more research and both public and private initiatives are encouraged to contribute to the development of Belém ecosystems services and contribute to the enhancement of public well-being.

KEYWORDS: Ecosystem services, environmental services, urban area, vegetation coverage, green coverage, green area, urban sustainability.

RESUMO

A ligação entre as zonas urbanas e as questões ambientais ficam mais próximas na medida em que cresce a conscientização global de conservar, melhorar e valorizar os serviços ambientais prestados pela natureza para a sustentabilidade da vida, dentro e fora da cidade. Cobertura vegetal (ou cobertura verde) está dentre as principais fontes de tais serviços. Uma vez que o processo de urbanização se mostra irreversível e os problemas ambientais urbanos se alastram em tamanho e extensão, a presença do verde está diretamente relacionada aos indicadores de qualidade de vida urbana. Como reflexo do processo de urbanização, a cidade de Belém perdeu uma grande porcentagem de seus ecossistemas naturais, de modo que este trabalho se concentrou em analisar alguns serviços ecossistêmicos—qualidade do ar, poluição do ar e regulação do clima - fornecidos pela qualidade e pela quantidade de cobertura vegetal local, considerando as alterações na distribuição espaço-temporal, em três distritos administrativos. Um marco teórico foi construído e analisado; a cobertura vegetal foi calculada, utilizando-se NDVI e Cobertura Vegetal Fracional em imagens do LANDSAT 5, ao longo de um período de 23 anos. A partir de uma proposta de escala mais detalhada de NDVI, análises quantitativas e qualitativas da cobertura verde evidenciaram perda significativa de cobertura muito densa, densa, moderada e aumento de áreas de pouca ou nenhuma vegetação. Ademais, lesão das áreas verdes sinalizou tendências de aumento da poluição do ar, da poluição sonora e da temperatura. A carência de dados relacionados ao meio ambiente não deixa dúvida sobre a urgência de investimento nos serviços ambientais provenientes da cobertura vegetal, para a sustentabilidade urbana em Belém, cujos cenários previstos são de drásticas perdas de área verde. Mais pesquisas e iniciativas de instituições públicas e privadas são necessárias para a contribuição aos serviços ambientais em Belém e, consequentemente, ao bem-estar público.

PALAVRAS-CHAVE: Serviços Ambientais, áreas urbanas, cobertura vegetal, áreas verdes, cobertura verde, sustentabilidade urbana.

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ABBREVIATIONS AND ACRONYMS

	English	Portuguese
CAP	Central Arizona-Phoenix	Centro Arizona-Phoenix
DABEL	Administrative District of Belém	Distrito Administrativo de Belém
DAGUA	Administrative District of Guamá	Distrito Administrativo do Guamá
DASAC	Administrative District of Sacramenta	Distrito Administrativo da Sacramenta
Dba	A-weighted decibels	Medida do Ruído relativa a decibel
EMBRAPA	Brazilian Agriculture Research Corporation	Empresa Brasileira de Pesquisa Agropecuária
EU	European Union	União Europeia
FADESP	Research Support and Development Foundation	Fundação de Amparo e Desenvolvimento da Pesquisa
GDP	Growth Domestic Product	Produto Interno Bruto
IBGE	Brazilian Geography and Statistics Institute	Instituto Brasileiro de Geografia e Estatística
IDESP	Economic, Social and Environmental Institute of Pará	Instituto de Desenvolvimento Econômico, Social e Ambiental do Pará
INPE	National Space Research Institute	Instituto Nacional de Pesquisa Espacial
INMET	National Institute of Meteorology	Instituto Nacional de Meteorologia
LWIR	Long wave infrared	Infravermelho longo
MA	Millennium Assessments	Avaliação do Milênio
MMA	Ministry of the Environment	Ministério do Meio Ambiente
NASA	National Aeronautics and Space Administration	Agência Aeroespacial Americana
PDU	Belém Director Plan	Plano Diretor de Belém
RMB	Belém Metropolitan Region	Região Metropolitana de Belém
PMB	Belém Municipal Government	Prefeitura Municipal de Belém
PROCONVE	National Program for Controlling Air Pollution Caused by Vehicles	Programa Nacional para Controle da Poluição do Ar por Veículos
SWIR	Short wave infrared	Infravermelho onda curta
UHI	Urban Heat Island	Ilha de Calor Urbano
UM	United Nations	Organização das Nações Unidas
VOC	Volatile Organic Compounds	Compostos Orgânicos Voláteis
WHO	World Health Organization	Organização Mundial de Saúde

SUMMARY

1 INTRODUCTION

The Brazilian Amazon occupation process during 1960s and 1970s, sponsored by government policies, was established mostly based on a model of intensive and exponential exploitation of natural resources. Such process directly affected local environment, rapidly generating unbalanced outcomes for both natural ecosystems and socioeconomic relations.

This same scenario caused the Amazon region to occupy a prominent place in global debate on the planet's future, as well as led to its status of environmental "sanctuary". However, very often, these debates did not take into account the population (almost 16 million) and their needs (INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA, 2012). Locals have played a key role in the past environmental changes in natural ecosystems and, for obvious, reasons still do in the present. The natural resources have been exploited to the point of destroying countless ecosystems in the Amazon and, in spite of the global awareness, the situation has not changed much. However, local population also holds the key to the future of Amazon. Forest and human coexistence must outline the relations between humankind and the environment, for our long-term survival depends on a successful symbiosis. Protection and preservation will ensure the future for the generations to come and will sustain life on Earth. Indeed, sustainability should be the word that best describes this connection that must also take into account social, economic and cultural development.

The concept of sustainable development appeared in the Brundtland Report[1] with a purpose to reconstruct the vision of environmental issues, where conservation and biodiversity use are linked as inseparable. Fenzl and Machado (2009) claim that sustainable development is more than a "late twentieth century intellectual fad, but instead the result of consciousness over the serious environmental and socioeconomic problems that humanity is facing," where the planet's limits are being perceived by social forces worldwide. Consequently, sustainable development can be in some ways considered a *counter-concept* to the extent that it arises as an

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[1] Formally known as *Our Common Future*, the report was produced by United Nations Environment Commission and was published in 1987. Its contents confront the exploratory development model applied by rich nations and widely replicated in developing countries, where the use of natural resources does not consider the carrying capacity of ecosystems. The report also affirms that sustainable development concept is not compatible with the consumption basis and production patterns that currently dominate the planet (United Nations, 1987).

antithesis of an economic and social development of the planet, which is perceived as unsustainable.

The future of Amazon region is inextricably linked to the sustainable use of its remaining natural resources, to the protection and recovery of degraded areas and to the equilibrium between urban and rural coexistence.

In most current concerns and debates, the issue of climate change as critical to Earth's survival is responsible for expanding the strategic role of the Amazon region in all spheres—local, national and international. There is a notable redirection of approaches for environmental preservation, where global and public goods classify biodiversity, rather than the irrational and unsustainable use of natural resources. This horizon calls for protection and appraisal of services provided by the nature.

Such services are present everywhere. At a first glance, nature's services could commonly be linked to forest environments, or to surroundings dominated by natural biomes. Of course, areas dominated by nature are characterized by the highest amount of services provided. However, this does not exclude the increasingly crowded urban areas—an example of a human creation that significantly alters natural geography.

Humanity is expanding its outreach at a fast pace. World population just reached 7 billion; it is expected to rise to 8 billion people by 2030, and 9.3 billion by 2050 (UNITED NATIONS, 2012) (Table 1). Moreover, by 2050, urban population will reach 69% of the total population (Graph 1). The historical process of human settlement dates back from the abandonment of nomadic roots and has culminated to spaces now called "urban". The accelerated population growth directly leads to the cumulative concentration of people in certain areas and therefore causes urbanized areas to expand (KOTKIN, 2012).[2]

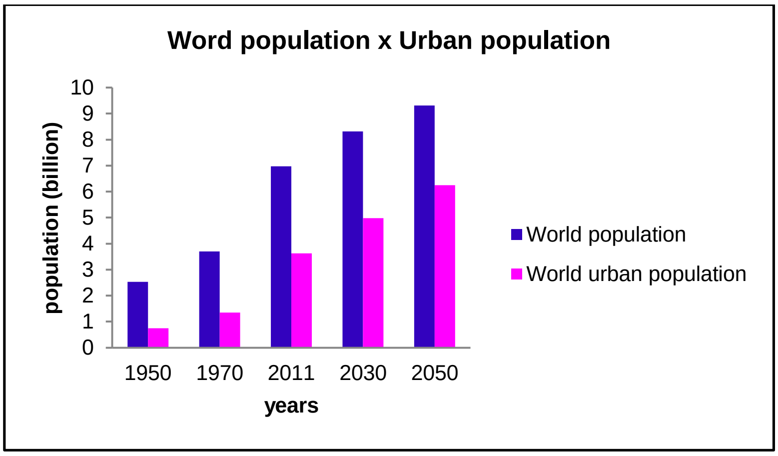
[2] The end of Ice Age, around 7000 BC, was marked by the development of agriculture and animal husbandry, allowing humans to lead not only a more sedentary lifestyle, but also causing higher population concentration around living spaces, which became centers for craft and activities. The most advanced villages or settlements became the "*proto-cities*" (KOTKIN 2012).

Table 1 - Total urban and rural populations by development group 1950-2050.

	Population (billions)				
	1950	**1970**	**2011**	**2030**	**2050**
Total population					
World	2.53	3.70	6.97	8.32	9.31
More developed regions	0.81	1.01	1.24	1.30	1.31
Less developed regions	1.72	2.69	5.73	7.03	7.99
Urban population					
World	0.75	1.35	3.63	4.98	6.25
More developed regions	0.44	0.67	0.96	1.06	1.13
Less developed regions	0.30	0.68	2.67	3.92	5.12

Source: United Nations (2012).

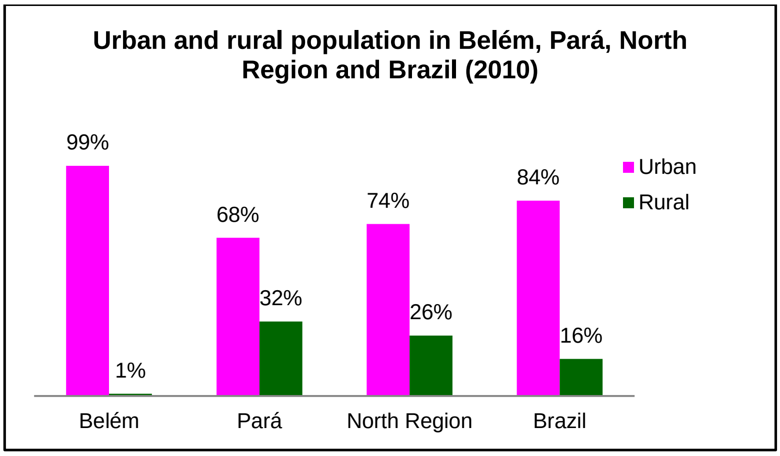
Graph 1 - World urban and general population.



Source: United Nations (2012).

High population density in urban areas is a reality in Brazil as well, where 84% of the population lives in urbanized zones. Even in the tropical rain forest of the Amazon region in Brazil, 74% of inhabitants are urban. The state of Pará, one of the states of the Brazilian Amazon, is a clear example of this process, where more than 68% of the residents live in cities. The capital, Belém accounts for 99% of urban population (INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA, 2012) (Graph 2). The urbanization process and pressures unify spatial clusters denominated as metropolitan areas. Owing to the constant growth pace, areas covered by these urban agglomerates are often extended, absorbing and incorporating adjacent zones, in a continuous movement that keeps on dilating urban areas.

Graph 2 - Urban and rural population of Belém, Pará, North Region, and Brazil in 2010.



Source: IBGE (2012).

Environmental issues specific to urban sites also tend to expand in size and numbers along with the city growth. They can be as diverse as the different surroundings in which people settle in, indicating that environmental concerns also correlate to urban and highly anthropized areas. In addition, no matter how far from the forest, human well-being is strongly dependent on nature and on the services it provides at all times and places, including cities. Thus, the role of ecosystem services in the maintenance of urban life is vital, given that the quality of the environment is strongly linked to the presence of natural ecosystems and the services they provide. Among the natural elements that deliver ecosystem services, urban trees and green areas, particularly in a tropical region, are most multi-functional and contribute in both quantity and intensity of services.

Bolund (1999) identifies seven different urban ecosystems called “natural” in spite of human presence and manipulation: street trees, lawns/parks, urban forest, cultivated lands, wetlands, lakes/sea and streams. Vegetation and flora is certainly present in almost all of them, clearly associating their existence to the provision of most ecosystem services in urban environment.

After three decades of demographic hibernation due to the ending of *golden rubber cycle,*[3] Belém’s population increased exponentially, as evident in the 134% growth in the 1960s and 1980s, finally reaching almost one million people. The growth continued on a steep rate, reaching around 66% in the last thirty years, which can be

[3] *Ciclo dourado da borracha* or golden rubber cycle refer to the prosperous times experienced by Belém, because of international latex trade. It started around the second half of century XIX and lasted until 1920s (CORRÊA et al., 2005)

explained primarily by the urge of public policies to consolidate urban hubs while attracting and concentrating strategies to valorize the region. As a result, the state capital concentrated labor forces, capital, goods, public services and information with the goal of achieving development through modernization policy. Unfortunately, the promise of “development” came before its accomplishment. As a result, significant number of people was attracted to the region from neighboring counties. Still, the city grew without the required public and private investments on infrastructure, urban planning, social and economic efficient policies (INSTITUTO DE DESENVOLVIMENTO ECONÔMICO, SOCIAL E AMBIENTAL DO PARÁ, 2011; MITSCHEIN, 2006).

Since urbanization and loss of primary vegetation coverage cannot be viewed separately in the Amazon context, it is most logical that Belém’s vegetation coverage[4] and even its urban trees have already suffered significant loss. After analyzing a 40.2 km^2 of land, Brazil (1995) estimated that on average there were 64.85 trees per square kilometer, which is considered low for the local characteristics. Nearly a decade later, Paranaguá et al. (2003) affirmed that, in the last 15 years, 17% of green coverage was lost in the Great Belém[5] as a result of accelerated urban growth, lack of planning and land use rules. Later, Leão et al. (2008) indicated a loss of 69% of original green coverage in the RMB from 1986 to 2006. Ferreira et al. (2012) also indicated a high deforestation rate in Great Belém, varying from 51% in Belém to 67.2% in Benevides, providing evidence that continental deforestation in Belém is much greater than insular (87.5% against 32.6%).

While each of the studies cited above utilized their own methods of measuring and assessing vegetation coverage, their findings still provide evidence of vegetation coverage loss in Belém and their results point at major damage of green area in Belém and its metropolitan surroundings. However, these studies focused on quantitative vegetation coverage, and do not assess the quality of the green areas lost. Moreover, they fail to indicate the quality of the remaining vegetation and do not mention any particular ecosystem service provided by urban trees and vegetation in general.

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[4] There is still a lack of consensus on the terms vegetation coverage, green coverage, green area and urban forest. This work will treat them as synonyms.

[5] Great Belém or Belém Metropolitan Region (RMB) refers to the cities of Belém, Ananindeua, Marituba, Benevides and Santa Bárbara, which form one of the major metropolitan areas in the Brazilian Amazon.

In the urban scenario, vegetation coverage changes can take place gradually, owing to the urbanization process and pressures. When natural ecosystems are destroyed, ecosystems services decrease at the same rate. Thus, classifying Belém green areas and providing detailed information on their development over the years, explaining where and how their loss took place, and evaluating the remaining coverage, will hopefully help to understand, diagnose and provide instruments to act toward recovering urban green areas and protect the existing ones. That will allow deriving the benefits from the ecosystem services provided by such environments—the key to urban life sustainability.

Original ecosystems are shrinking all over the Belem Metropolitan Region (RMB). According to Mercês (1997), LANDSAT images were used to attest expressive vegetation loss in 1997, in comparison to images from 1986. Leão et al. (2008) affirms that Belém lost 36.5 km² of its urban forest between 1986 and 2006. Rodrigues and Luz (2007) also report on vegetation coverage reduction.

In addition, the latest study identified as an inventory (although partial) of Belém urban forest that dates back to 1995 also affirms that general conditions of Belém urban trees were considered poor, as 82% of those assessed were infested, 50% had deformed canopies, 85% had trunk deformities and 55% suffered exposed rooting. Moreover, the irregularity on trees resulted from lack of urban planning, including maintenance and replacement of trees (BRASIL, 1995).

The connection between urban planning and environment has already been established and studied in Brazil and in Belém. The findings of various studies of this type revealed the importance of urban green areas to Belém's sustainability (HARDER; RIBEIRO; TAVARES, 2006; LIMA; FONSECA; ARAÚJO, 2011; NASCIMENTO, 1995; ROSSET, 2005). Therefore, it is evident that the interface between urban space and environmental services of vegetation coverage within the city of Belém must be recognized in academic discussions and reflected in public policies.

Cities are a reality of humankind. Thus, they could represent a solution to the environmental crises, as high concentration of people in certain areas could be seen as a synonym to more efficient land use and energy production, as well as a sign of more effective exploitation of natural resources and improved ecosystem conservation (DAVIS, 2006).

Undoubtedly, the influential role of urban environments and their consequences on local, surrounding, regional and global scale cannot be underestimated. Cities will continue to grow in size and number. This also applies to the Brazilian Amazon and Belém—one of the largest urbanized conglomerates that must find the balance between the land occupation and demographic concentration and healthy urban environment.

2 HYPOTHESES

In the context presented above, the following hypotheses are proposed, guiding the present study:

a) Three central administrative districts in Belém have been experiencing loss of urban vegetation coverage in the past two decades;

b) Part of Belém is also experiencing a loss of ecosystem services provisioning in the past two decades;

c) In the past two decades, in three administrative districts of Belém, there has been a direct link between ecosystem services and vegetation coverage, in particular with respect to air and noise pollution and climate regulation.

3 OBJECTIVES

This chapter presents the objectives that this study will aim to achieve, categorized as one main aim and three general ones, which will contribute to fulfilling the proposed general goal.

3.1 General Objective

Analyze ecosystem services (noise pollution, air pollution and climate regulation) provided to the local population by urban vegetation coverage in three districts of the municipality of Belém (state of Pará, Brazil), considering the heterogeneity of such coverage, the spatial distribution, and temporal changes.

3.2 Specific Objectives

a) Establish relevant connection between urban ecosystem services and green areas/green coverage;
b) Identify the spatial and temporal distribution of vegetation coverage areas in three administrative districts of the municipality of Belém, Sacramenta (DASAC), Belém (DABEL), and Guamá (DAGUA), during 1986, 1993, 2001, and 2009;
c) Analyze three ecosystem services (noise pollution, air pollution and climate regulation) provided by the vegetation in each of the three districts individually and collectively and establish their interface with vegetation coverage.

4 STUDY AREA

Belém was established in 1916, as a Portuguese strategy to protect the region from British, French and Dutch invasions. Its most prominent feature was a fortress constructed on the confluences of Guajará Bay and Guamá River. The city was initially located along the river and bay shores and its inner lands that were once mainly wetland were dried out to make space as its population grew. Belém is located on a low-lying flat zone characterized by a dense fluvial network, exposing large areas to floods resulting from tide variation and rainfall. However, as it also lacks adequate of urban infrastructure, the entire city suffers adverse effects of floods, with most severe consequences found in the so-called periphery where poorest population is concentrated (PINHEIRO et al., 2007).

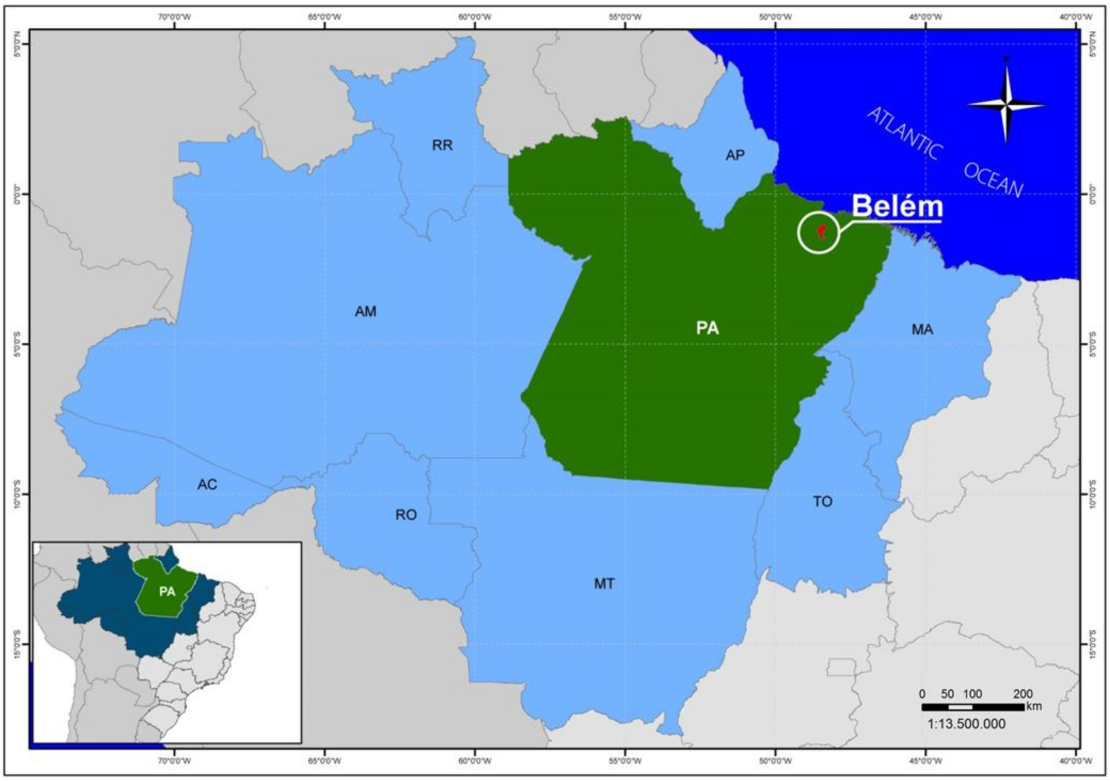
Situated in the Brazilian rainforest equatorial zone, the climate of Belém is hot (average annual temperature is 27 ˚C), humid (86% average annual humidity) and wet, with annual average precipitation above 3000 mm (CORRÊA et al., 2005).

The capital of the State of Pará occupies an area of 1,059,402 km² with a population of 1,393,399 inhabitants—the highest population density among Amazonian cities in Brazil (1,315 inhabit. /km²) (INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA, 2012) (Map 1).

The city is currently divided into administrative districts, redistributed to facilitate decentralized administration and higher participation of local people. Central idea was to divide Belém into smaller areas to be run by a district agent named by the mayor. This strategy was indicated by the Urban Development Plan (PDU) and Municipal Law no 7.682 of May 05, 1994. Thus the following district were established: Administrative District of Mosqueiro (DAMOS), Administrative District of Outeiro (DAOUT), Administrative District of Icoaraci (DAICO), Administrative District of Benguí (DABEN), Administrative District of Entroncamento (DAENT), Administrative District of Sacramenta (DASAC), Administrative District of Belém (DABEL) e Administrative District of Guamá (DAGUA) (JÚNIOR, 2013).

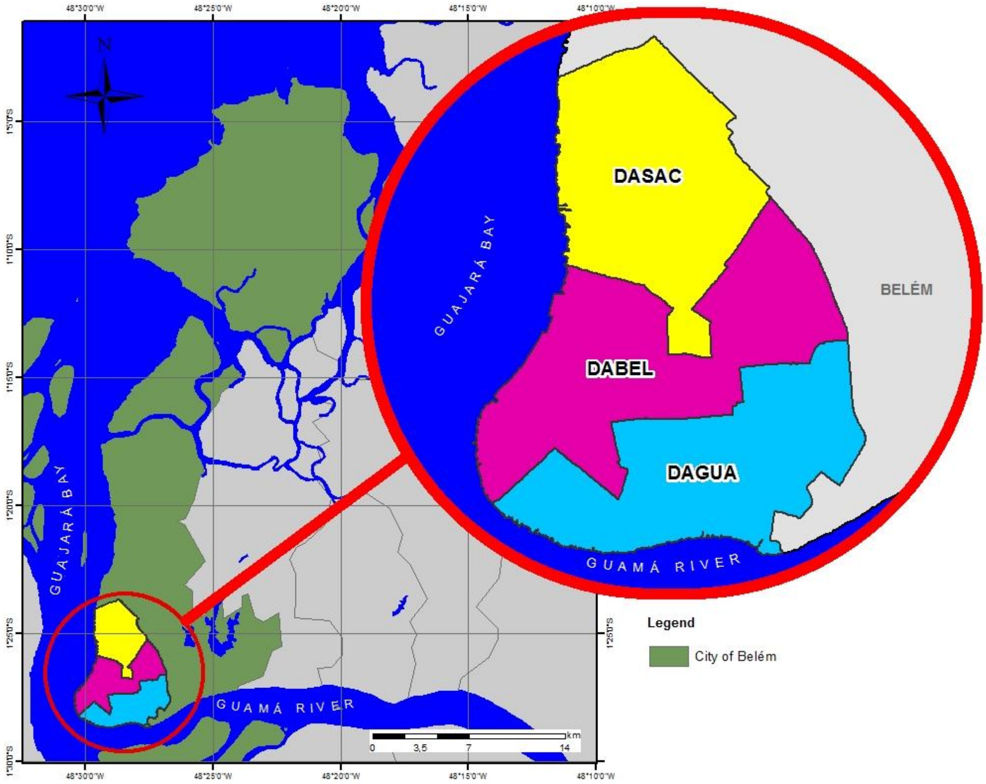
Although Belém’s territory is formed both by insular and continental land, the area of this study is located in mainland central Belém, distributed throughout three administrative districts—DAGUA, DASAC and DABEL (Map 2).

Map 1 - Map of Belém, the State of Pará and the Brazilian Amazon.



Source: Belém (1998).

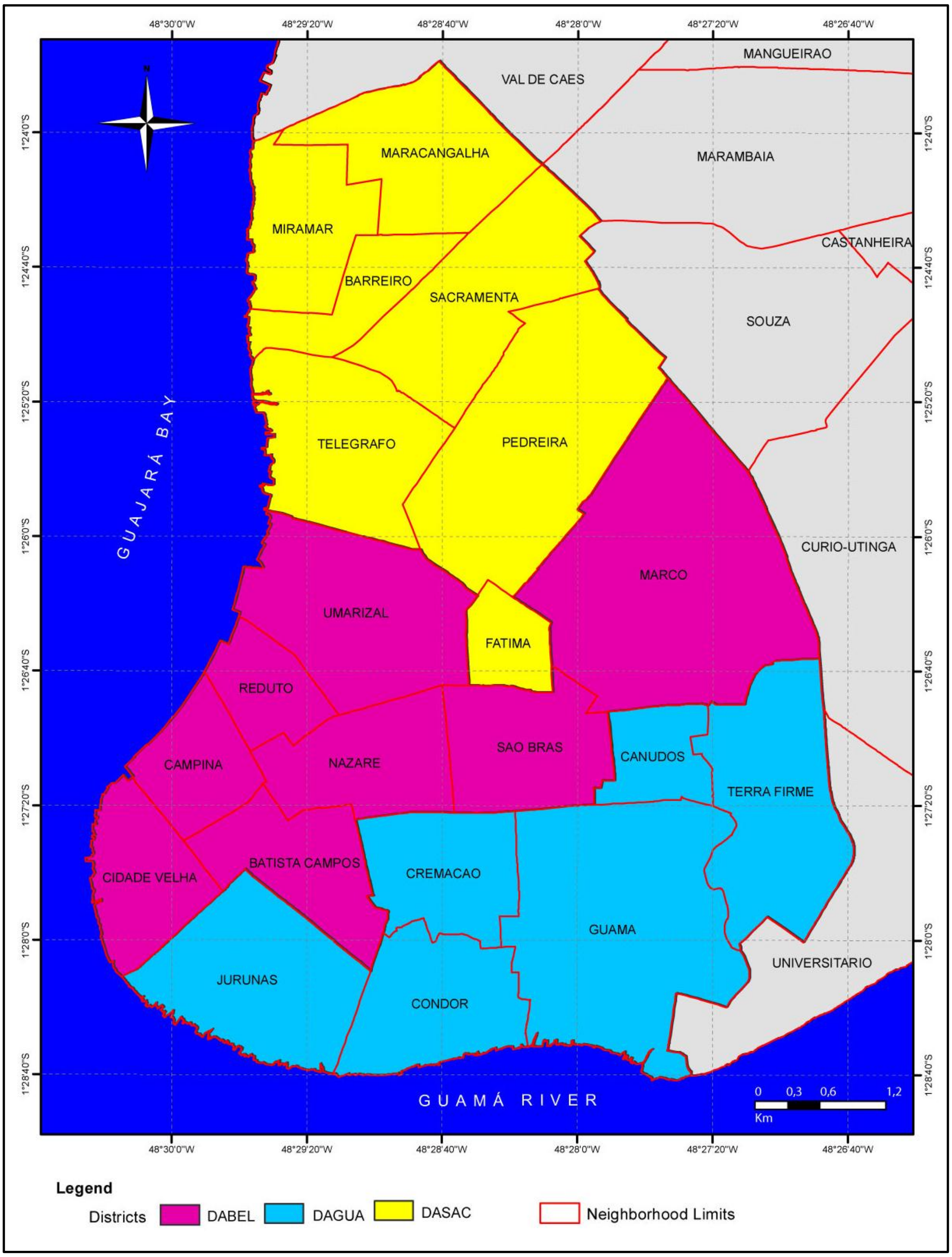
Map 2 - Map of surrounding and highlighted study area.



Source: Adapted from Belém (1998).

These districts comprise 21 neighborhoods in total (Map 3). The DABEL district is composed by eight neighborhoods—Cidade Velha, Campina, Reduto, Umarizal, Batista Campos, Nazaré, São Bras and Marco, distributed across 13.7 km² area and inhabited by 144,948 people (corresponding to around 10% of the city population and the lowest density of all three areas). The DAGUA district consists of six neighborhoods—Guamá, Condor, Jurunas, Cremação, Canudos and Terra Firme, distributed across 14 km², and home to 342,742 inhabitants (it is the most populous district with almost 25% the city's population and the highest density among studied sites). The DASAC district includes six neighborhoods—Telégrafo, Barreiro, Miramar, Maracangalha, Sacramenta, Pedreira and Fátima, spread across 15 km² area and serving a population of 256,641 residents, corresponding to 18% city's inhabitants (BELÉM, 2008; INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA, 2012). In total, the three districts cover a 42.7-km² area and have population of around 750,000 inhabitants, which is equivalent to more than 50% of the entire city population.

Map 3 - Map of Belém administrative districts and neighborhoods.



Source: Belém (1998).

Over the last four decades, Belém was marked by lack of urban planning, as housing complexes were built to serve the fast-growing population while attracting new arrivals to the periphery. This led to the conurbation process and the creation of RMB (CORRÊA, TOURINHO, et al., 2005, p.45). In 1970, the areas on the periphery started to be utilized, promoted by owners who possessed large areas of land and motivated by the irregular land occupation. In fact, by 1990, irregular land occupation gained strength and became really evident (PINHEIRO, LIMA, et al., 2007). Although the poorer population was attracted to areas further away from central Belém, their move was not followed by the offer of urban services, as the metropolis continued to focus on developing its trade and services zone.

Between 1950 and 1990, population of Belém increased from 255 thousand to over one million people, which brought about housing defect. From 1991 to 2000, of the focus was on development of trade and services hubs, characterized by the highest concentration of high-income population. In the same period, there was also a tendency for the richer population to expand towards neighborhoods of Umarizal, Batista Campos and Marco (all part of DABEL), prompting a progressive verticalilzation in such areas (CORRÊA, TOURINHO, et al., 2005).

According to Ampla Terra *apud* Corrêa (2005), intensive land occupation, achieved by developing high-rise buildings reflects the valuation of the urban space. The 1990s were marked by the increase of such constructions, which were located around Belém's main trade and service areas. This particular movement led to the present scenario, where Nazaré, Reduto, Batista Campos, Umarizal and Marco are main destinations for higher income families, who tend to live in high-rise buildings (CORRÊA, TOURINHO, et al., 2005) and (PINHEIRO, LIMA, et al., 2007).

Previous scientific works that used a variety of methods have already identified vegetation coverage loss in this area. Rodrigues and Luz (2007) mapped the loss of urban green in DABEL, DAGUA and DASAC in 1984 and 2004. The authors used four land use and coverage criteria (bare soil, low density, medium density and high density), noting that, in 2004, there was 29% of general green coverage in DABEL, followed by DAGUA, 18% and DASAC 17%. However, this paper does not report on the quality of the vegetation coverage. A study on urban forest in the entire RMB by Leão et al. (2008) also provided evidence of deforestation in Belém from 2002 to 2006. Castro (2009) affirms that, from 1997 to 2008, there was a loss of 13% of vegetation coverage in Belém. Ferreira et al. (2012) notes that 87.5 km^2 of Belém lost all green coverage.

Other studies were also conducted in some other neighborhoods that are located at RMB, but outside the research area. Their findings indicate the loss of green coverage, suggesting that urban green areas need urgent improvement (ARAÚJO;

LUZ; RODRIGUES, 2011; ARAÚJO; LUZ; RODRIGUES, 2012; LUZ; ARAÚJO; RODRIGUES, 2012).

Still, in March 2012, a City Arborization Plan was developed for Belém (Law 8.909) that, despite being approved, has not yet been applied. The main aim of the plan is to complement Belém Director Plan (PDU) with respect to urban environmental policies in Belém. This Plan recognizes arborization as an instrument or urban development that contributes to improvement of quality of life and environmental equilibrium. It also monitors, establishes parameters, plans, inspects, and defines criteria, as well as aims to involve civil population in developing and maintaining public urban green areas. Other important topics embraced by this law are provision of technical research and assistance, environmental licenses, and seedlings, as well as development of management plan and conservation plan. These initiatives pertain to general and specific care for urban species, as well as environmental education, among others services. This omnibus document offers considerable support to improving public policies of urban green and trees in the city of Belém. Thus, it reflects upon future green coverage scenarios and the provision of several ecosystem services that would benefit the city. Its key suggestion is that the Plan be put to practice as soon as possible. Nonetheless, it is worth mentioning that due to some official limitations imposed on the plan implementation, many activities are likely to be running behind schedule.

5 METHODS

The methods utilized in this study can be divided into three stages, with each being linked to the accomplishment of one of the three specific objectives. Activities pertaining to each of the stages were performed either in sequence and/or concomitantly.

The first stage included describing and analyzing the theoretical framework by conducting a thorough scientific literature review.

The second stage pertained to elaborating and interpreting the vegetation coverage maps, using available GIS data and satellite imagery. In this stage, spatiotemporal changes of the urban green coverage were also calculated. This work defines "Vegetation Coverage" as the green vegetated area that is directly detectable by remote sensing (PUREVDORJ et al., 1998).

Vegetation cover in the three administrative districts is monitored over a time horizon of 23 years—from 1986 to 2009—with spatiotemporal sub-analyses conducted in 1986, 1993, 2001 and 2009.

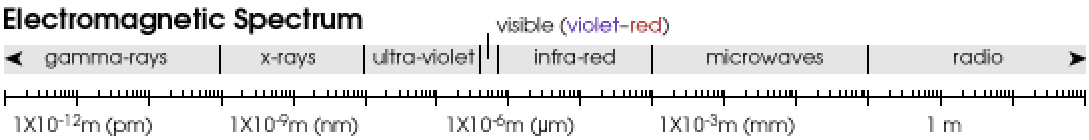
In general, this research relied on remote sensing to produce all the data for vegetation coverage in Belém. Remote sensing includes all techniques that acquire information on objects or phenomena from away. It captures electromagnetic radiation of different wavelengths reflected or emitted from distant elements (NASA, 2013a; USGS, 2007a).

> There are two types of remote sensing instruments—passive and active. Passive instruments detect natural energy that is reflected or emitted from the observed scene. Passive instruments sense only radiation emitted by the object being viewed or reflected by the object from a source other than the instrument. Reflected sunlight is the most common external source of radiation sensed by passive instruments. Scientists use a variety of passive remote sensors. (NASA, 2013a)

In contrast, active sensors function by emitting radiation to scan target elements and areas in order to detect and measure the energy reflected. Radar technology is an example of active sensors.

Out of the wide range of wavelengths and each one's specific profile, shorter waves (higher frequency) are gamma rays and x-rays. They are followed by ultraviolet, red (visible), and infrared light, and microwaves. The wavelength of visible light is in the 0.4 to 0.7 µm range (NASA, 2013a) (Diagram 1).

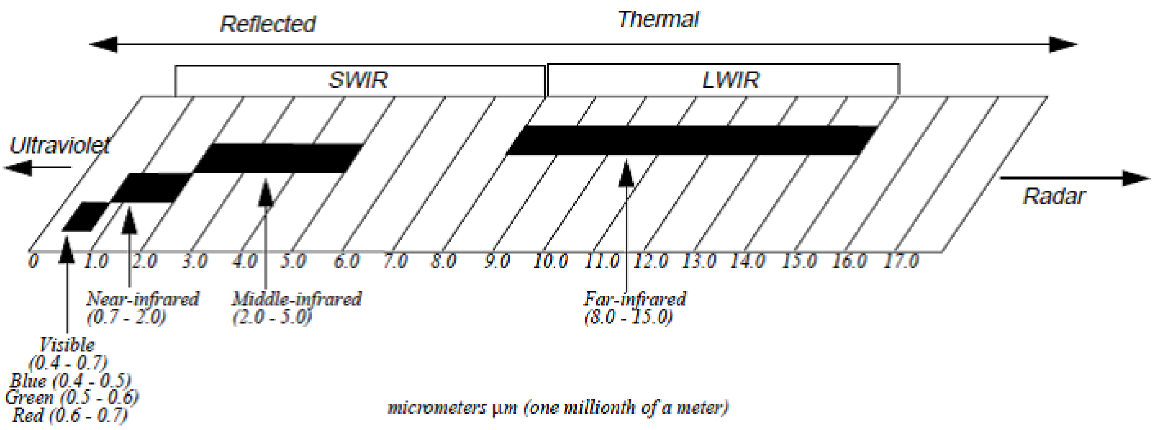
Diagram 1 - Electromagnetic spectrum.



Source: NASA (2013a).

The infrared (IR) wavelengths vary between 0.7 and 100 µm. The near-infrared and middle-infrared sections of the electromagnetic spectrum can be classified as short wave infrared (SWIR) and long wave infrared (LWIR), responsible for thermal radiation (heat). While SWIR refers to reflected radiation, LWIR pertains to emitted rays (ERDAS, 1999; NASA, 2012b;USGS, 2007b) (Diagram 2).

Diagram 2 - Infrared light spectrum.



Source: ERDAS (1999).

In sum, remotely sensed data contributes to the understanding of ecosystems and the capabilities for predicting ecosystem change. As one of its most important instruments, the Landsat Program is the longest operating project aimed at acquiring land remote sensing data (first launched in 1972). Over the years, the satellite sensors have captured valuable historic series of images that signifies a long-term record of natural and human-induced global changes. Thus far, eight satellites have been launched. The newest version, Landsat 8, called Landsat Data Continuing Mission, was launched on February 11, 2013. Such characteristics led to the decision to use Landsat 5 (one of the two machines working during this research chronogram) to allow the accomplishment of the present study's goals (NASA, 2013b; US GEOLOGICAL SURVEY, 2013a; US GEOLOGICAL SURVEY, 2013b).

Landsat 5 carries a sensor with spatial resolution of 30 m for six spectral bands and 120 m for its only thermal band (CHANDER; MARKHAM; HELDER, 2009). Its radiometric resolution is 8-bit and each pixel (the smalest ellement of an image) generated in the image includes values that range from 0 to 255. Althoug separate units, pixels are displayed as if connected (ERDAS, 1999) (Table 2).

Table 2 - Landsat bands and wavelengths.

Spectral band	Class	Wavelength
Band 1	Visible	0.45 - 0.52 µm
Band 2	Visible	0.52 - 0.60 µm
Band 3	Visible	0.63 - 0.69 µm
Band 4	Near-infrared	0.76 - 0.90 µm
Band 5	Near infra-red	1.55 - 1.75 µm
Band 6	Thermal	10.40 - 12.50 µm
Band 7	Mid infra-red	2.08 - 2.35 µm

Source: USGS (2013)

The next step was downloading Landsat TM5 imagery (band 3 and 4 precisely)[6] corresponding to the three study areas (path 223, row 61) pertaining to years 1986, 1993, 2001, and 2009 from the United States Geological Survey (www.glovis.usgs.gov). Imageries were radiometrically calibrated and corrected for atmospheric effects using ERDAS Imagine 2011[7] (CHANDER; MARKHAM; HELDER, 2009; MATHER, 2004) in order to assess vegetation coverage at the selected sites.

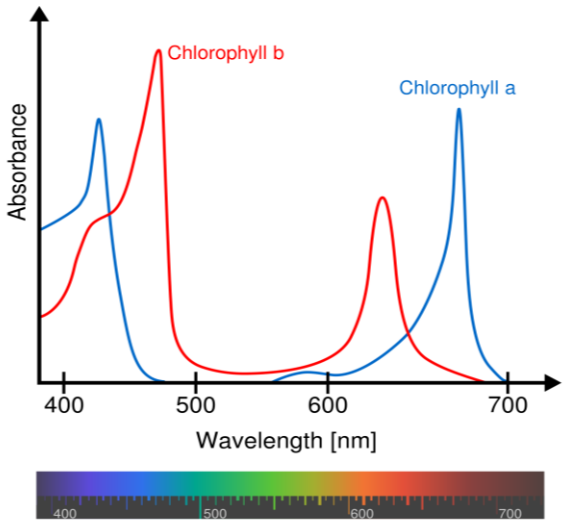
Vegetation indices are frequently used to map green coverage density from local to global scales. This work used one of the most common indices to measure wide range biomass, namely the Normalized Difference Vegetation Index (NDVI) (MATRICARDI et al., 2007; PUREVDORJ et al., 1998). NDVI, the outcome of an equation composed by near infra-red and red energy captured by remote sensing devices, is an instrument used to identify vegetation coverage and land use “taking advantage of the contrast between soil and vegetation reflectance” (MATRICARDI et

[6] If Landsat 5 imagery is downloaded with all its bands, the file can be extremely large in size. Therefore, it is convenient to download the required bands only.
[7] ERDAS Imagine 2011 is a program that processes, displays and enhances geospatial data system (ERDAS, 1999).

al., 2007). Graphic elements evaluate results obtained by remote sensing measurements and assess whether the area observed contains live green vegetation or not, and in what density.

> To determine the density of green on a patch of land, researchers must observe the distinct colors (wavelengths) of visible and infrared sunlight reflected by the plants. As can be seen through a prism, many different wavelengths make up the spectrum of sunlight. When sunlight strikes objects, certain wavelengths of this spectrum are absorbed and other wavelengths are reflected. The pigment in plant leaves, chlorophyll, strongly absorbs visible light (from 0.4 to 0.7 µm) for use in photosynthesis. The cell structure of the leaves, on the other hand, strongly reflects near infrared light (from 0.7 to 1.1 µm). The more leaves a plant has, the more these wavelengths of light are affected, respectively (NASA, 2012a, no page) (Graph 3).

Graph 3 - Chlorophyll wavelength.



Source: Chlorophyll (2013).

Next, the shapefiles[8] of the three District boundaries were obtained online[9] from the *Plano Diretor de Belém* (Belém Director Plan) (BELÉM, 2008). Once the shapefiles were imported, their boundaries had to be adjusted to match each of the three districts to specify each study area (Imagery 1). The shapefiles were subsequently clipped on the images exported to ERDAS. The downloaded image

[8] Shapefiles (or ESRI Shapefile) store geometry and attribute information for the spatial features in a data set. The geometry for a feature is stored as a shape comprising a set of vector coordinates and assumes geometric figures, such as points, polylines, and polygons. Its format is also compatible with other software products (ESRI, 1998).
[9] BELÉM (2008).

format had to be converted from TIF into IMG, to make the extraction of statistic information possible.

Imagery 1 - Alignment of shapefile to better match the districts' boundaries.

Source: the author (2012).

Subsequently, spectral enhancement function was used to calculate NDVI. NDVI results range from -1 to +1; "however, no green leaves gives a value close to zero. A zero means no vegetation and close to +1 (0.8 - 0.9) indicates the highest possible density of green leaves" (NASA, 2012). The indices were generated from the difference of reflectance values of two downloaded spectral bands, the red and near-infrared, i.e., band 3 and 4, respectively (NASA, 2012), represented by the following equation:

$$NDVI = \frac{band\ 4 - band\ 3}{band\ 4 + band\ 3} = \frac{NIR - R}{NIR + R}$$

where NDVI= Normalized difference vegetation index, NIR= near-infrared reflectance (NIR), and R= red reflectance.

Fractional green vegetation coverage (FVC or FC), the fraction of green vegetation within a pixel, was then further used to achieve higher accuracy of vegetation patterns (intensity). Satellite imagery from the same spot can vary in terms of presence and distribution of green leaves, its size and, consequently, its pixel values. Seasonal changes in canopies, for example, could cause such variation. Although, in Belém, there is very little canopy variation and seasonal changes, such differences can also stem from tide variation and floods (JOHNSON; TATEISHE; KOBAYASHI, 2012; LI; CHEN; SHI et al., 2003; MATRICARDI et al., 2007; QI et al., 2000).

Therefore, in order to achieve more accurate results, ERDAS model maker tool and NDVI values were used to establish regular patterns according to the equation (QI et al., 2000):

$$fc = \frac{NDVI - NDVI\,min}{NDVI\,max - NDVI\,min}$$

where FC= Fractional Vegetal Cover, NDVI= Normalized difference vegetation index, NDVI min= minimum NDVI found, and NDVI max= maximum NDVI found.

Fractional vegetation coverage images were then opened using the *raster* function, and were displayed in *pseudo color,* allowing the raster attributes to be identified. ERDAS' *criteria function window* was the tool used to input thresholds that identified individual classes by applying different colors to each one. As previously noted, it is widely known that NDVI measures the vegetation intensity or concentration within a certain area and works efficiently with LANDSAT imagery (PUREVDORJ et al., 1998). According to NASA (2012a),

> Satellite maps of vegetation show the density of plant growth over the entire globe (…)Very low values of NDVI (0.1 and below) correspond to barren areas of rock, sand, or snow. Moderate values represent shrub and grassland (0.2 to 0.3), while high values indicate temperate and tropical rainforests (0.6 to 0.8). (NASA, 2012a, no page)

One of the main goals of this work was to try to identify vegetation coverage quantitatively and qualitatively. Thus, considering degrees of green density obtained from NDVI and Fractional Coverage, this work proposed an even more detailed vegetation scale (Table 3).

Table 3 - NDVI criteria and color match.

NDVI criteria	Class	Classification	Map colors
<= 0.0	1	no vegetation, water, etc	Blue
> 0.0 < 0.15	2	no vegetation	Red
>= 0.15 < 0.30	3	poor vegetation	Yellow
>= 0.30 < 0.45	4	moderate vegetation	Cyan
>= 0.45 < 0.60	5	dense vegetation	Magenta
>= 0.60	6	very dense vegetation	Dark green

Source: the author (2012).

This analysis considered classes 2 to 6 only, as they stand for vegetation indices. The background represented in blue (class 1) stands for water, as well as soil and other areas not included in the administrative districts. The surrounding blue used in class 1 helped delimitate the area of study. Next, the ERDAS' *attribute window tool* was used to calculate the area for each class and its percentages, providing input for a spatial temporal changes analysis.

At first, all three areas were analyzed independently. Maps and graphs provided evidence of vegetation coverage proportion, revealing changes over the years, and distinguishing between individual classes.

Initially, the goal was to assess data from the periods eight years apart. Nonetheless, images from 1985 revealed a large amount of clouds, which could jeopardize the results. Therefore, the year 1986 was chosen instead, explaining the first seven-year interval from 1986 to 1993. The following data collection points are eight years apart from each one. All three district areas were analyzed according to five proposed categories of soil coverage/land use. Bare soil represents total lack of vegetation. The vegetation coverage itself is divided into four classes: poor, moderate, dense and very dense. This allowed qualitative and quantitative identification of changes in land coverage throughout the proposed period for each of the sites, as well as facilitated comparative analyses between the districts.

A comparison among all districts and the years analyzed revealed those marked by the greatest changes in land coverage, as well as the differences and similarities among different areas. It should be noted that this comparison focused on the vegetation classes.

Subsequently, three additional figures were composed using the background of NDVI maps from 2009, overlaid by a rough mask of each of the districts' neighborhoods. As a result, vegetation losses could be more accurately related to the specific neighborhoods. The goal was to more accurately analyze the most recent stage of vegetation coverage in all three districts and find similarities and differences not only among the districts, but, whenever possible, among the neighborhoods.

The fieldwork produced samples of images identifying each of the categories in each of the districts. This was achieved by using the overlapped maps and visual-on-site identification. Of the 55 images taken, 15 that best represented the type of vegetation coverage observed were selected.

The last stage consisted on relating the outcomes of previous steps to each of the three ecosystem services proposed to be assessed (noise pollution, air pollution and climate regulation), as well as to other relevant issues between ecosystem services and urban area in Belém. Whenever possible, all three administrative districts were evaluated independently with respect to each of the services. While each of the services was treated individually, there was a considerable attempt to assess how, where and by how much these services were benefiting the quality of life in the three districts.

With the aim of further investigating the relationship between the ecosystem service of noise pollution regulation and vegetation coverage, the Belém Acoustic Map provided data for almost all neighborhoods comprising the three administrative districts. It was not possible to establish the evolution of noise rates in Belém using the acoustic map concentrates on static measures instead of historical series. Thus, only vegetation coverage from 2009 was crossed with the Acoustic Map outcomes.

In order to overcome the challenges posed by the lack of local data pertaining to air pollution, it was necessary to apply data from other parts of Brazil and the world, allowing assessment of the local environment by inferring similar scenarios for Belém. The methodology applied to establish the patterns for air pollutant removal by urban trees in Belém was adopted from a study conducted by McPherson et al. (1997) in Chicago. Bolund and Hunhammar (1999) study conducted in Stockholm was also used as a reference, as it estimates that one ha of mixed urban forest can remove 15 t of particles of air pollutant component per year. In the present study, mixed forest will stand for the sum of dense and very dense vegetation. A variety of elements have to be considered for measuring the capacity of a tree to filter the air, such as tree species, size and type of leaves and canopy, trunk diameter and even distances between trees (BOLUND AND HUNHAMMAR, 1999). Moreover, even though there are differences between Stockholm and Belém environments, the methodology used allowed estimating the role of urban green coverage on air pollution.

The last ecosystem service assessed was climate regulation. Temperature data adopted from other scientific works were grouped according to the administrative districts. In some cases, it was also possible to analyze specific neighborhoods. Other elements that influence urban climate regulation were also assessed. Once again, these data were linked with vegetation coverage rates of each of the districts. However, instead of taking in consideration temperature data for each of the years proposed by this research (1986, 1993, 2001, 2009), lack of available records for each year made it possible to only assess temperature rates from periods very close to the years marking the start and end of this work, i.e., 1997 to 2008.

6 RESULTS AND DISCUSSIONS

To better delineate this research, the results were divided into two major groups. The first relates to vegetation coverage, starting with Belém in general, and going deeper into each one of the districts. The second group concerns ecosystem services. It starts with a general view, definition and historic placement, followed by other relevant connections of ecosystem services. Finally, it focuses on the specific services of noise pollution, climate and air pollution regulation. It should be noted that outcomes from vegetation coverage were also input for ecosystem services.

6.1 Vegetation Coverage in Belém

Results of this research indicated decrease of vegetation coverage in DABEL, DAGUA and DASAC in comparison to the earlier periods under investigation. All the sites present alarming increase of bare soil and poor vegetation and decrease of moderate, dense and very dense vegetation, creating a somehow regular pattern that does not differ from site to site. Incidentally, it was possible to observe that, in all districts, the significant loss of vegetation, accompanied by the increase of areas with complete lack of vegetation and most intensive changes, occurred from 1993 and 2001.

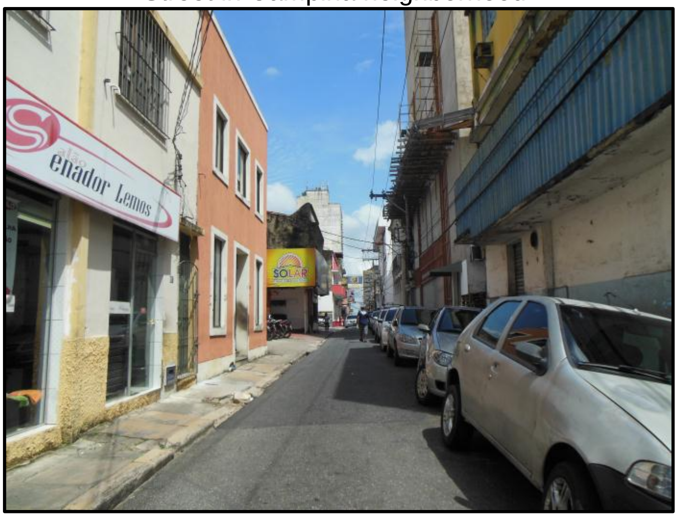
This period shows the most significant loss at all three sites. This process intensified after 1997, when the irregular land occupation escalated at the city peripheries, or less affluent areas of the city. Such parts still kept their natural coverage, partially caused by population increase due to immigration flow (from 1995 to 2000, Belém alone received 76,276 immigrants and RMB 170,209 people) (OBSERVATÓRIO DAS METRÓPOLES, 2008) and the urban expansion that required former rural areas to be used for residential development, which later became *favelas* (slums) (CARDOSO; NEGRÃO; PEREIRA, 2012).

6.1.1 Vegetation Coverage in DABEL

DABEL shows a reduction in moderate, dense and very dense vegetation, which was replaced by poor vegetation and bare soil areas (Graphs 4 and 5 and Map 4).

In fact, 1986 bare soil covered 2.04% of the entire area, corresponding to 0.28 km^2. There is a slight decrease in 1993, reaching 1.97%. However, in just the following eight years (1993 to 2001) the percentage of bare soil in DABEL increased dramatically to four times the original measure. Notwithstanding, it continued to increase and in 2009 reached 20% of DABEL territory, corresponding to 2.74 km^2 out of the total 13.7 km^2. In short, in 23 years, bare soil percentage increased ten times its initial value. In addition to the sprawl, some neighborhoods also presented areas with high concentration of bare soil that could be easily observed. Bare soil concentrations areas are more commonly observed in the west side of the district, next to the coastline, where the first neighborhoods of the city (Picture 1) and in the northeast region were built.

Picture 1 - Bare soil example in DABEL, 2013. Campos Sales Lane, from the corner of Aristide Lobo Street in Campina neighborhood.



Source: the author (2012).

In 1986, poor vegetation extended over 3.45 km^2 (25% of the total DABEL area), clearly concentrated in the west part, and had almost no change until 1993. In 2001, it doubled to impressive 50% of the district, representing 7.12 km^2 (Picture 2). In 2009, bare soil and poor vegetation contributed by 72% to the DABEL's total area, compared to only 27% of the territory in 1986.

Picture 2 - Poor vegetation in DABEL, 2013. Tamandaré Avenue in Cidade Velha neighborhood.

Source: the author (2012).

Moderate vegetation was the characteristic of 37% of DABEL in 1986 and was concentrated in the central and western area DABEL, according to the two first records. In 1993, there was an increase to 41% of the entire area, still concentrated in the same sites. Yet, in 2001, a significant decrease to 27% was evident, reaching 17% in 2009. This represents a loss of 2.75 km^2 of moderate vegetation. Consequently, the moderate vegetation areas easily identified in 1993 could hardly be located in the 2009 map (Picture 3).

Picture 3 - Moderate vegetation example in DABEL, 2013. Gentil Bittencourt Avenue in front of Soledad Cemetery in Nazaré neighborhood.

Source: the author, 2013

In 1986, 24% percent of DABEL was covered by dense vegetation, compared to 22% in 1993. Due to the subsequent sudden loss of dense vegetation coverage, it reached 9% in 2001, and 6% in 2009. Therefore, DABEL lost 18% of dense vegetation so important for ensuring that the urban environment is receiving the services urban forest provides (Picture 4).

Picture 4 - Dense vegetation example in DABEL, 2013. Dr. Freitas Avenue, close to Almirante Barroso Avenue in Marco Neighborhood

Source: the author, 2013

Very dense vegetation coverage covered about 12% of the district in both 1986 and 1993. In 2001, it reached 5%, indicating that more than half of its initial area was lost. In 2009, very dense vegetation practically disappeared from the map, with very scarce zones in extreme north, south and southwest. The great majority of areas that still had this type of land coverage in 2009 belong to public squares and parks (Picture 5).

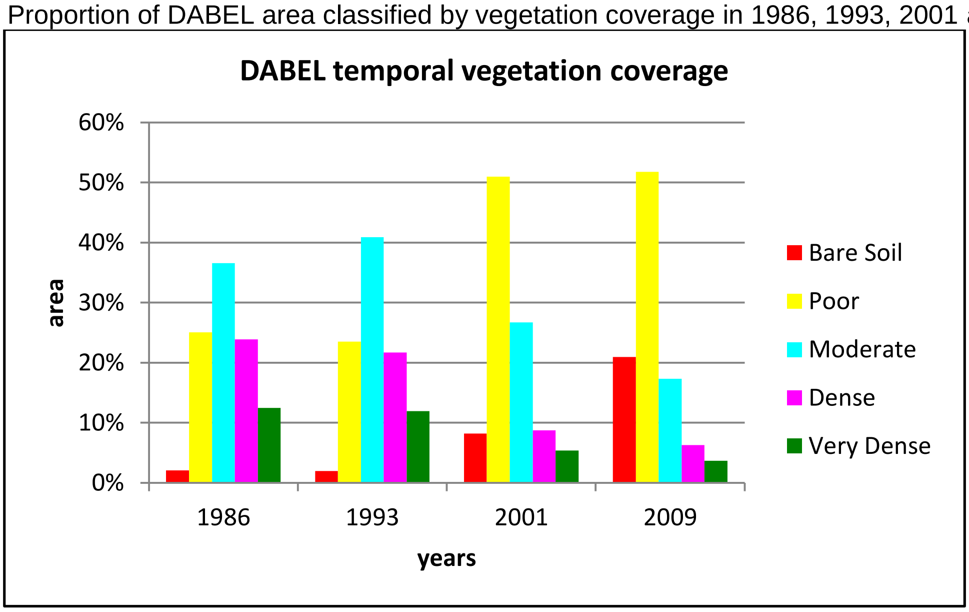
Picture 5 - Very dense vegetation example in DABEL, 2013. Batista Campos Square in Batista Campos Neighborhood.

Source: the author, 2013

Together, dense and very dense vegetation coverage represented 36% of DABEL in 1986. In 2009, the same two classes decreased to 10% or 1.37 km^2. Almost 3.6 km^2 of important vegetation coverage was thus lost in 23 years.

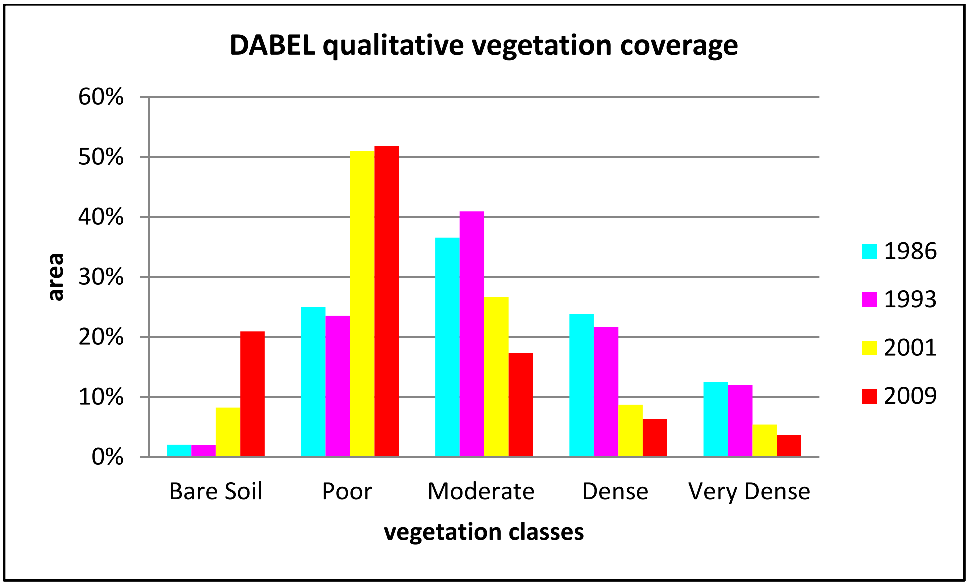
There is a general tendency towards loss of vegetation coverage, accompanied by increase of bare soil and poor vegetation areas. Very dense vegetation areas gradually transform into dense vegetation areas. Dense vegetation is also lost from urban green zones and is gradually transformed into moderate vegetation zones. Spaces once covered by moderate vegetation continue to lose natural ecosystems and change into poor vegetation or bare soil spaces.

Graph 4 - Proportion of DABEL area classified by vegetation coverage in 1986, 1993, 2001 and 2009.



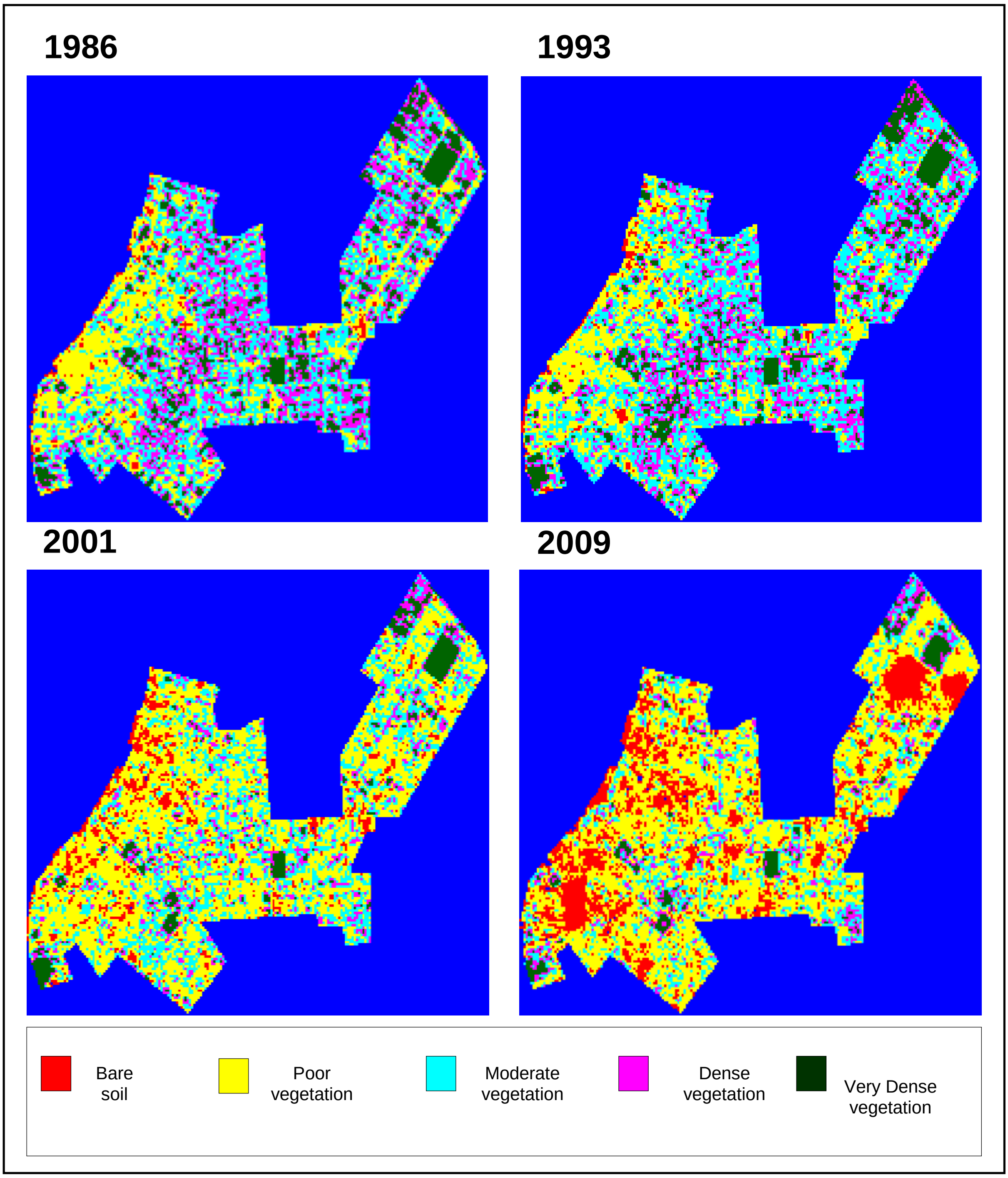
Source: the author (2012).

Graph 5 - Proportion of DABEL area classified by vegetation classes in 1986, 1993, 2001 and 2009.



Source: the author (2012).

Map 4 - Remote sensing maps of vegetation coverage in DABEL on 1986, 1993, 2001 and 2009.



Source: the author (2012).

6.1.2 Vegetation Coverage in DAGUA

This analysis utilized data presented on Graph 6 and 7 and Map 5.

In 1986, DAGUA was characterized by a large area that extended throughout its entire territory and included moderate vegetation and dense vegetation, revealing very clear concentrations of very dense vegetation in the northeastern part. The 2009 scenario considerably differs from the initial period. In a 23-year period, there was a sprawl of poor vegetation all over the area, accompanied by a few already concentrated spots of bare soil. Almost none of the original very dense vegetation coverage has been preserved.

DAGUA had 1% of bare soil in 1986 and 1993. In 2001, bare soil reached 2% and in 2009, 6% of the district, concentrated in a small zone at northwest of the district (Picture 6).

Picture 6 - Bare soil example in DAGUA, 2013. Paes de Souza Street, viewed from Silva Castro Lane in Guamá neighborhood.

Source: the author (2012).

The results for poor vegetation are, perhaps, the most alarming. In 1986, it occupied 12% of DAGUA and increased to 15% in 1993. In the following eight years, its percentage rose to 48% and in 2009, to 62% (8.7 km^2) (Picture 7).

Picture 7 - Poor vegetation example in DAGUA, 2013. Liberato de Castro Lane, viewed from Barão de Igarapé Miri Street in Guamá neighborhood.

Source: the author (2012).

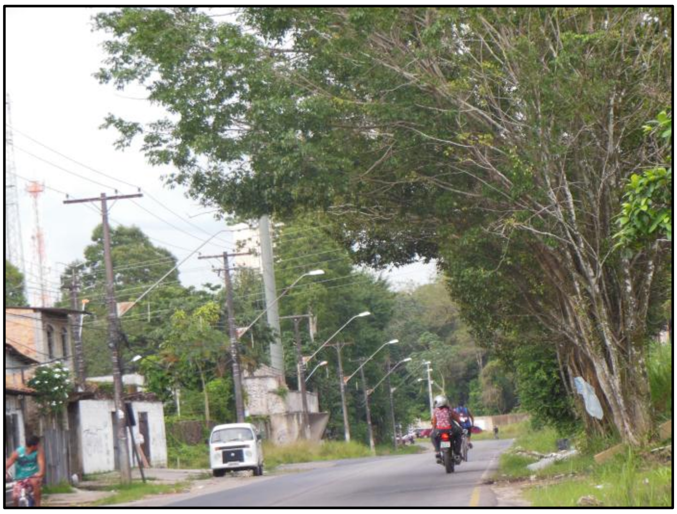
In 1986, moderate vegetation covered 33% of the district, increasing to 48% in 1993. Unfortunately, in the following period, the coverage first declined before rising to 35% in 2001, falling again to 22% in 2009. In sum, 11% of moderate vegetation coverage was lost in 23 years (Picture 8).

Picture 8 - Moderate vegetation example in DAGUA, 2013. Silva Castro Lane close to José Bonifácio Avenue in Guamá neighborhood.

Source: the author (2012).

Dense vegetation follows a downward trend. DAGUA was characterized by 28% of dense vegetation in 1986; however, eight years later, this percentage declined to 22%. In 2001, this district lost more than half of its former dense vegetation, which shrunk to 9%, and declined further to 5% of the entire area in 2009. This denotes a loss of 23% of dense vegetation over a 23-year-period, indicating that the initial 3.92 km^2 reduced to 0.7 km^2 (Picture 9).

Picture 9 - Dense vegetation in DAGUA, 2013. Perimetral Avenue, in Terra Firme neighborhood.



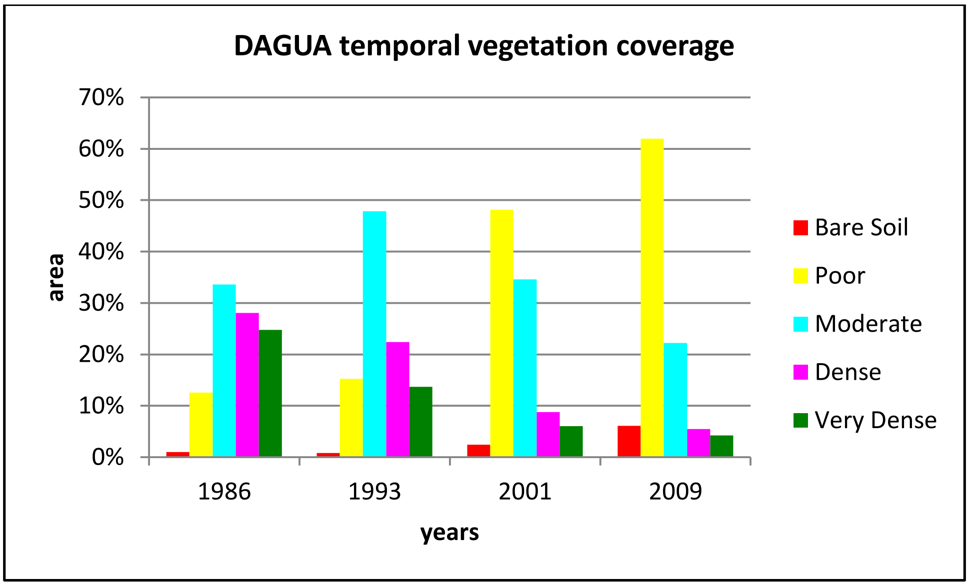
Source: the author (2012).

In 1986, very dense vegetation (Picture 10) accounted for 25% of the area, decreasing to 14% in 1993. It reached 6% in 2001, and 4% in 2009. In sum, the period under study, DAGUA lost 21% of its very dense vegetation areas.

Picture 10 - Very dense vegetation in DAGUA. Santa Izabel Cemetery in Guamá neighborhood.

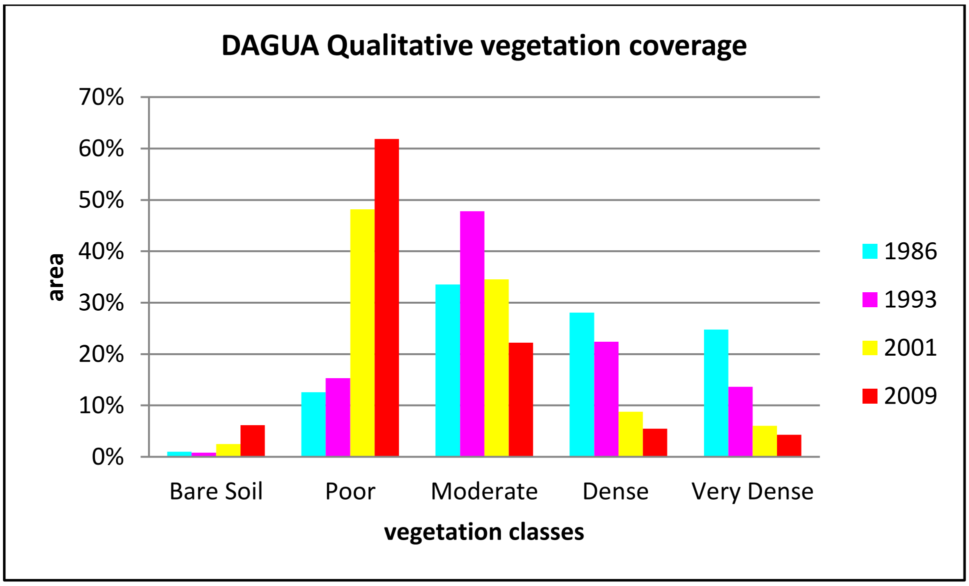
Source: the author (2012).

Graph 6 - Proportion of DAGUA area classified by vegetation coverage in 1986, 1993, 2001 and 2009.



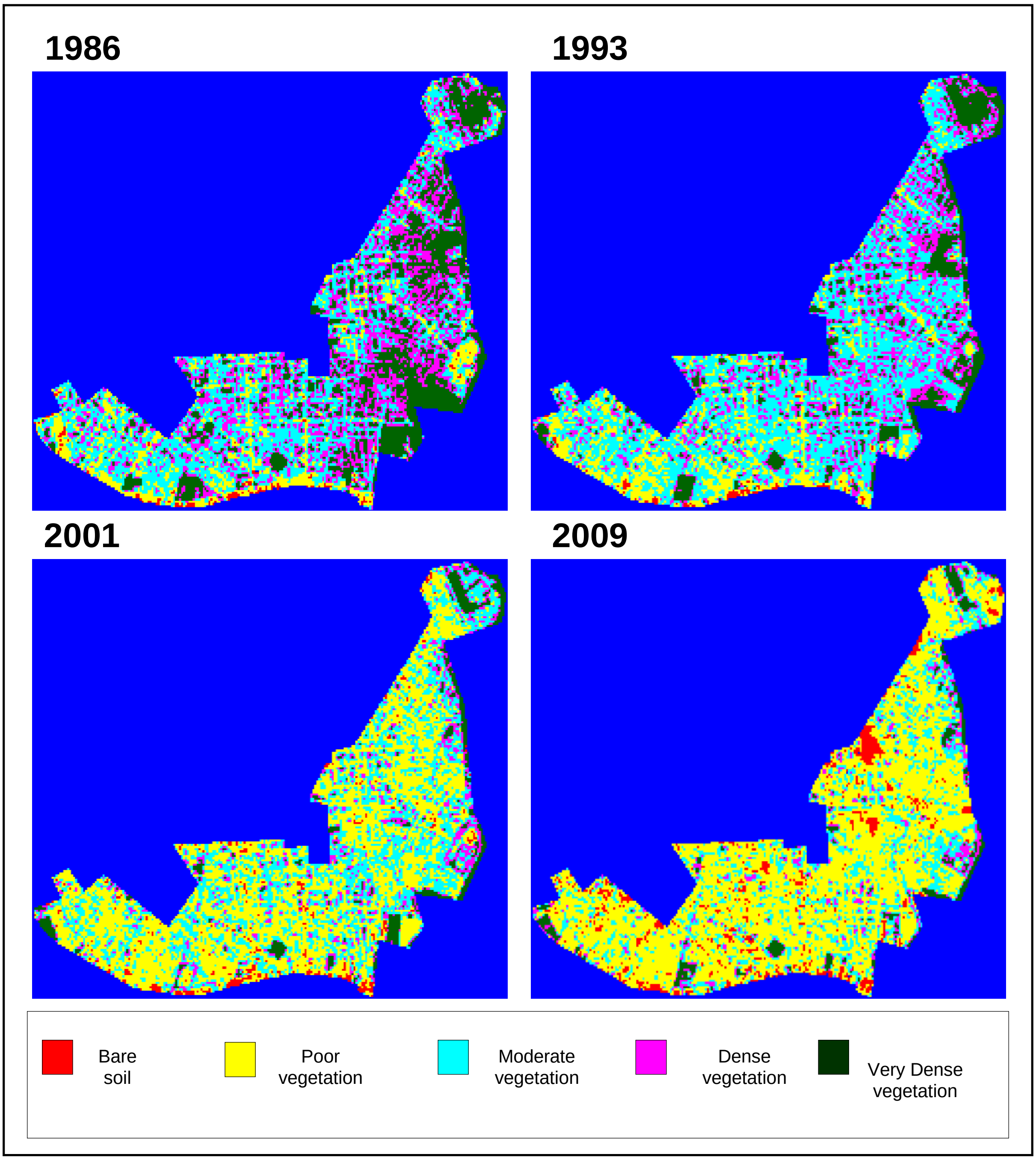
Source: the author (2012).

Graph 7 - Proportion of DABEL area classified by vegetation classes in 1986, 1993, 2001 and 2009.



Source: the author (2012).

Map 5 - Remote sensing map of vegetation coverage in DAGUA on 1986, 1993, 2001, and 2009.



Source: the author (2012).

6.1.3 Vegetation Coverage in DASAC

This analysis was based on the data extracted from Graph 8 and 9 and Map 6.

In 1986, different classes of vegetation covered the entire DASAC area. There were very few areas with poor vegetation, mostly concentrated along roads and avenues, and even fewer with bare soil. The last scenario analyzed indicated a complete change in the land coverage in this district.

Evidencing this change, the bare soil covered initially only 1% of this district, and decreased further to 0.7% in 1993, and to 0.3% in 2001. However, in the last measurement period, the bare soil percentage increased dramatically, reaching 16% in 2009. Most of the bare soil area replaced former very dense vegetation, corresponding to 2.4 km^2 lacking any type of vegetation (Picture 11).

Picture 11 - Bare soil example in DASAC. Júlio Cesar Avenue close to Centenário Avenue, in Sacramenta neighborhoods.

Source: the author (2012).

With respect to poor vegetation area, DASAC followed the same pattern in 1986 and 1993, with around 14% being scattered along roads and avenues, accompanied by some few concentrated areas in the northwest. Yet, alarming changes took place from 1993 to 2001, as poor vegetation area increased to 47%. In 2009, it occupied 55% of this district. Thus, in 23 years, DASAC poor green coverage increased four times—from 2.1 km^2 to 8.25 km^2 (Picture 12).

Picture 12 - Poor vegetation example in DASAC. Alferes Costa Lane viewed from Pedro Miranda Avenue in Pedreira neighborhood.

Source: the author (2013)

The 1986 results for moderate vegetation coverage showed that it occupied 29% of the total DASAC area, reaching 40% in the next eight years. In 2001, a loss of 12% occurred, resulting in 28% or 4.2 km^2, a scenario very close to the initial measures. The downward trend continued, resulting in moderate coverage area occupying 17% of the DASAC district in 2009. Thus, when the entire 23-year period is analyzed, it is evident that DASAC lost 12% of moderate vegetation coverage, i.e., 1.8 km^2 of moderate urban forest disappeared (Picture 13).

Picture 13 - Moderate vegetation example in DASAC. Pedro Miranda Avenue close to Chaco Street junction in Pedreira neighborhood.

Source: the author (2012).

DASAC also lost dense vegetation coverage. In 1986, this class occupied 23% of the total area, and then lost 2% in the following eight years, reaching 3.15 km^2. From second to third time interval (1993-2001) dense vegetation coverage lost more than half of its former area and decreased to 9%. It was last measured at 6% in 2009. In total, DASAC lost 17% of dense vegetation coverage over the assessed years (Picture 14).

In DASAC, it was rather challenging to recognize both moderate and dense vegetation *in locus*. In contrast to other districts, where all land use and coverage types were clearly distinguishable, DASAC had very few and rather small spots with moderate and dense coverage, making them hard to identify. Moreover, most of these two kinds of green coverage are located at the borders of DASAC, DABEL and another district not included in this study.

Picture 14 - Dense vegetation example in DASAC. Agua Cristal Grove in Sacramenta neighborhood.

Source: the author (2012).

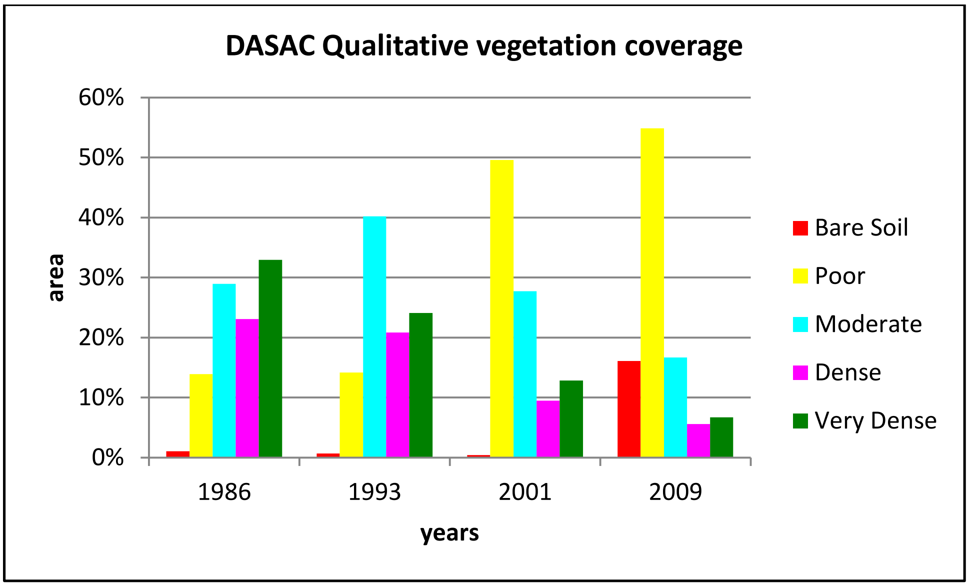
DASAC presented clear concentrations of very dense vegetation in northern areas. Moreover, there was also a dramatic loss of very dense vegetation, which was replaced by bare soil areas in the north side of the district. Poor vegetation dominated the rest of the district and continuously replaced dense and moderate urban green (Picture 15).

Picture 15 - Very dense vegetation example in DASAC. Arthur Bernardes Road in Miramar neighborhood.

Source: the author (2012).

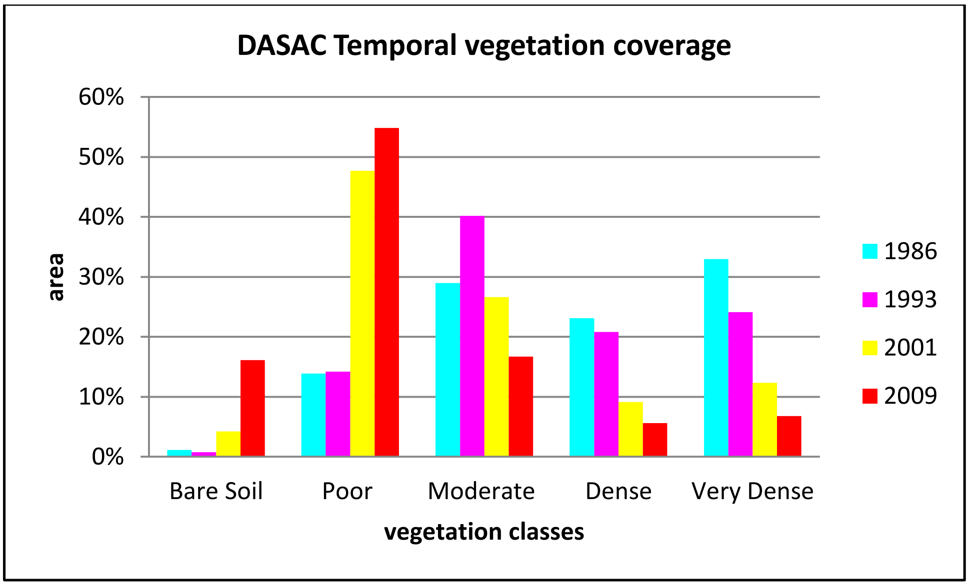
There was 33% of very dense vegetation in 1986 that decreased to 24% in 1993, reaching 13% in 2001. In 2009, only 7% of the area was covered by urban dense forest. In sum, almost 4 km^2 of very dense green area vanished in 23 years.

Graph 8 - Proportion of DASAC area classified by vegetation coverage in 1986, 1993, 2001, and 2009.



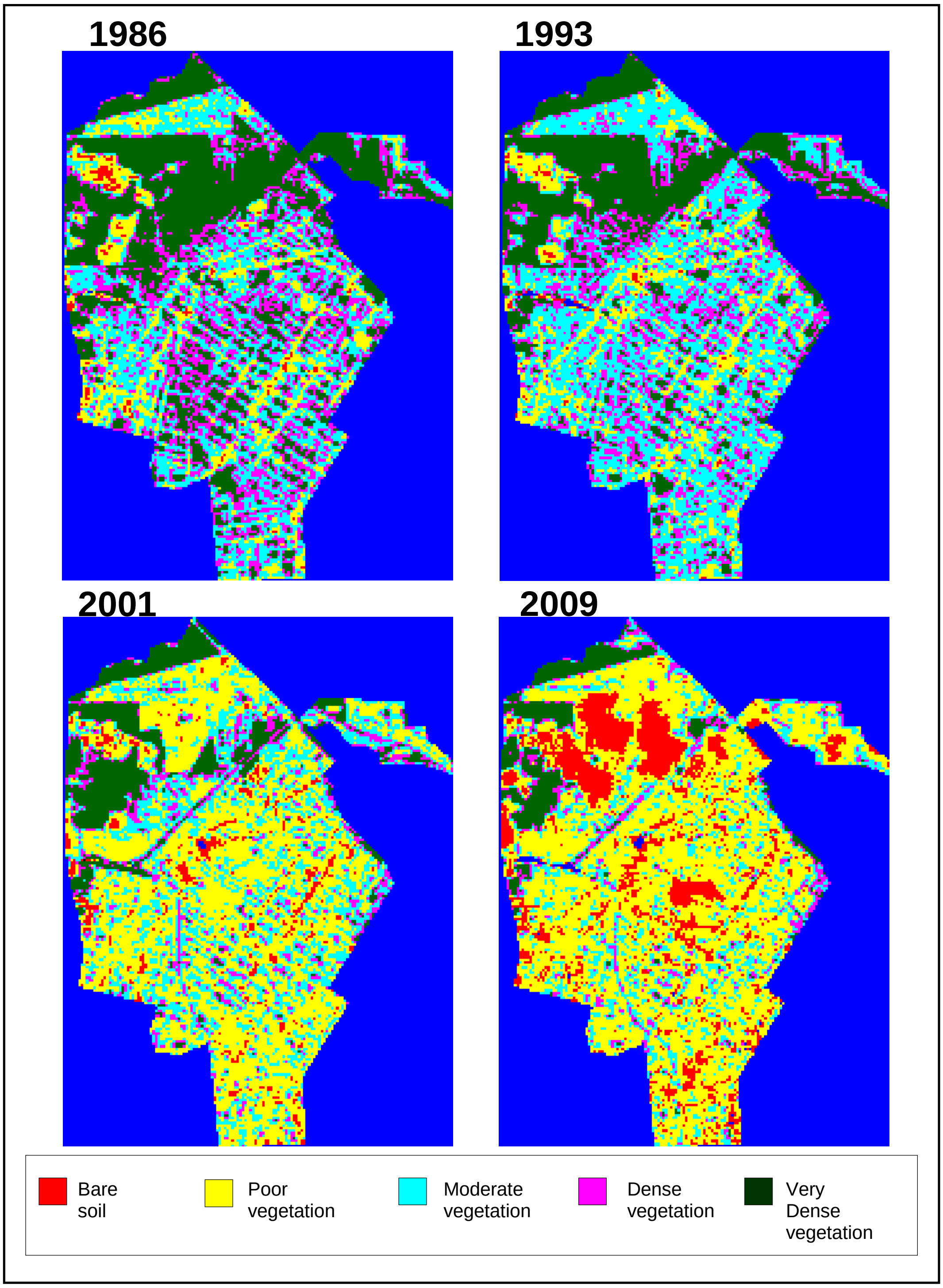
Source: the author (2012).

Graph 9 - Proportion of DASAC area classified by vegetation classes in 1986, 1993, 2001 and 2009.



Source: the author (2012).

Map 6 - Remote sensing maps of vegetation coverage in DASAC on 1986, 1993, 2001 and 2009.



Source: the author (2012).

6.1.4 Vegetation Coverage in DABEL, DAGUA and DASAC – a Comparison

This section compares the three areas according to the previously defined green coverage classes. This analysis utilized the data extracted from Figure 34, 35, 36 and 37.

a) Bare Soil

From 1986 to 1993, the three districts had less than 2% of bare soil. During the following period (1993 – 2001), the percentage of bare soil differs, and DABEL is characterized by the highest increase. In 2009, DABEL was still ahead with impressive 20% of bare soil, followed by DASAC, with 16%, and finally DAGUA with only 6%. The overall increase of bare soil percentage in DABEL, DASAC and DAGUA, was 18%, 15% and 5%, respectively.

b) Poor Vegetation

In 1986, DABEL had the highest proportion of area covered by poor vegetation (25%), followed by DASAC (14%) and DAGUA (12%). Small changes took place in 1993 (a decrease of around 2% was observed in all districts). However, in 2001, there was a significant increase in poor vegetation areas and, in DABEL, 51% of the total area was covered by poor vegetation, followed by DASAC (50%) and DAGUA (49%). In 2009, in DAGUA, DASAC and DABEL the poor vegetation area respectively increased to 62%, 55% and 52%. During the assessed period, the overall increase in poor vegetation was 27% in DABEL, 41% in DASAC and 40% in DAGUA. It can be noted that, while DABEL initially had the highest area of poor vegetation, it gained the lowest percentage.

c) Moderate Vegetation

Moderate vegetation had different patterns compared to the prior two types of land coverage analyzed here. Initially, DABEL had 37%, DAGUA 34% and DASAC 29% of moderate coverage. The measures from 1993 showed an increase of moderate vegetation coverage by 4%, 14% and 11%, respectively. By then, DAGUA had almost 50% of its territory occupied by moderate urban green coverage. During the following period (1993 – 2001), a drastic decrease takes place in all three districts. In 2009, DABEL and DASAC presented with only 17% of moderate vegetation, while DAGUA had 22%. DABEL was the district with the greatest loss, 20% in total, and both DAGUA and DASAC lost 12% of moderate vegetation along the 23-year period.

d) Dense Vegetation

Overall, there was a high loss of dense vegetation throughout the years in every district studied. Along with most of the coverage types, there was a small loss from 1986 to 1993. DAGUA initially had the largest proportion of area covered by dense vegetation (28%). In 1993, owing to coverage reduction, the districts presented similar dense vegetation areas (around 21%). However, following a pattern of great changes land coverage, in 2001 they all measured 9% of dense urban forest. This decrease continued in 2009, when DABEL and DASAC had 6% of dense areas left and DAGUA only 5%. During the period measured in this work, DAGUA lost 23% of its coverage, DABEL, 18% and DASAC 17%.

e) Very Dense Vegetation

DASAC had the highest concentration of very dense vegetation compared to the other two districts (33% of the total territory), followed by DAGUA (25%) and DABEL (12%). In 1993, DABEL's very dense coverage remained the same, while DASAC suffered a decrease to 24% and DAGUA to 14%. Again, this is followed by further decreases from 1993 to 2001, when DABEL reached 5%, DAGUA 6% and DASAC 13%. Unfortunately, the scenario continued to worsen, as in 2009, DABEL and DAGUA had 4% and DASAC 7% of total area covered by very dense vegetation. When observing the entire 23-year period, while DABEL was the district that showed lowest decrease in very dense vegetation (8%), it still remained the area with the lowest percentage of this type of coverage. On the other hand, DASAC had the large area with this characteristic, with 33% in 1986, but also lost the larger percentage of its very dense coverage (26%). Finally, DAGUA lost 20%, resulting in only 4% of its area covered by very dense coverage.

6.1.5 The Latest Scenario – 2009

This analysis was based on the data extracted from Graph 10 and Map 7, 8 and 9.

There are clear resemblances, as well as a few differences among the three districts. DABEL presented the highest rate of bare soil, followed closely by DASAC and DAGUA. On the other hand, DAGUA had the highest area covered by poor vegetation (60%), although in all three sites, poor vegetation covers over 50% of the territory. Moderate vegetation presents similar results and DAGUA still displays the highest rate. DAGUA also has a higher rate for dense vegetation, although the difference is quite small across the districts. DAGUA and DASAC had also similar areas of very dense vegetation coverage.

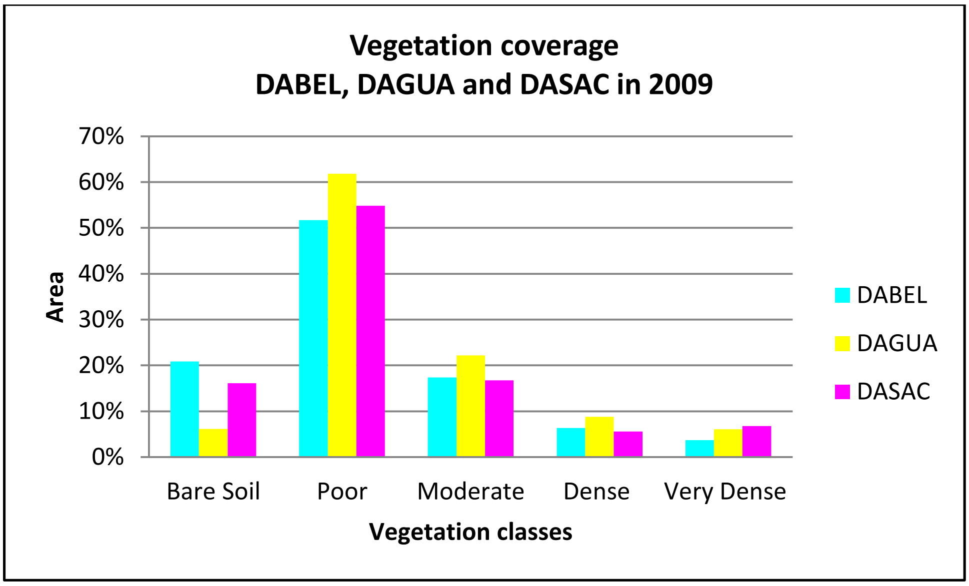
There are some DABEL characteristics that could explain the results noted at this district. Campinas is one the oldest neighborhoods of Belém and has the highest rate of bare soil, followed by Cidade Velha (the first neighborhood)—although Cidade Velha still conserves a small area of dense vegetation. On the other hand, São Brás is the neighborhood with less bare soil, even though it belongs to Marco the largest bare soil area in DABEL. There are a few spots with very dense vegetation—Marco has the largest percentage, and is followed by São Brás and Batista Campos. Most of the very dense vegetation is located at squares or parks. In Marco, the *Bosque Rodrigues Alves* is a park inside the city that provides home for some native species of the natural biome of the region.

In DAGUA, of the changes in bare soil and very dense vegetation are very similar to those described above. Both are scattered along the district and present few areas with a more noticeable concentration of the coverage type. Canudos is the area with the highest portion of bare soil and Condor displays two distinguishable areas covered by dense vegetation. While Jurunas, Guamá and Terra Firme also have areas of very dense vegetation, the largest one is located at the north of DAGUA. Terra Firme has the smallest bare soil coverage and poor vegetation coverage zones. This neighborhood has clearly managed to conserve some important areas with moderate vegetation.

DASAC results indicate that Maracangalha has the highest rates of bare soil, followed by Barreiro and Miramar. Those three areas form a cluster that seems to be the area most affected by lack of vegetation across all districts. On the other hand, Miramar also has the largest area with very dense vegetation inside this district. Poor vegetation covers the other neighborhoods, accompanied by occasional spots of bare soil. Telégrafo presented the smallest area of bare soil. There are very few sports of moderate and dense vegetation in all neighborhoods.

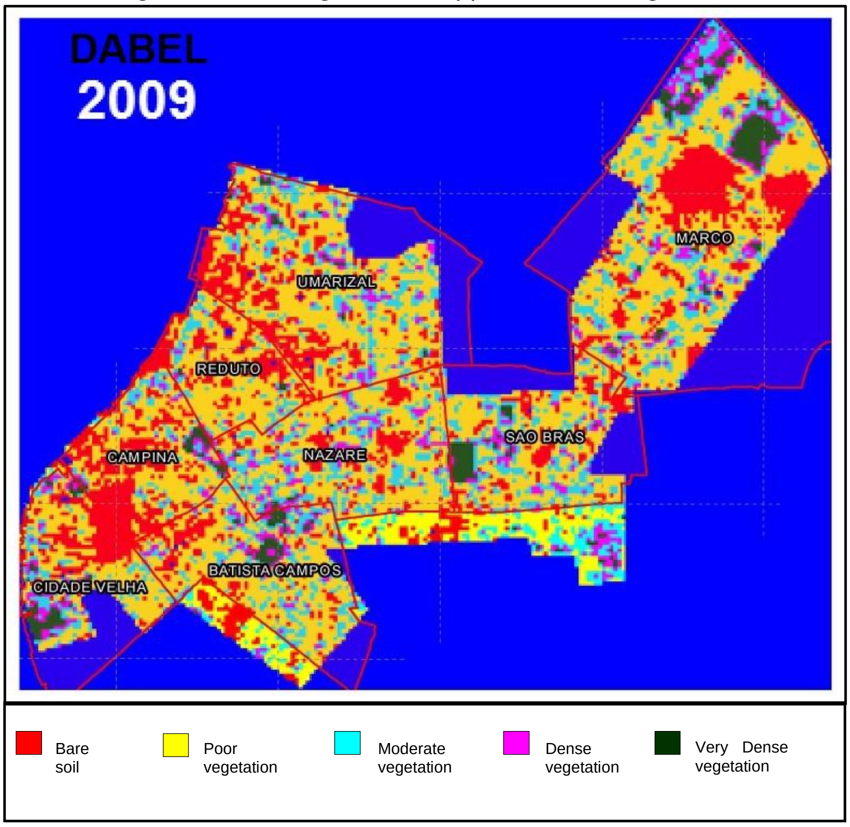
After comparing all neighborhoods, it seems that Campinas and Marco (DABEL) and the adjacent Maracangalha, Barreiro and Miramar (DASAC) clearly present large and concentrated areas with no vegetation coverage whatsoever. The neighborhoods of DAGUA, except for Canudos, show very similar vegetation coverage. Finally, in DABEL, all the neighborhoods, except Campinas and Reduto, still show implicit differences in the vegetation coverage even within each neighborhood.

Graph 10 - Comparison of the last measure of vegetation coverage in DABEL, DAGUA and DASAC, 2009.



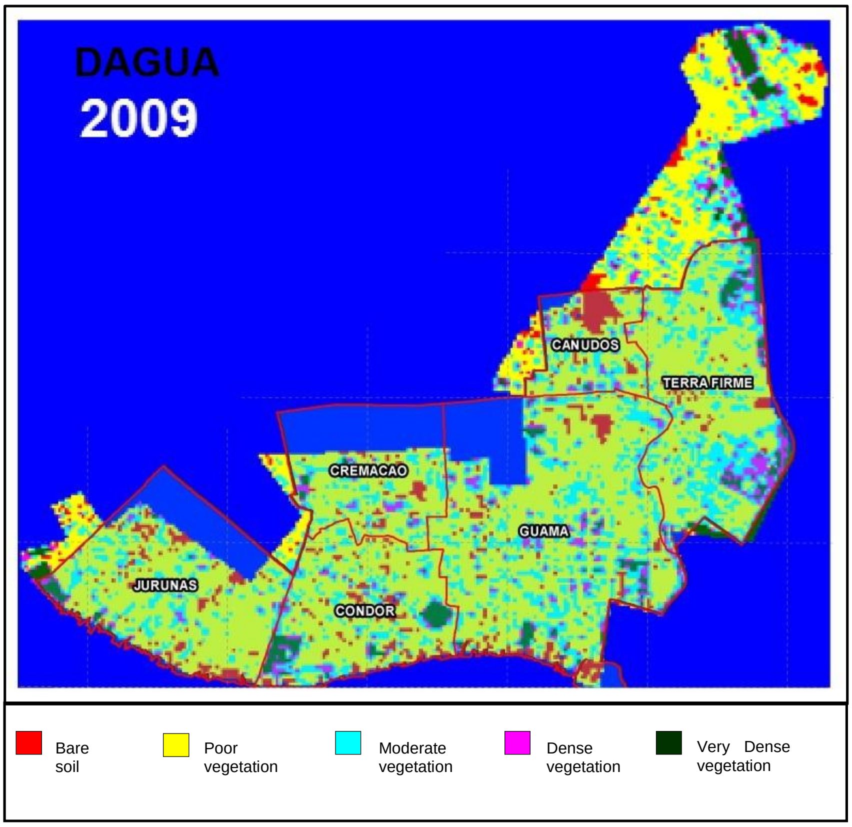
Source: the author (2012).

Map 7 – DABEL vegetation coverage and its approximated neighborhood limits in 2009.



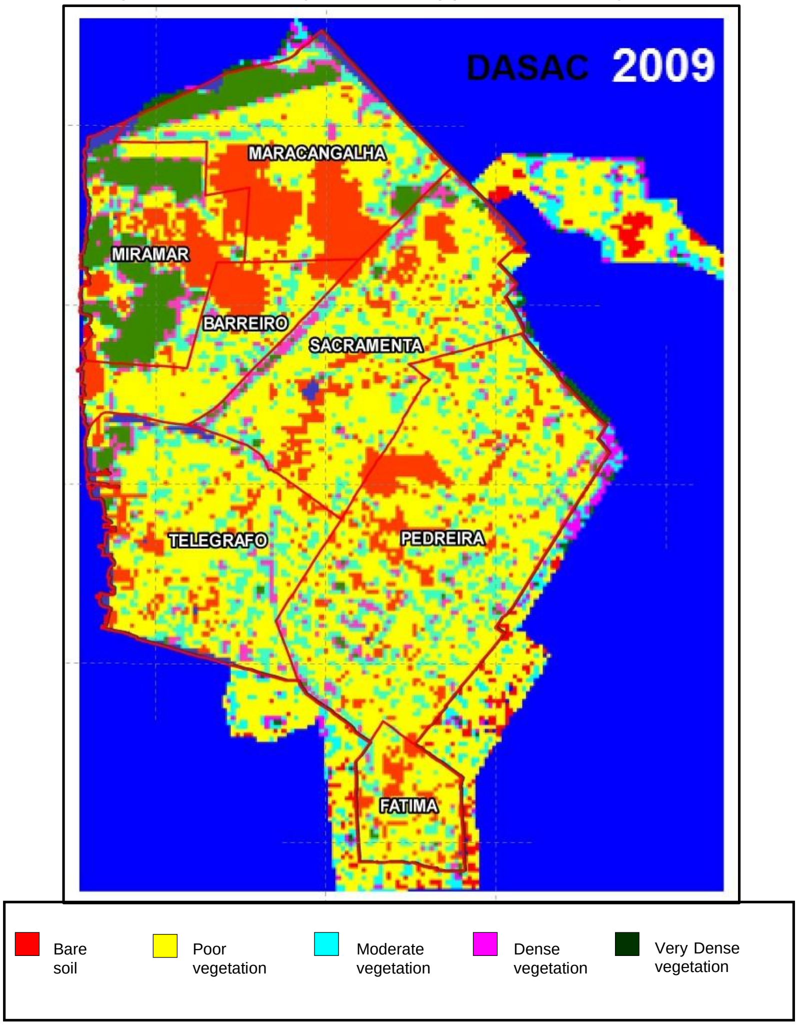
Source: the author (2012).

Map 8 - DAGUA vegetation coverage and its approximated neighborhood limits in 2009.



Source: the author (2012).

Map 9 - DASAC vegetation coverage and its approximate neighborhood limits in 2009.



6.2 Ecosystem Services

Benefits nature provides humanity have not always been recognized as essential to the maintenance of life on Earth. Such recognition is indeed recent, and related to problems that address the sustainability of human presence on Earth.

According to Bastian et al. (2011), the concept of Environmental/Ecosystem Services emerged back in the 1960s; however, it was first introduced to the international discussion on environmental issues in 1990s, with the book *Nature's Service: Societal Dependence on Natural Ecosystems* (DAILY, 1997). The author defines ecosystem services as "the conditions and processes through which natural ecosystem, and the species that make them up, sustain and fulfill human life." Complementing the concept, some major examples of environmental services are:

> Purification of air and water; mitigations of floods and droughts; detoxification and decompositions of waste; generation and renewal of soil and oil fertility; pollination of crops and natural vegetation; control of vast majority of potential agricultural tests; dispersal of seeds and translocation of nutrients; maintenance of biodiversity, from which humanity has derived key elements of its agricultural, medicinal, and industrial enterprise; protection from the sun's harmful ultraviolet rays; partial stabilization of temperatures extremes and force of winds and waves; support of diverse human culture; providing of aesthetic beauty and intellectual stimulation that lift the human spirit. (DAILY, 1997, p. 3)

Despite the importance of the subject, there are still inconsistencies in the concepts and the terminology used (Table 4). For instance, Boyd and Banzhaf (2007) consider many of the environmental services as, in fact, being processes and ecosystem functions. Moreover, the terms 'function' and 'services' are considered both as synonyms and as distinct concepts. According to Bastian et al. (2011), 'function' is the mostly used word in the German academic literature, while 'services' gained momentum in the works published in English-speaking countries. For Spangenberg and Settele (2010), ecosystem services (rather than functions) are the term that will mostly likely "help to convey the message to decision-makers in a terminology they are used to and which might stimulate them to act."

Table 4 - Timeline for ecosystem services definitions.

Author (year)	Definition
Constanza et al. (1997)	Benefits people obtain from ecosystems.
Daily (1997)	Conditions and processes through which natural ecosystems, and the species comprising them, sustain and fulfill human life.
MA (2005)	Benefits people obtain from ecosystems.
Boyd and Banzhaf (2007)	Components of nature, directly enjoyed, consumed, or used to yield human well-being. Differentiate ecosystems services and the benefits generated by them.
Fisher et al. (2009)	Aspects of ecosystems that, actively or passively, provide human welfare.
THEEB (2010)	Direct or indirect contributions of ecosystems to human well-being.
Bastian et al. (2011)	The actually used or demanded contributions of ecosystems and landscapes to human benefits and the human well-being.

Source: Based upon information from Bastian et al. (2011).

Notwithstanding the definitions of Environmental Services, the concept of ecosystem itself can also be considered polysemous. According to Moll and Petit (1994) and Bolund and Hunhammar (1999), ecosystem can be defined “as a set of interacting species in their local non-biological environments function together to sustain life.” However, the authors also note that, “ecosystem borders are often diffuse” and in what concerns urban environment, a city can be regarded as one single ecosystem as well as being composed by several individual ones. This characteristic leads to innumerous path of different sizes and relevance, where almost every element can be called an ecosystem. Therefore, a city can be considered a single organism or be composed of several others, as well as be viewed as a fragment of greater and global networks of ecosystems.

At present, the most comprehensive classification of scientific literature on environmental services is provided by the study of Constanza et al. (1997), which identifies 17 main groups of services, functions and examples (Table 5).

Table 5 - Ecosystems services, their functions and examples.

Type	Ecosystem services	Ecosystem functions	Examples
Regulating services	Gas regulation	Regulation of atmospheric chemical composition	CO_2/O_2 balance, O_3 for ultraviolet protection, and SO_x levels
	Climate regulation	Regulation of global temperature, precipitation, and other biologically mediated climatic processes response to environmental fluctuations	Greenhouse gas regulation, Dimethyl sulfide production affecting clouds formation
	Disturbance regulation	Capacitance, damping and integrity of ecosystem response to environmental fluctuations	Storm protection, flood control, drought recovery and other aspects of habitat response to environmental variability, mainly controlled by vegetation structure
	Water regulation	Regulation of hydrological flows	Provisioning of water for agricultural (i.e., irrigation) or industrial (i.e., milling) processes or transportation
	Erosion control and sediment retention	Retention of soils within an ecosystem	Prevention of loss of soil by wind, runoff, or other removal processes, storage of stilt in lakes and wetlands
	Waste treatment	Recovery of mobile nutrients, and removal or breakdown of excess or xenic nutrients and compounds	Waste treatment, pollution control, and detoxification
	Biological control	Trophic-dynamic regulations of populations	Keystone predator control of prey species, reduction in the number of herbivores by top predators
	Pollination	Movement of floral gametes	Provisioning of pollinators for the preproduction of plan population
Provision services	Food production	Portion of gross primary production extractable as food	Production of fish, game, crops, nuts, fruits by hunting, gathering, subsistence farming or fishing
	Raw materials	Portion of gross primary production extractable as raw material	Production of lumber, fuel or fodder
	Genetic resources	Sources of unique biological material and products	Medicine, products for materials science, genes for resistance to plant pathogens and crop pests, ornamental species (pets and horticultural varieties of plants)
	Water supply	Storage and retention of water	Provisioning of water by watersheds, reservoirs and aquifers
Supporting services	Soil formation	Soil formation processes	Weathering of rock and the accumulation of organic material
	Nutrients cycling	Storage, internal cycling, processing and acquisition of nutrients	Nitrogen fixation, N, P and other element or nutrient cycles
	Refugia	Habitat for resident and transient populations	Nurseries, habitat for migratory species, regional habitats for locally harvested species, or overwintering grounds
Cultural services	Recreation	Providing opportunities for recreational activities	Ecotourism, sport fishing, and other outdoor recreational activities
	Cultural	Providing opportunities for non-commercial uses	Aesthetic, artistic, educational, spiritual, and/or scientific values of ecosystems

Source: Constanza et al. (1997).

This paper relies on the concept described in the "Millennium Ecosystem Assessment" (Millennium Ecosystem Assessment, 2005) where “Ecosystem services are the benefits provided by ecosystems,” in which four types of environmental services are considered:

a) Provisioning Services: goods produced and provided by ecosystems including, among many others, food, water, fuel, fiber, genetic resources, natural medicines;
b) Regulating Services: the regulation of ecosystem processes such as air quality, climate and water regulation (i.e., flood and drought control), water purification, erosion control, human diseases control, biological control, and mitigation of risks;
c) Supporting Services: required to produce all other services, and include soil formation and retention, photosynthesis, nutrient cycling, primary production, oxygen production, pollination and habitat provision;
d) Cultural services: intangible benefits that enrich welfare, classified as recreational, aesthetic and spiritual (i.e., religious values, traditional and formal knowledge, inspiration, social relations, sense of place, the value of cultural heritage, ecotourism).

Studies conducted in Stockholm (Sweden), Chicago, Baltimore, and Phoenix (United States) have identified key ecosystem services in urban areas (BOLUND; HUNHAMMAR, 1999; GRIMM et al., 2011; MCPHERSON et al., 1997; PICKETT, 2010). Prominently featured in these studies are urban forests and the analyses of their impacts on urban atmosphere. The study conducted in Chicago reveals the importance, benefits and valuation of urban forests and demonstrates that green areas contribute to save energy, mitigate air pollution, prevent soil erosion, and contribute to climate regulation, among other beneficial effects. The cost of planting and maintaining trees, compared to the economic benefits, represents a saving of 38 million dollars over thirty-year period, or U$ 402 per planted tree (MCPHERSON et al., 1997). It is worth mentioning here that, among some of the most commonly identified urban environmental services, the presence of green areas is always rated as one of the most important, or the main, service provider.

6.2.1 Ecosystem Services and Human Well-Being

The valuing, the preserving and the expanding of nature's capacity to provide city dwellers with environmental or ecosystem services will directly improve human well-being and increase the likelihood of sustaining quality of urban life that faces the steady expansion of the urbanization process. Millennium Assessment describes human well-being, noting that the term subsumes several important elements (Millennium Ecosystem Assessment, 2005).

> Including the basic material for a good life, such as secure and adequate livelihoods, enough food at all times, shelter, clothing, and access to goods; health, including feeling well and having a healthy physical environment, such as clean air and access to clean water; good social relations, including social cohesion, mutual respect, and the ability to help others and provide for children; security, including secure access to natural and other resources, personal safety, and security from natural and human-made disasters; and freedom of choice and action, including the opportunity to achieve what an individual values doing and being. Freedom of choice and action is influenced by other constituents of well-being (as well as by other factors, notably education) and is also a precondition for achieving other components of well-being, particularly with respect to equity and fairness. (Millennium Ecosystem Assessment, 2005, preface)

The conceptual framework for the Millennium Assessment (MA, 2005), suggests that people are fundamental parts of ecosystems. Moreover, as a dynamic interaction exists between them and the other parts, changes in human life implicitly lead to changes in the environment and affect human well-being. In other words, the degradation of natural ecosystems influences the provision of environmental services and exhibits significant effects on the well-being of populations.

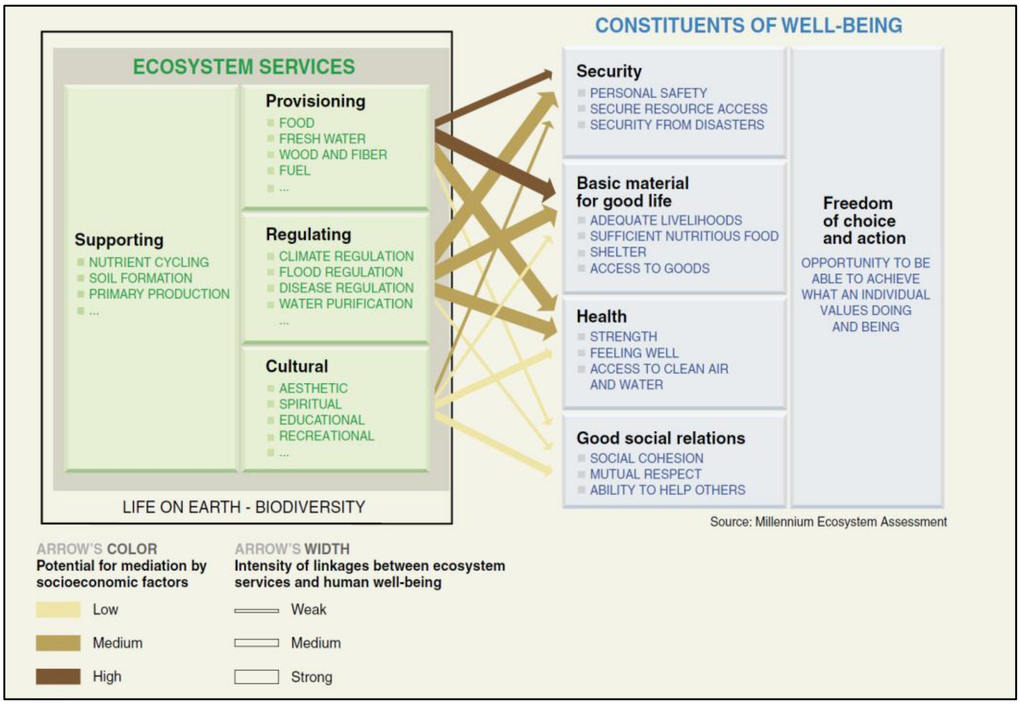
Without questioning the interconnection between human well-being and environmental services, Andrade and Romeiro (2009) state that causality relations are not fully mastered yet:

> The relations between well-being and ecosystem services are complex and nonlinear. When an ecosystem service is abundant relative to its demand, a marginal increase in its flow represents only a small contribution to human welfare. However, when the ecosystem service is relatively scarce, a decrease in its flow can substantially reduce human well-being. (ANDRADE; ROMEIRO, 2009, p. 17)

By linking the interdependence flows of ecosystem services generation with well-being components, the complexity of these flows and their interconnection are evident. The effects on the provision of ecosystem services are closely tied to basic indicators of human well-being.

These associations are observed (Diagram 3), establishing links between ecosystem services and human well-being, as well as highlighting the need to recognize that any action to improve the quality of populations' life and accelerate sustainable development process should take into account the importance of services provided by the ecosystems for the maintenance of human life. Such bond only reinforces the significance of recovery and preservation of nature and its services and functions.

Diagram 3 - Ecosystems and human well-being.



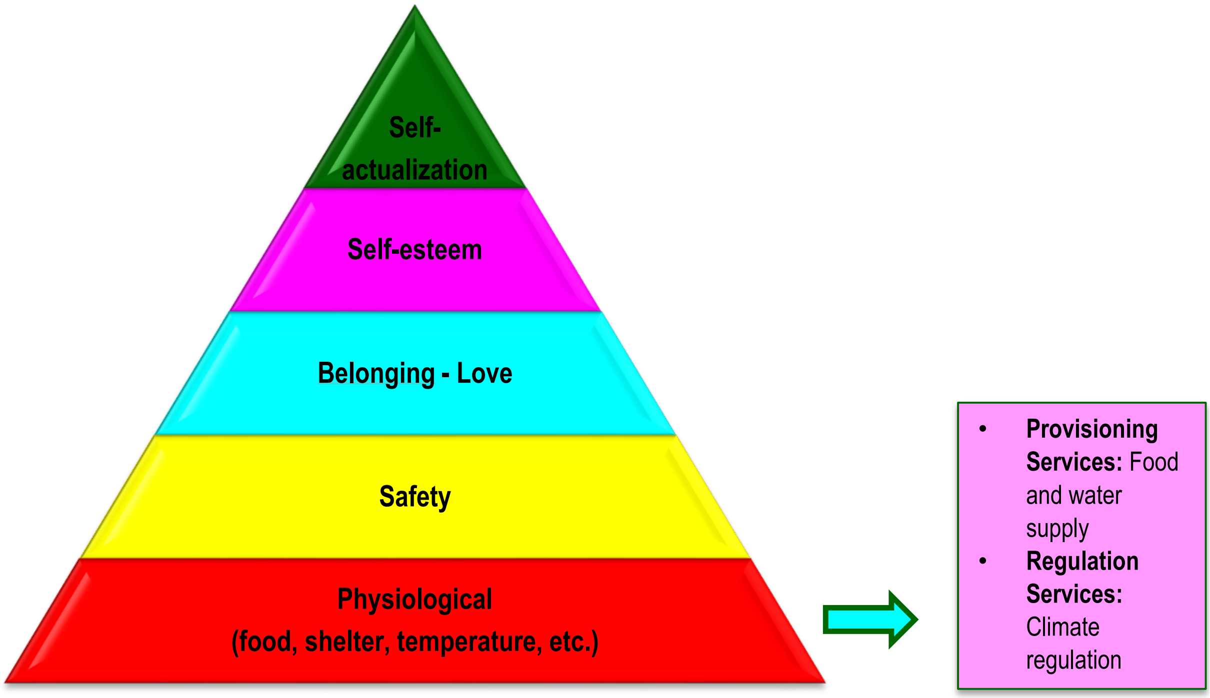
Source: Millennium Ecosystem Assessment, 2005.

6.2.2 Ecosystem Services and Human Hierarchy of Needs (Maslow's Pyramid)

American psychologist Abraham Maslow, a leading expert on human motivation in mid-20th century, created a hierarchy of human needs called Maslow's Pyramid of Needs, where needs are divided into levels to be achieved from bottom up. In this structure, the apex refers to self-realization and in the base presents the most basic physiological needs (CHIAVENATO, 2004).

Physiological needs relate to individual survival and preservation of human species. This closely ties the basis of human needs (i.e., food, shelter) to nature's provisioning capacity, reassuring that the man and his survival are completely dependent on the services provided by ecosystem. Given that food supply and climate regulation are provisioning of environmental services, Maslow, back in 1954, already recognized the nature and environmental issues as the most important actors for human survival (Diagram 4).

Diagram 4 - Ecosystem Services and Maslow's Pyramid.



Source: Millennium Ecosystem Assessment, 2005.

6.3 Belém and Ecosystem Services

Belem is known as the "mango trees city" in allusion to the fruit trees along its main and older streets and avenues, planted by architect Antônio Landi with the seedlings 'imported' from India in 1786. By taking important steps to valorize and expand the city's vegetation areas, the architect made his acknowledgement of the importance of street trees and green area to urban salubriousness very clear and graphic. Perhaps, this initiative should be viewed as one step toward the valorization of ecosystem services and their importance for urban context (IINSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA, 2012; BRASIL, 1995). In those areas, the mango trees help make the typical tropical hot and humid weather more pleasant (INSTITUTO DE DESENVOLVIMENTO ECONÔMICO, SOCIAL E

AMBIENTAL DO PARÁ, 2011). As pedestrians are benefiting from dense and wide canopies that provide shadows, this is an excellent example of Belém common urban scene (BRASIL, 1995).

Apart from Mango trees (*Mangifera indica*), other 80 tree species were identified in Belém, predominantly *Castanhola* (*Terminalia catappa*), Cassod (*Senna siamea*) and *Oitizeiro* (*Licania tomentosa*). Moreover, presence of 759 herbaceous species was also noted, including eight endangered species, within reminiscent forest fragments (BRASIL, 1995; FERREIRA et al. 2012).

6.3.1 Noise Pollution Regulation

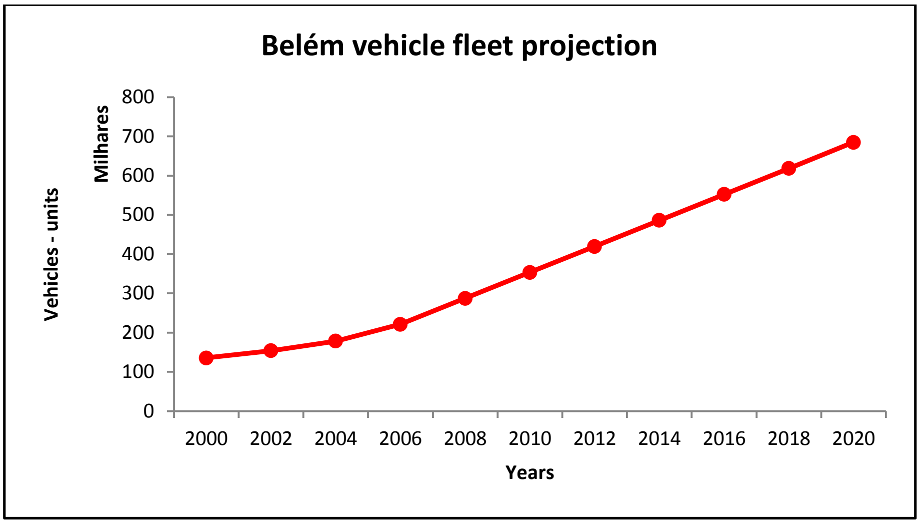
The urbanization process brings along the increase of noise pollution that is reaching alarming rates, contributing to urban environment disturbance to the point of affecting human health (BOLUND; HUNHAMMAR, 1999). Regulation of sound pollution recently became an issue of social interest and an instrument that can be used to achieve a balanced and healthy environment for humankind (MORAES, 2010; PICKETT, 2012).

Bolund and Hunhammar (1999) affirm that, among major influencers of noise pollution, are the traffic and the type of soil used for coating (i.e., concrete, asphalt and other similar materials), which can increase the rate of noise pollution by 3 dBA compared with natural and green soils. Therefore, there is a certainty a need to recognize the contribution of urban vegetation to the decrease in urban noise. However, more work is needed in order to establish the exact link between the two. Given the uncertainty pertaining to the exact contribution of sound regulation services delivered by urban green areas and trees, Bolund also gathered various other measurement examples. According to this author, “a dense shrubbery, at least 5 m wide, can reduce noise levels by 2 dBA and a 50 m wide plantation can lower noises levels by 3-6 dBA” (NATURVARDSVERKET, 1996 apud BOLUND; HUNHAMMAR, 1999). The European Union estimates the overall cost of noise pollution as ranging from 0.2 to 2% of European Union GDP (KOMMUNFORBUNDET apud BOLUND and HUNHAMMAR, 1999). In local terms, this could represent around 360 million (local currency – Real) per year, based on the Belém’s GDP, which was R$ 17,987,323,000 in 2010 (INSTITUTO DE DESENVOLVIMENTO DO PARÁ, 2013).

According to Belém Municipal Law 7990/2000, noise pollution is any sound emission or vibration that is offensive or harmful to physical and mental health, safety and welfare of the individual, or collective. Still, in spite of this law, according to Moraes (2010), there are still needs for norms, patterns and regulation of noise pollution public policies, as actual rules are general and superficial.

In fact, concerns about noise rates in Belém are responsible for a significant increase of citizens' complaints to policy makers and public offices (LEÃO et al., 2008), with particularly high rates noted in 2007. Nonetheless, one of the most significant contributors to urban noise pollution is the growing number of motor vehicles (MORAES, 2010) (Graph 11).

Graph 11 - Belém fleet projection



Source: Moraes (2010).

In 2010, Moraes (2010) developed the Acoustic Map of Belém and the data it provided was used in an attempt to establish a local connection between green areas and sound pollution in Belém. The Acoustic Map measured the noise level in 18 neighborhoods, having all equipment placed on avenues and streets of significant traffic and pedestrian flow. Since this study proposed analyzing the ecosystem services at 21 sites, the following three locations in DASAC lack acoustic data: Barreiro, Miramar and Maracangalha.

The noise level data provided by the Acoustic Map of Belém (MORAES, 2010) was used to accomplish the next stage of the present study. However, as in the Map all the measures are identified by neighborhood, it was necessary to group them according to the administrative districts.

Reports by the World Health Organization (WHO) show that exposure to noise can be extremely harmful to humanity, especially when an individual is exposed on a regular basis. Moreover, after air and water pollution, noise pollution is the environmental issue that most affect people. Innumerous are the health problems caused by noise exposure, ranging from mild discomfort and annoyance, to heart disease and even mortality. Noise exposure interferes in the psychological and mental performance, adversely affects work efficiency, disturbs sleep, and causes many other ailments (WORLD HEALTH ORGANIZATION, 2011). Noise above 65 dB(A) is considered beyond bearable and beyond 85 dB(A) can cause permanent hearing loss if exposure is continued (LEÃO et al., 2008; WORLD HEALTH ORGANIZATION, 1999) (Table 6).

Table 6. Ranges for the relationship between nocturnal noise exposure and health problems.

Noise pressure dB(A)	**Consequences on human health**
< 30	Although individual sensitivities and circumstances differ, it appears that up to this level, no substantial biological effects are observed.
30 – 40	A number of effects are observed; notably an increase in body movements, awakenings, self-reported sleep disturbance and arousals. The intensity of the effect depends on the nature of the source and the number of events. Vulnerable groups (for example, children, chronically ill and elderly people) are more susceptible. However, even in the worst cases, the effects seem modest.
40 – 55	Adverse health effects are observed among the exposed population. Many people have to adapt their lives to cope with the nighttime noise. Vulnerable groups are more severely affected.
> 55	The situation is considered increasingly dangerous for public health. Adverse health effects occur frequently, and a sizable proportion of the population is highly annoyed and sleep-disturbed.

Source: WHO (2011).

In Belém, patterns for acceptable urban noise, regulated by municipal Law 7990/2000, follow the instruction issues by Brazilian Association of Technical Standards (ABNT) and its normative instruction number 10.151. It recommends a maximum of 50 dB(A) noise level during daytime and 45 dB(A) at night for urban residential areas or other sites that require low noise rates, like schools and hospitals surroundings. Moreover, the day and night values of 60 dB(A) and 55 dB(A) are respectively recommended for mixed-purpose areas mostly used by businesses. For industrial zones, maximum acceptable noise level is permitted, 70 dB(A) and 60 dB(A), for the day and night values, respectively (Table 7) (ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS, 2003).

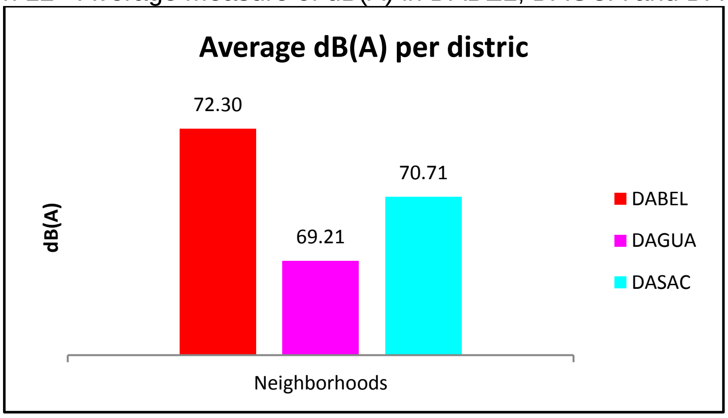
Table 7. Criteria for outside environments in dB(A).

Areas	Day	Night
Farms and ranch	40	35
Urban residential and hospitals	50	45
Mixed, predominantly residential	55	50
Mixed, business and administrative orientation	60	55
Mixed, recreational oriented	65	55
Predominantly industrial	70	60

Source: ABNT (2003).

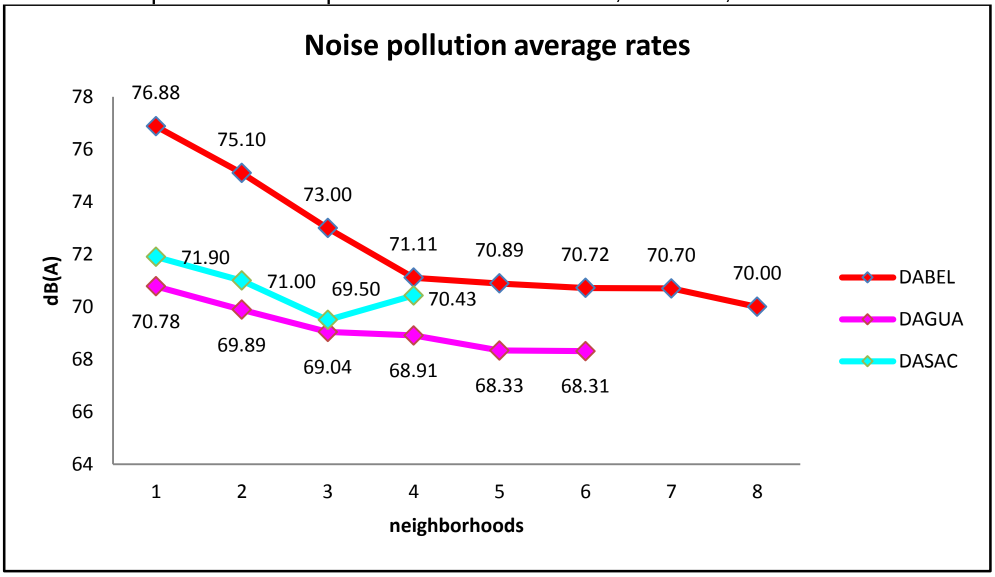
Results from the Acoustic Map indicate that all noise level measures are above the maximum established, with the highest levels noted in DABEL—a district characterized by the lowest area of very dense forest and highest area of bare soil, based on 2009 data. DABEL is also home to the commercial center of Belém, where not only business areas are concentrated, but public offices and most of the city's tourist attractions are located as well. Consequently, in spite of being home for 10% of the citizens and present the lowest density of all three, it attracts more people during the day—the period when all the measures of noise pressure were collected. In Addition, DABEL also presented the highest average noise level of the tree districts—72.30 dB(A)—and the highest average among all the neighborhoods, 76.88 dB(A) (Graph 12 and 13). This same zone also marked the highest single measure of 78 dB(A), on Avenida Almirante Barroso, where the highest flow of transportation vehicles is concentrated. More data on this issue can be found in an earlier study forecasting extreme traffic conditions for Belém (CORRÊA et al., 2005).

Graph 12 - Average measure of dB(A) in DABEL, DAGUA and DASAC.



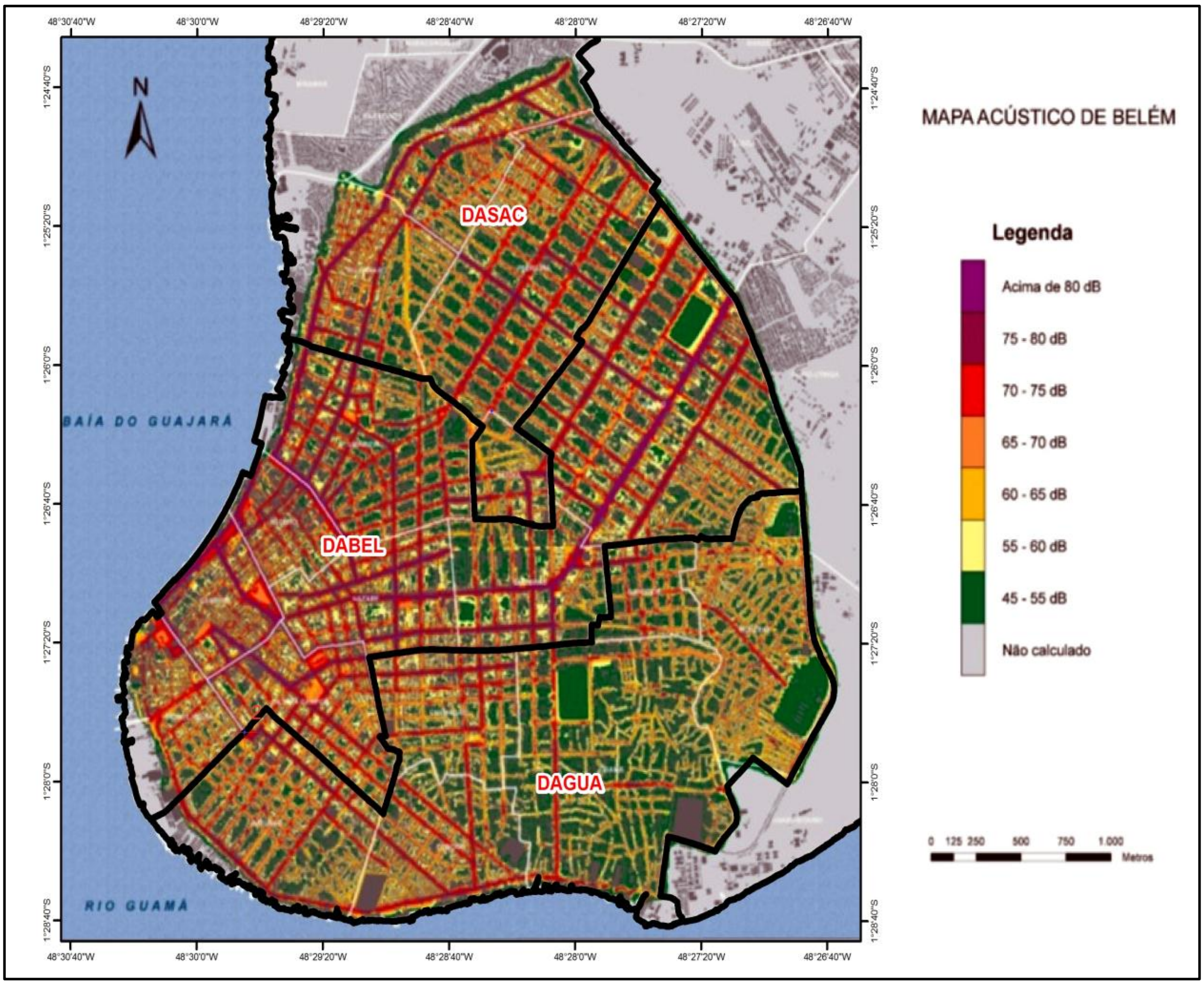
Source: Moraes (2010).

Graph 13 - Sound pollution rates in DABEL, DAGUA, and DASAC.



Source: Moraes (2010).

Imagery 2 - Acoustic Map, districts and neighborhoods.



Source: created using data sourced from Moraes (2010) and BELÉM (2008).

Given that only four out of seven neighborhoods were included in the Acoustic Map, the study of noise pollution is incomplete.[10] Nonetheless, it can be noted that, in terms of noise levels, DASAC is placed in the middle, both based on the general average (70.71 dB(A)) and on the individual measures. This group of neighborhoods forms the district with second highest bare soil area, but with the larger area with very dense vegetation. DAGUA is the most populated of the three districts, but has the lowest noise rates. On the other hand, it has the largest area covered by dense and very dense vegetation, as well as the highest amount of moderate vegetated zones and highest poor vegetated area, as well as the smallest area with no vegetation at all 6.15% (Graph 13) and (Table 8).

[10] The goal of the Acoustic Map was to identify noise pressure in the *1a. Légua Patrimonial*, a division of Belém that includes 18 neighborhoods.

Table 8 - Vegetation percentage in 2009.

Vegetation Area in 2009 (%)			
Year	DASAC	DABEL	DAGUA
Bare	16.11	20.89	6.15
Poor	54.85	51.73	61.84
Moderate	16.71	17.35	22.21
Dense	5.58	6.32	8.78
V Dense	6.75	3.71	6.05

6.3.2 Air Pollution

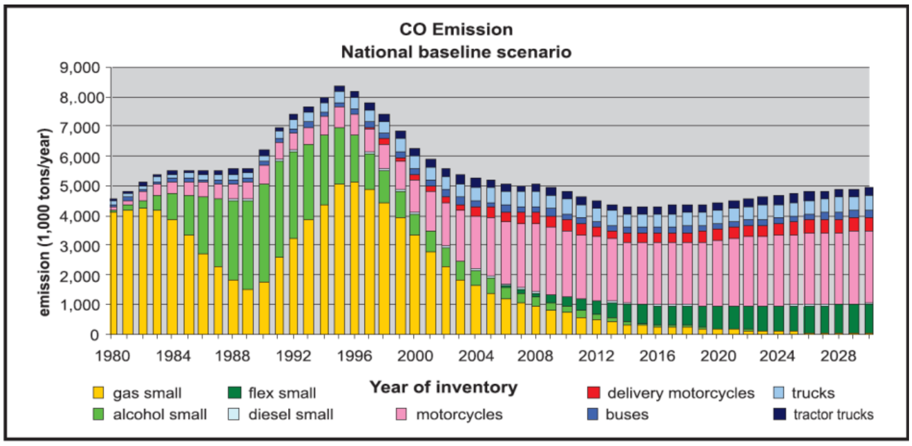
Air pollution has been a worldwide concern and probably one of the most common urban environmental issues. Among the several ecosystem services provided by vegetation, air pollution is definitely one of the most relevant, as it directly affects human health and quality of life in cities, which impacts on the sustainability of urban atmosphere.

Vegetated area, urban trees in particular, can play a noteworthy role in attempts to reduce air pollution in cities. However, the rates vary according to characteristics and relations the site and the type of vegetation itself exhibit (BOLUND; HUNHAMMAR, 1999; NOWAK et al., 2000). The potential of urban trees or shrubs to help reduce air pollution is strongly dependent on tree characteristics, such as the canopy, leaf, stomata, and trunk size, as well as the overall tree height (NOWAK; DWYER, 2007; NOWAK et al. 2006). For instance, proximity to pollutant source and pollution concentration can boost trees' ability to improve air quality. In fact, trees in more polluted industrial zones were more effective in removing air pollutants than trees within higher air quality environments (JIM; CHEN, 2008).

Other factors affecting air pollution are the urbanization process, the loss of vegetation and the decrease in general air quality. The three elements cannot be dissociated from each other since an urban region necessarily signifies altering land use and coverage. This is particularly true if the city is located in an originally forested area, as trees and vegetation have to be eliminated to make room for homes, buildings, roads, constructed sites, and any other typical urban elements.

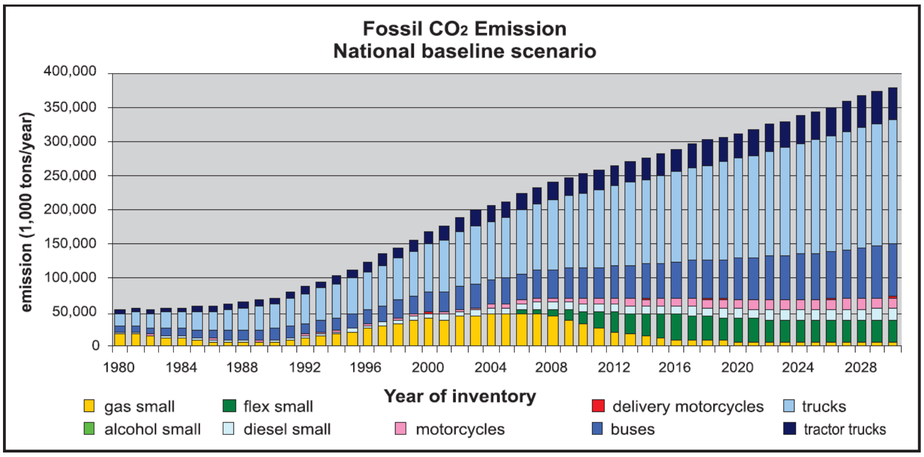
In addition, urban environments are typically characterized by higher numbers of vehicles, which corresponds to higher urban pollutant emissions. To better illustrate and exemplify the severity of air pollution rates in cities, the Brazilian Ministry of the Environment published the results of a national research of 2007. It focused on the status and trends of pollutant emissions by motorized vehicles, to provide the National Program for Controlling Air Pollution Caused by Vehicles with data and instruments to develop policies towards air pollution actions in the next decade. The document relates air pollution to one of its main causes, vehicle CO and CO_2 emission (Graphs 14 and 15), as well as an assessment of annual emissions of other pollutants in some of the largest Brazilian capitals (Graph 16)—Belo Horizonte, Curitiba, Rio de Janeiro, Salvador, Federal District, Porto Alegre, São Paulo, Recife and Vitória. Although Belém is not included in the study, presumably its scenario does not differ from these other Brazilian urban areas (BRASIL, 2011).

Graph 14 - National CO emission baseline and prediction.



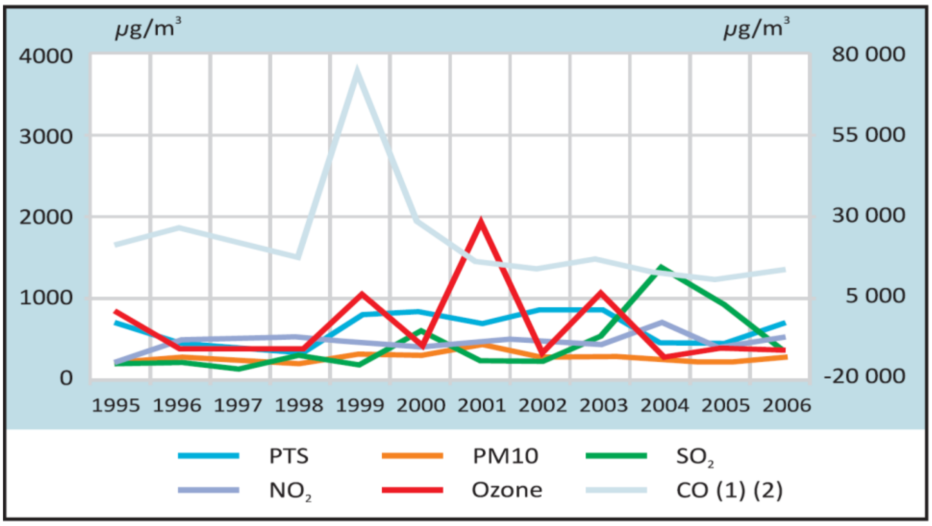
Source: Brazil (2011).

Graph 15 - National CO2 emission baseline and prediction.



Source: Brazil (2011).

Graph 16 - Maximum annual concentration of some pollutants in metropolitan areas of Belo Horizonte, Curitiba, Federal District, Porto Alegre, Rio de Janeiro, Salvador, São Paulo, Recife and Vitória. 1995-2006.



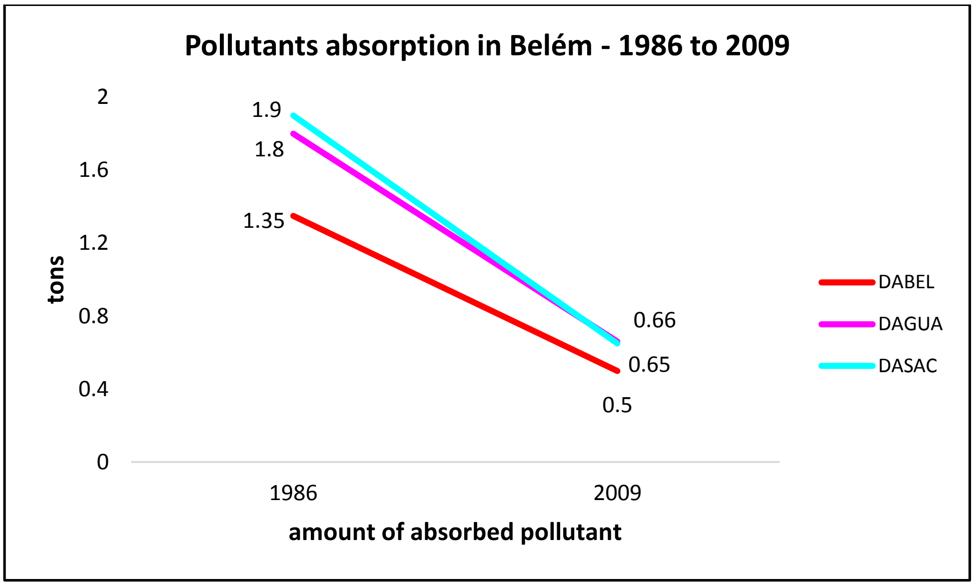
Source: Brazil (2011).

Globally, there are many references on measuring the pollutant absorption capacity of urban trees and green areas, and their effect on air quality. Such measurements often include the assessment of different environments, such as urban and rural forest, as well as consider the rates of volatile organic compounds (VOC), carbon, ozone, and a series of other pollutants (JIM; CHEN 2008; MCPHERSON; NOWAK, 1993; NOWAK et al., 1996, NOWAK et al., 2000; NOWAK et al. 2006; NOWAK; GREENFIELD, 2012; PEDLOWSKI et al., 2003).

In the case of Belém, it was observed that, despite the relevance of the matter, no data on local air pollution was found. In fact, no published scientific paper or even other kinds of reports that would offer pertinent information on the subject were identified.

In 1986, there was 0.099 ha of mixed forest in DABEL, which decreased to 0.037 ha in 2009. In terms of pollutant absorption, this represents a difference of almost one ton less pollutants being absorbed in the 23-year period (from 1.35 t to 0.5 t). DAGUA lost 0.077 ha of mixed forest in 23 years, decreasing from 0.121 ha to 0.044 ha. Therefore, in 1986 1.8 t of pollutants were being absorbed, compared to only 0.66 t in 2009. DASAC mixed urban green coverage decreased from 0.127 ha to 0.0435, from 1986 to 2009, corresponding to a decrease in the absorption rate from 1.9 t to 0.65 t.

Graph 17 - Amount of pollutants absorbed by vegetation coverage in DABEL, DAGUA and DASAC.



Source: the author, 2013.

Facing these records, all three districts suffered similar losses of pollutant absorption capacity over the years under study. Along with the greater loss of vegetation coverage, DASAC was probably the district that suffered the highest negative impact on the quality of urban air, since loss of vegetation corresponds to the loss of ecosystems. This scenario complements the higher increase of bare soil percentage in DASAC than in DABEL and DAGUA, both of which were characterized by higher presence of urban elements. Moreover, DASAC initially had concentrated areas of very dense and dense vegetation, but it suffered significant decrease from 1986 to 2009.

6.3.3 Climate Regulation

Among the most common urban problems that intensify environmental comfort, especially in warmer climates, is the temperature increase within city limits. This condition can be further aggravated by the so-called “urban heat islands” (UHI) (CABRAL, 1995; TRAVASSOS; SILVA, 2008).

According to Cabral (1995), “heat islands are not the only consequence of urbanization, but together with air pollution is one the aspects that affect comfort and salubrity of urban life.” On the other hand, there are also urban cool islands—areas with the temperature lower than their surroundings. Such zones, typically linked to vegetation coverage, can be of great relevance for thermal comfort in cities

(LOMBARDO, 1985 apud CASTRO, 2009). Therefore, the ecosystem services of climate regulation rely on urban green areas as its most vital tools.

In other words, the population in Belém can easily identify some of the benefits or ecosystem services provided by vegetation, where the shade provided by urban trees results in lower temperatures compared to sites directly exposed to sunlight. It is actually part of local culture to “hide” from the sun beneath canopies shadows. In addition, urban trees also play an important role when contributing to helping lowering energy use and cost of operating fans and air conditioners.

For instance, Bolund and Hunhammar (1999) affirm that a single large tree can transpire 450 L of water per day, consuming 1000 MJ of heat in the entire process. McPherson et al. (1997) indicate that vegetation can help decrease temperatures by shading houses. This can be particularly important for Belém, a city with high temperatures all year round and very little variation in between them. In a study published by Santos (2009), the INMET meteorological station records from 1923 to 2006 indicated that an average maximum temperature of 33 ºC was registered in 2005 and an average minimum of 21.1 ºC in 1976, pointing toward an increase in average temperatures since the 1970s. Nevertheless, it should be noted that temperature can vary a few degrees according to the characteristics of the site and these findings should not be generalized.

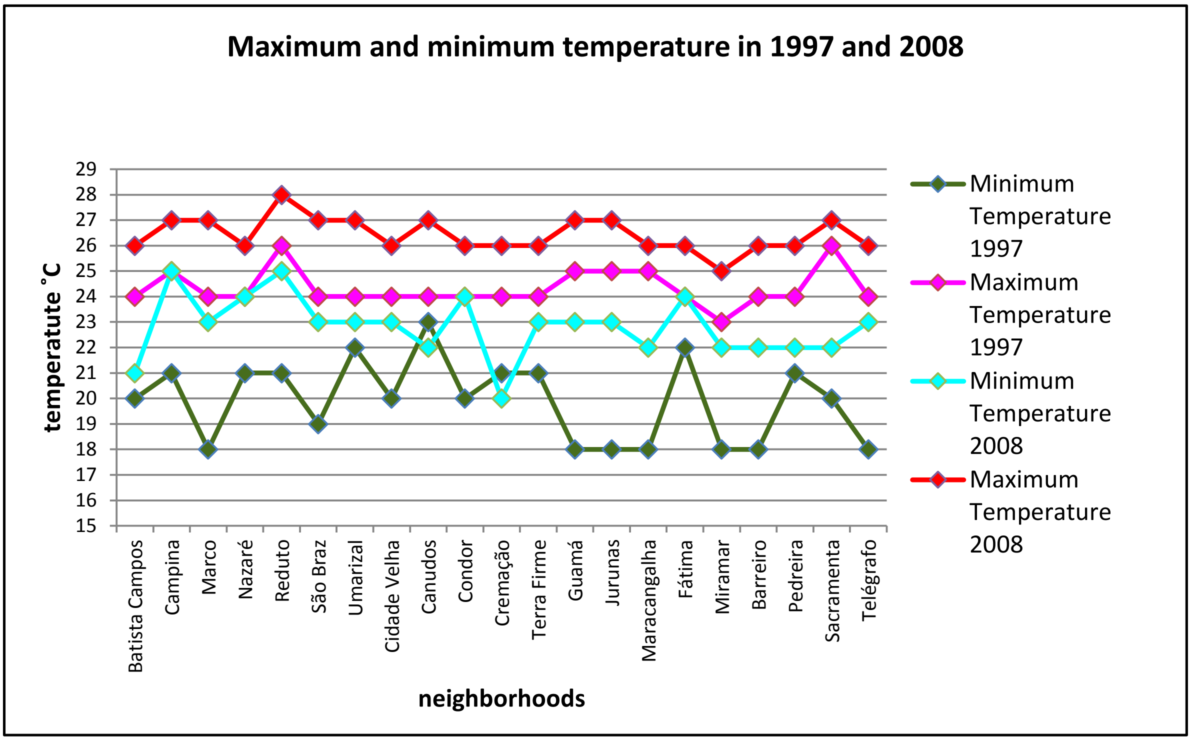
Reduto neighborhood had the higher average temperatures in 2006 (27.5 ºC), followed by Canudos and Fátima, both with 25.5 ºC (COSTA, 2009). They belong to DABEL, DAGUA and DASAC, respectively. On the other hand, the three neighborhoods that marked the lowest temperatures are located in a less urbanized area and outside the study area. Vitorino et al. (2011) affirm that there is a direct link between urbanized areas and higher temperatures. Data on Belém confirm this argument, as higher temperatures are registered in the most urbanized areas (i.e., Reduto).

In addition, a study by Castro (2009) provided further relevant data on Belém’s temperature and climate. The analysis performed in this study covered 47 neighborhoods within RMB, and included all 21 zones distributed along DABEL, DAGUA and DASAC, identifying maximum and minimum temperatures in 1997 and 2008. These measurements enabled a more detailed analysis of temperature data from the districts and their neighborhoods.

When evaluating the temperature patterns in each neighborhood (Graph 18), the highest measurements are found for Reduto, confirming the results reported by Santos (2009). This neighborhood was originally an industrial area that housed many plants and warehouses. Therefore, it was characterized by densely distributed construction sites, with an extended portion of its area covered by bare soil or poor vegetation. Reduto was among the neighborhoods characterized by the highest temperature in 1997 and became the warmest neighborhood in 2008. Castro (2009) also states that the areas where Reduto presented lower temperatures were near neighborhoods of Nazaré and Umarizal. Both are a part of the urban cool island areas and are characterized by a more extensive and denser vegetation coverage (such as parks and squares), responsible for lowering the heat.

In general, work performed by Castro (2009) indicates that temperature is linked to the presence of vegetation coverage. In other words, the highest temperatures in the neighborhoods are linked to the lack of vegetation coverage. The great majority of neighborhoods with highest maximum temperatures in 2008 (Campina, Canudos, Guamá, Jurunas, Marco, Sacramenta, São Bras, Umarizal and Reduto) also exhibit the decrease in the difference between minimum and maximum temperatures, based on the data from 1997 and 2008. This shows an increasing trend in temperature levels.

Graph 18 - Temperatures in Belém neighborhoods.



Source: Costa (2009).

When grouped according to the administrative districts this study focused on (Graph 19), temperature data in DABEL presents the highest average temperature in both 1997 and 2008. These results can be justified by the fact that this district houses five among the eight warmest neighborhoods.

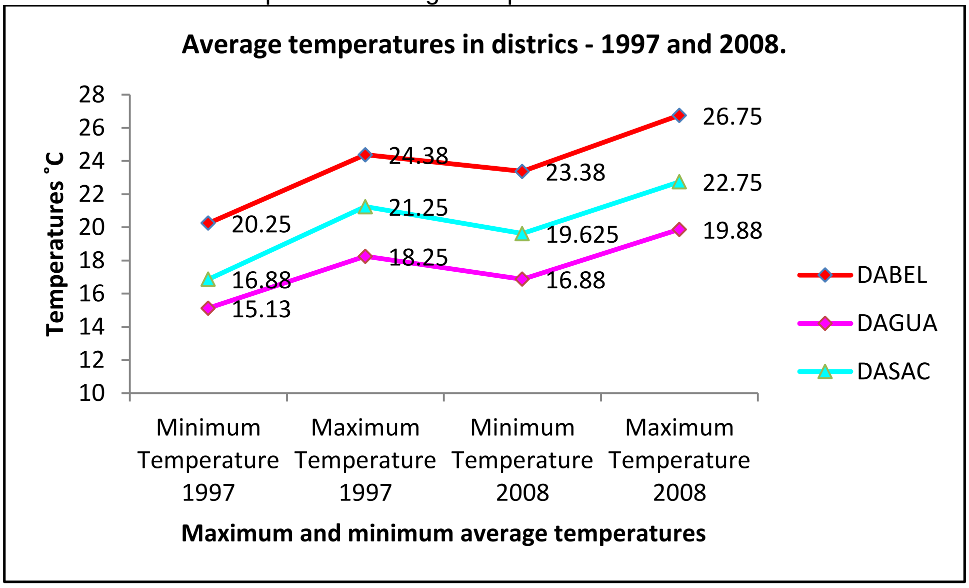
Considering, in the case of Belém, the inverse proportional relation between temperature and vegetation coverage, DABEL presents the highest loss of vegetation, and the highest area with bare soil. In fact, DABEL presents the highest percentage of bare soil and poor vegetation among the three districts.

It is important to mention that, in 2009, there was one urban cool island distributed along Nazaré, São Braz, Batista Campos, Campina, Umarizal and Cremação (the other cool islands are in the RMB). These same neighborhoods are characterized by the greater number of squares, parks and urban trees, some of which date back to the XVIII century urban structure improvements performed by architect Antonio Landi (INSTITUTO DE DESENVOLVIMENTO ECONÔMICO, SOCIAL E AMBIENTAL DO PARÁ, 2011; MERCÊS, 1997).

In addition, the other two districts, DAGUA and DASAC, also displayed a general increase in temperature, as a further evidence of a clear tendency of temperature increase in Belém.

As temperature is one of the elements of climate regulation, it is expected that the data presented above will call attention to the increased environmental discomfort in urban areas and highlight the need to urgently accelerate public policies aimed at recovering and amplifying vegetation coverage. In return, the ecosystem services of climate regulation in Belém will improve, benefiting local population.

Graph 19 - Average temperatures in districts.



Source: Costa (2009).

7 CONCLUSION

Urban environmental issues are directly linked to compromising urban natural resources, as they adversely affect life quality of urban population. The importance of ecosystems services to human life is unquestionable, as is the role of green areas and green coverage in providing such services to cities. Thus, there is a need to standardize even basic definitions of common terms pertaining to environment and its protection. Moreover, measurement techniques and ways to quantify the services and their influence on the maintenance and improvement of urban environment must also be standardized to allow meaningful assessment and comparison.

Belém lacks urban green and other natural areas. It is also characterized by the absence of programs aimed at maintenance and/or recovering the ecosystems. The city is also unaware of the characteristics and distribution of its urban vegetation. Thus far, no urban tree inventory or any similar work has been conducted in the area. Thus, in concluding the present study, also it is proposed that Belém should have an inventory of its urban trees. Since it has been proved that different tree species can provide ecosystem services of different quality and intensity, urgent inventory development in needed, so that the results can help identify the most optimal and most beneficial investment strategies into urban trees and vegetation.

The vegetation coverage in the city of Belém, more precisely in the three administrative districts studied, suffered noticeable decline in the 1986-2009 period, not only quantitatively but qualitatively as well. All three areas have shown losses of vegetation that gradually increased at each of the years assessed. In the three districts, very dense, dense and moderate vegetation coverage decreased, while areas covered by poor vegetation and characterized as bare soil expanded. Consequently, it is of extreme importance to Belém to identify how similar areas cope with local urban pressure and to what extent their vegetation coverage is affected and affects ecosystem services provided by natural environments.

Although scientific proof is always of value, local citizens can also provide valuable input, as they can recall times when vegetation was present in high concentration and describe its loss over time (and its negative impacts). It is widely accepted that, the faster the city expands and the urbanization process progresses, the greater the loss of urban vegetation coverage.

In order to interpret present figures and use them for forecasting future developments, detailed information that would enable monitoring and prompt further actions towards a construction of a healthier city is needed. Despite the relevance of the environmental issues noted here, it is important to mention that Belém and its environmental conditions lack sufficient and relevant scientific data, historical series and, consequently, research outputs, especially in relation to the three ecosystem services here studied. For instance, very little scientific information was available on local air pollution.

Clearly, actions cannot have their maximum benefit without a suitable monitoring system. Past experiences could guide actions in the future and help develop monitoring tools that can be used to assess environmental issues of Belém and the life quality of its citizens.

Some of the study findings pertaining to individual objectives could have been even more fruitful had the lack of data not been a barrier. Even though the most complete analysis was performed on noise pollution, as three neighborhoods from DASAC were not included in the Acoustic Map, they were not assessed by this research.

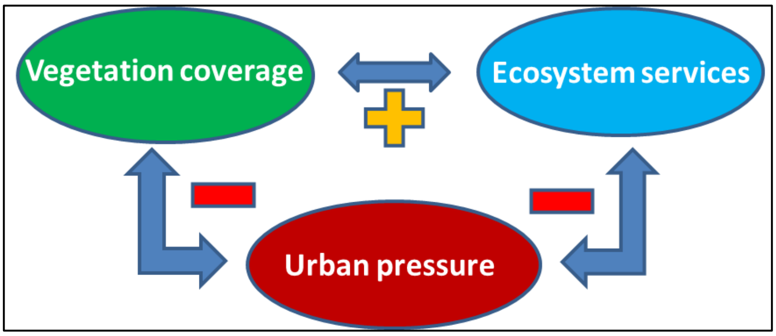
For that reason, this work strongly encourages the Acoustic Map to incorporate the entire city. Moreover, the data should be updated periodically, allowing noise pollution to be measured and monitored. This should hopefully lead to reduction in noise rates throughout Belém.

Another suggestion for future work based on this study pertains to the designing of environmental public policies that should derive from data provisioning, research and monitoring systems. Such policies could be aimed at environmental compensation, for instance, and various other ways that involve public government, both at municipal and state levels, and civil society in general.

If there is no change in the scenario, and vegetation loss continues to advance, it is likely that the city will soon be covered by bare soil or poor vegetation. The immediate effect of this degradation of urban environment on the provisioning of ecosystem services in the three districts explored by this work is evident, and will also adversely affect climate regulation and air and noise pollution reduction.

The direct link of urban noise pollution with vegetation coverage and ecosystem services should be taken in consideration in every way (Diagram 5). While urban noise rates noted in Belém accentuate negative impacts on both vegetation coverage and ecosystem services, the last two present a positive relationship, whereby the increase in vegetation coverage amplifies the offer of ecosystem services and vice versa. Thus, it is evident that urban pressure should be not only contained but transform, so that it can produce a positive or less damaging effects on the environment.

Diagram 5 - Relationship among vegetation coverage, ecosystem services and urban pressure.



Source: the author, 2013.

Although the study findings pertaining to Belém should not necessarily be generalized to wider urban issues, it is clear that urbanization has both advantages and drawbacks. Still, in case of Belém, there is evidence of “wild urbanization” process restraining local citizens’ access to the benefits of living in a city. The most common issue stems from high demographic concentration due to the rapid migration between rural and urban areas. This, in turn, led to a marked increase in poverty, as well as property speculation and real estate market pressures. The citizens in some areas presently lack access to basic services, such as water treatment and sewage system. Moreover, these newly developed districts are characterized by rapid vegetation loss and the decrease of ecosystem services provides by them, including climate regulation, noise pollution and air pollution mitigation.

Considering that the general objective of this work was to understand the relations between ecosystem services and vegetation coverage in three districts, it possible to conclude that, given the accelerated loss of vegetation coverage, with almost no process of recovery and monitoring of green areas, the offer of ecosystem services in Belém is on decline.

In order to quantify, better identify and improve ecosystem services provided by vegetation coverage in Belém, there is an urgent need for an urban tree inventory.

Regarding noise reduction, there is also a clear tendency of aggravating the already high rates, which will result in more serious health problems and lower life quality for the citizens of Belém.

Air pollution data also reveal that much needs to be done to quantify and qualify the air in this city. Guided by studies conducted elsewhere, it can be inferred that quality of urban air is negatively affected by lack of vegetation. Increasing number of vehicles also presents a threat to the ecosystem services.

Finally, climate regulation findings presented in this study also show a tendency of increasing rates in every district. Moreover, for a city located in tropical area with high humidity and temperatures, environmental comfort is of vital importance. As the temperature raises, the urban cool island and its benefits are becoming increasingly endangered.

There should also be permanent dialog between the government and population, not only pertaining to the regulatory issues, such as norms, laws, and order rules. The communication should go beyond the necessary topics and include attempts to establish incentives, so the population feels involved in the process. The land coverage and land use should be high on the agenda, as well as the awareness of environmental issues, helping citizens appreciate their role and ability to contribute to improving quality of life in the city.

This is not only a matter of environmental issues, but also a social economic matter, as the poorest suffer the most as a result of poor environmental quality. However, in a way, everyone should be a part of the solution.

The present study established a relationship between environmental services and urban areas, highlighting the contribution of natural urban ecosystem to public health and increasing well-being of urban citizens. Moreover, it reiterates that most of the problems present in urban areas are locally generated. As a result, the best way to deal with local environmental problems certainly includes local solutions. Each region has its own identity concerning ecosystem services, linked to their own environment. Hence, the importance and value of each service may significantly vary, according to local characteristics.

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