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Abstract. Social and spatial inequality regarding environmental resources and services is one of most complex issues affecting contemporary urban life. The objective of this research is to study the spatial distribution of trees in public areas in Campos dos Goytacazes, Rio de Janeiro, Brazil. This research presents data gathered in ten neighborhoods in Campos. These neighborhoods were split into three distinct groups using wealth levels. Data obtained include the number of trees and private gardens and tree species diversity per neighborhood street. Our results demonstrate that the wealthier neighborhoods have both the highest tree biodiversity and number of trees. In contrast, the poorer neighborhoods present a low biodiversity level and fewer tree species. Our results also showed that age of the neighborhoods was not a factor in explaining the number of trees in public spaces. Socioeconomic and education levels of the population seem to play a more causal on tree quantity and species diversity. This inequality stresses a problem with environmental justice, a characteristic of Brazilian cities intrinsically connected to urban sustainability.

Keywords: urban forest, tree planting, spatial segregation, environmental justice, biodiversity

Introduction

Urban environmental issues are becoming paramount as a result of increased urbanization and the dependence of urban environments for sustaining life in cities. Increasingly, urban environmental inequities have been recognized as worsening the plight of marginalized urban residents and lowering their overall quality of life as compared to urban elites. In Brazil, which has a long history of great economic, political and social inequities, this issue is of special concern (Schonleitner, 1998).

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There has been a calling to better demonstrate how urban inequities manifest as a result of the myriad of social processes that lead to the production of cities (Swyngedouw, 1999). This is important because through understanding the processes that contribute to urban environmental inequities, policy makers can design strategies to combat environmental problems and ultimately improve the quality of life of those that suffer from inequities.

Green spaces and trees planted along streets play a key role in improving the quality of life in urban areas (Spirn, 1995) and thus warrant greater attention within the context of urban environmental inequity. The purpose of the paper is to empirically investigate issues tied to urban environmental inequity, specifically through the context of urban forestry in Campos dos Goytacazes. Urban forestry is the focus of the paper because trees in urban areas have been shown to be one of the most important environmental resources for sustaining urban areas (Nowak, 1994). Furthermore, the link between urban forestry and other urban processes is under researched and in need of further investigation (Heynen, 2003).

The paper begins with a brief introduction of the importance of urban forestry, especially as it contributes to the health of urban environments. Next, notions of urban environmental inequity will be discussed within the context of urban forestry in order to motivate the main research questions within the paper. The study site, data and methods will then be reviewed. A discussion of the empirical results will then be followed by a brief conclusion.

The importance of urban forestry

Urban forests, broadly defined, constitute all the vegetation within urban areas (Rowntree, 1986). There is some skepticism, however, about referring to the collective mass of urban vegetation as an urban forest according to Rowntree (1986) because there is the potential that the notion overstates the situation, and instead some people prefer the idea of an "urban savanna". Urban vegetation is commonly referred to as an urban forest because most of the strategies and practices used for managing urban vegetation initially came from and continue to be updated by foresters.

Urban trees contribute in many ways to the quality of urban life. The existence of suitable trees provide increased and diversified fauna and a multiplicity of landscapes that improves overall urban ecosystem quality (Beatle and Manning, 1997; Bolund and Hunhammar, 1999; Mascaró, 1996; Soares, 1998). More specifically, urban trees contribute to energy and water conservation while at the same time helping to manage carbon dioxide (Heisler, 1986; McPherson, 1990; Meier, 1991; Rowntree and Nowak, 1991; Nowak and McPherson, 1993). Oke (1989) suggests urban greenspace moderates urban climate. To this end, the lack of suitable tree coverage causes higher temperatures (McPherson and Nowak, 1993; Nowak, 1993; Rowntree and Nowak, 1991) and increased quantities of particulate matter suspended in the urban atmosphere. Sanders (1986) suggests urban trees help control flooding and rainfall runoff. Cook (1978) suggests urban trees reduce urban noise levels. Among social benefits, urban trees reduce human stress levels (Ulrich, 1984), enhance the attractiveness of cities (Schroeder, 1989; Oliveira, 1991), positively contribute to the social fabric of inner-city neighborhoods (Brunson *et al.*, 1999), and promote social integration of older adults with their neighbors (Kweon *et al.*, 1998). Trees can also conserve energy, reduce storm-water runoff, increase property values and provide a sense of connection to nature

(Akbari *et al.*, 1992; Lormand, 1988; Sanders, 1986; Anderson and Cordell, 1988; Dwyer *et al.*, 1992). While there are inherent costs to the planting and maintenance of urban trees, they are one of the largest contributors to improved urban qualities of life (Grey and Deneke, 1986).

An emerging body of literature suggests that urban trees provide many benefits that spill over into public space, and thus are of social and cultural value (see McPherson, 1992). As a result, it is reasonable to apply a social justice framework to the distribution of urban trees. A discussion of urban environmental inequity provides the necessary framework for the research questions within this paper.

Urban environmental inequality and urban forestry

Various authors suggest that residential segregation in North American cities is directly associated with race (Kushner, 1980; Feagin and Feagin, 1986; Bullard and Feagin, 1991). Bullard (1995) indicates that most North American cities are facing a process of impoverishment and environmental degradation, especially in areas occupied by racial minorities, demonstrating a direct relationship between household quality and urban infrastructure. Accordingly, Bryant (1995) argues that the negative impacts of environmental degradation are concentrated in areas occupied by social groups characterized by low wealth and non-Anglo backgrounds. Alva (1997) indicates that environmental segregation also occurs in Latin American cities where smaller, wealthier segments of society have access to public services and environmental amenities while the majority of the population lives in poverty and has no access to these benefits. This situation has been aggravated by an unequal allocation of economic resources in urban infrastructure that reinforce the process of urban segregation.

Low and Gleeson (1998:1) suggest: "The question of justice is today being reshaped by the politics of the environment. For the first time since the beginning of modern science we are having to think morally about a relationship we have assumed was purely instrumental." To this end, additional evidence suggests that spatial segregation in the placement of green spaces leads to social conflicts in urban areas (Martínez-Alier, 1999). Spatial segregation among social classes in urban space results from a process in which different classes or segments tend to concentrate their presence in different regions or neighborhoods according to wealth. As a result of distinct levels of wealth accumulation, the urban environment then becomes a mosaic of segregated social spaces marked by unequal access to resources (Campbell, 1999). Martínez-Alier (1999) further indicates that a major characteristic of segregated urban spaces is an unequal access to environmental services in which poorer segments are left in worse living conditions. At the same time, other authors have suggested that the access to green spaces and trees can be used as a key indicator for measuring the degree of social access to urban environmental amenities (Novaes, 1997; Seabra, 1991).

Various authors have also related the presence of trees in public areas to increased property values. The results of such studies have indicated that areas with high vegetation cover are usually occupied by the wealthy segments of society (Anderson and Cordell, 1988; Morales *et al.*, 1983; Payne, 1973; Neely, 1988; Miller and Tangley, 1991). Meanwhile, the uneven distribution of trees serves to reinforce the process of social segregation because poor neighborhoods do not have same type of access to the environmental services provided by trees. Growing evidence also suggests that the results of environmental degradation and profits produced by economic activities are not equally distributed in the population. While privileged social groups accumulate profits, low income and minorities face degradation of their living space (Bullard, 1993; Haughton, 1997).

The recognition that a direct relationship exists between environmental and social justice has grown, as well as the acknowledgment that this relationship is of great importance for the future of human society (Friedmann, 1989; Harvey, 1992; Haughton, 1997; Smith, 1994). According to Bryant (1995) environmental justice refers to "those cultural norms and values, rules, regulations, behaviors, policies, and decisions to support sustainable communities, where people can interact with confidence that their environment is safe, nurturing, and productive." Environmental injustice occurs when a community is being neglected or not served equally by the State regarding the protection of their lives and the minimization of pollution and costs associated with its occurrence (Bretting and Prindeville, 1998).

The environmental agenda has widened its scope with the insertion of social issues, especially with the recognition that over the years, less empowered social groups have had diminishing access to a clean environment (Haughton, 1999). Haughton states that the debate on the matter of environmental and social justice is being placed into broader issues such as economic structure and social and political systems that are deemed as domains in which inequity between different social groups is materialized. Social equity and environmental protection are postulated as the basis of sustainable economic development (Campbell, 1997). Campbell argues that planners should include an interface between environmental and social theories in their daily practices to reduce conflicts related to economic inequity and environmental injustice in urban areas.

This paper seeks to unveil social segregation patterns in a medium-sized coastal city of southeast Brazil through the measurement of tree abundance and species diversity. The goal of the study is to test the hypothesis that tree density, species biodiversity, and existence of yard space vary according to neighborhood wealth levels. Furthermore, another objective of this study is to verify the existence of a relationship between social and environmental segregation in Campos dos Goytacazes based on the potential relationship between the distribution of wealth and both the amount and diversity of tree species.

Material and methods

The study was carried out in Campos dos Goytacazes (Latitude 21° 45' 15" S and Longitude 41° 19' 28' W), a city in the north of Rio de Janeiro State. According to Köppen, Campos can be classified as a tropical wet and dry (Aw) climate type and an average annual temperature between 20 and 23°C, with a maximum average temperature of 32°C (figure 1). Average annual rainfall is 1300 mm, unevenly distributed, with dry periods of high temperatures (FEEMA, 1993).

Campos dos Goytacazes was founded in 1835, whose economic basis relied heavily on sugarcane fields. Since the breakdown of the surrounding sugar industry in the early 1950's, Campos dos Goytacazes has experienced rapid urban growth. As a result, most urban areas created since the 1950s were built on former sugarcane fields. This fact makes the study

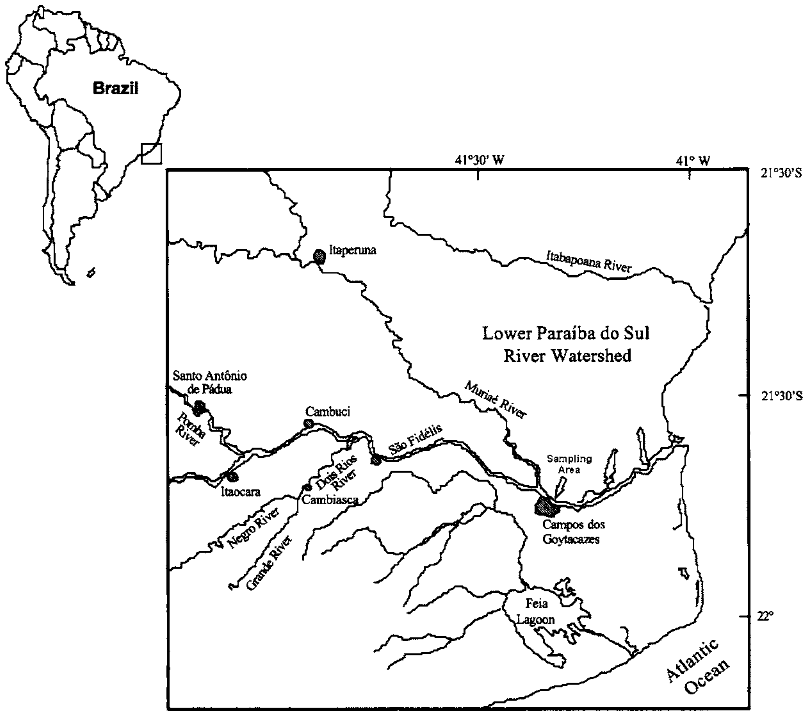

Figure 1. Geographic location of Campos dos Goytacazes in Brazil and in the Northern Fluminense region of Rio de Janeiro state.

of urban forests much easier. Because of the sugarcane monoculture, new neighborhoods were completely unvegetated at their point of formation. Therefore, the bulk of urban forests resulted from plantings by private and public agents.

For the present study, we randomly selected ten neighborhoods within the city limits and divided them into three categories using the square meter land value established by real estate market evaluations obtained from real state agencies in Campos dos Goytacazes. From the sampled neighborhoods, Flamboyant, Parque Tamandaré, Residencial Bougainville and Residencial do Horto were classified as Class 1 (i.e., formal or recognized neighborhoods with high land values); Parque Prazeres, Jockey, Turf Club, Parque Califórnia e Nova Brasília were classified as Class 2 (i.e., neighborhoods with low and average land values), and Favela D'Aldeia was classified as Class 3 (i.e., an informal neighborhood). Only one Class 3 neighborhood was sampled because our main interest was to study the condition of urban forests on neighborhoods in which the local government charges public taxes and is legally obligated to provide public services such as tree planting and management.

Data used in this study were also obtained from randomly-selected streets in each neighborhood. Our measurements were conducted only in public areas due to accessibility problems. We measured the number of trees per square meter, the presence (or absence) of trees per lot, the number of gardens per building, and species diversity. The Spearman correlation test was applied to the data to establish possible relationships between wealth (using the value per square meter of the land as reference) and the number of trees per square meter and per building, as well as the number of gardens per building. In this study, tree species abundance was assessed using an entropy statistic proposed by Shannon and Weaver (1949). We selected the Shannon-Weaver Index because it takes into account species richness and proportion of each species within a given community (Ricklefs, 1996). The Shannon-Wiever Index is calculated through the equation

$$H' = -\sum p_i \cdot \ln \cdot p_i$$

where the quantity p_i is the proportion of individuals found in the ith species. The maximum diversity ($H_{\max}$) could be found in a situation where all species were equally abundant (Magurran, 1991). Magurran adds that, although a heterogeneity measure, the Shannon-Weaver can be used to measure the evenness of the abundance of species. The measure of evenness is calculated by the ratio of observed diversity to maximum as

$$E = H'/H_{\max}$$

Results and discussion

Data were collected to assess urban forest structure in relation to the other aspects of the built environment. We excluded Favela D'Aldeia from further data analysis because no trees or private gardens were found in that neighborhood. Thus, Table 1 shows the nine neighborhoods used in the study with the number of trees per m^2, trees per building, garden per building, the age of the neighborhood and the designated class of each neighborhood.

Table 1. Trees per Square Meter (Tree$\cdot$m^{-2}); Trees per Building (Tree$\cdot$Bldg^{-1}), Private Garden, Land Value (m^2 value) and Neighborhood Age

Neighborhood	Tree$\cdot$m^{-2}	Tree$\cdot$Bldg^{-1}	Garden$\cdot$Bldg^{-1}	m^2 value (US$)	Age	Class
Flamboyant	0.30	3.93	1	100	18	1
Res. Horto	0.11	0.86	0.70	52	09	1
Res. Bouganville	0.10	1.00	0.50	108	13	1
Pq. Tamandaré	0.08	0.74	0.93	104	45	1
Pq. Prazeres	0.04	0.26	0.33	11	43	2
Jockey Club	0.07	0.40	0.53	24	47	2
Turf Club	0.05	0.37	0.46	31	44	2
Pq. Califórnia	0.04	0.35	0.22	39	29	2
Pq. Nova Brasília	0.05	0.38	0.26	11	46	2

Table 2. Spearman Correlation Coefficients between land value (m^2 value) and age and the existence of trees and gardens in nine formal neighborhoods in Campos dos Goytacazes, RJ

Variable	m^2 value	Age
Tree·building^{-1}	.74*	−.42
Garden·building^{-1}	.59*	−.20
Tree·m^{-1}	.72**	−.45

*99% confidence level.
**95% confidence level.

Our results indicate that the abundance of trees in Campos dos Goytacazes follows the same aggregation trend present in the land market values. In fact, we believe that our data confirms the existence of a direct relationship between neighborhood wealth and tree abundance. Accordingly, our results confirm the existence of a significant correlation between land value and all the measured variables (Table 2). Meanwhile, we found that the age of neighborhoods does not have a direct impact on tree abundance or on the existence of private gardens. We also ran three linear regression models using the three dependent variables against land value and neighborhood age and results were not significant. These results support the hypothesis that abundance of trees directly correlates to land value regardless of neighborhood age.

Based on the Shannon-Weaver Index, we identified that Class 1 neighborhoods presented an evenness ratio (E) closer to 1 than most Class 2 neighborhoods. These findings are emphasized by the fact that Parque Prazeres displayed the worst performance of tree quantity and species abundance. The exception to this pattern was Parque Califórnia that showed the greatest degree of evenness (Table 3).

Table 3. Shannon-Weaver Diversity Index (H) for nine formal Neighborhoods in Campos dos Goytacazes, RJ

Neighborhood	No. of species	H'	H_{max}	E
Flamboyant	23	2.59	3.14	0.82
Bougainville	14	2.03	2.63	0.77
Parque Tamandaré	19	2.44	2.94	0.83
Residencial do Horto	14	2.34	2.63	0.89
Parque Califórnia	16	2.50	2.77	0.90
Jóquei	14	1.84	2.63	0.70
Turf	11	1.59	2.40	0.66
Nova Brasília	11	1.80	2.40	0.75
Parque Prazeres	16	1.59	2.77	0.57

* H_{max} considering that all species were equally representative, thus the maximum that could be attained in the neighborhood.

Nowak (1994) points out that urban forest structure, including the spatial distribution of trees, is directly linked to land use, intensity of urbanization, and settlement age—with land use being the driving factor. Meanwhile, our data indicates distinct vegetation patterns in neighborhoods that are similar both in form and age of settlement. This is an important result because it demonstrates that areas that exhibit similarity with regard to urban form, but with distinct levels of wealth, can present very distinct vegetation patterns regardless of their age.

Moreover, we also constructed a scatter diagram that showed the unique characteristics of Flamboyant in terms of tree abundance and species diversity when compared to all other formal neighborhoods. We suggest that due to its high number and diversity of trees, Flamboyant presents a very distinct profile when compared to the eight other neighborhoods included in our study because of the high socioeconomic and educational standards of its population.

Data on species diversity also show an uneven pattern of individual species distribution among different neighborhoods. For example, 54% of all trees sampled in Class 2 neighborhoods belonged to the species *Caesalpinia peltophoroides*, a rather fast-growing and abundant tree species in Campos dos Goytacazes. In Class 1 neighborhoods, the amount of individual trees belonging to this species reached only 25%. Parque Prazeres—a Class 2 neighborhood-showed the worst performance in terms of tree species diversity with a total of nine species being found and a clear dominance of *Caesalpinia peltophoroides* that accounted for more than 70% of all trees sampled in that neighborhood. On the other hand, a total of twenty three species were found in the Flamboyant neighborhood, and *Caesalpinia peltophoroides* represented only 35% of all trees sampled there. A fact that must be taken into account is that in all neighborhoods where trees were found, *Caesalpinia peltophoroides* was the predominant species, ranging from 5 to 71% of the number of trees in the neighborhoods. The fast-growing *Bauhinia* sp, *Delonix regia*, *Tabebuia* sp., *Licania tomentosa*, *Ficus benjamina* and *Spatodea campanulata* were also found frequently. A clear demonstration that fast-growing trees were favored for planting in public areas in Campos dos Goytacazes was the fact that the Leguminoseae family was predominant with 61% out of the 44 identified tree species. In addition, only 60% of all trees planted on public areas belonged to native species, reinforcing the role of exotic species in the urban space of Campos dos Goytacazes.

Nonetheless, it is necessary to point out that overall results in Campos dos Goytacazes are not different from other Brazilian cities. A study done in the municipality of Rio Claro in the Brazilian state of São Paulo estimated that 80% of all trees planted in Rio Claro were of the species *Caesalpinia peltophoroides* (Cavalheiro, 1991). Both studies appear to demonstrate that the option for planting fast growing trees is widely spread among staff working in governmental agencies in charge of Brazilian urban forestry programs. The problems associated with tree monoculture have been already indicated. A study in Minneapolis (USA) showed that the extensive planting of a single species (i.e., elm tree) resulted in the loss of 90% of all trees (or all tree species within the city), prompting high economic and environmental losses for that city (Spirn, 1995). Tree monoculture may indeed cut economic costs of urban forestry programs in the short-term but results in negative effects in the middle- and long-term.

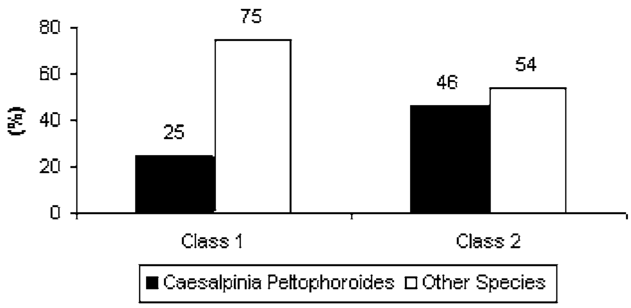

Figure 2. Presence of the species *C. Peltophoroides* in relation to other species in Class 1 and Class 2 neighborhoods.

In the present case, the dominance of *C. peltophoroides* may not only decrease the environmental services provided to human populations but also decrease the opportunities for the presence of other tree species in the local environment. Moreover, besides *Caesalpinia* being the most abundant tree species in Campos, its dominance in low-income neighborhoods clearly represents an additional disadvantage to these areas (figure 2).

Most of the *C. peltophoroides* were fully grown trees, many of which have been subjected to drastic pruning more than once, which is apparent from the irregular, rather, abnormal canopy shape, and which, according to records, were planted by the Municipality several years ago. No records exist for other tree plantings, neither in terms of species type nor time of planting for most neighborhoods. The neighborhood found to have the greatest amount and high diversity of tree species is the one where the inhabitants themselves planted trees along the streets and squares—Flamboyant.

The overwhelming predominance of *C. peltophoroides* might be explained by the ease of obtaining its viable seeds and its growth rate compared to other species, considering the relative scarcity of knowledge about tropical ornamental trees in the past. Nevertheless, considering the present state, other species (and families), should be considered when planning tree planting in urban areas, taking into account many different aspects such as beauty, growth, canopy shape, susceptibility to pests and disease and pollution tolerance.

The quality and life cycle of trees in Campos is also affected by tree management strategies adopted by the local government, especially tree trimming. According to Lutzenberger (1992), trees do not require trimming to stay healthy. Lutzenberger points out that trimming should not take place as part of routine maintenance procedure but should be done sparingly. Local agencies responsible for tree management in most Brazilian cities, however, routinely trim urban trees, resulting in tree mutilation and jeopardizing aesthetic and environmental values of urban trees (Soares, 1998). This scenario is especially acute in Campos dos Goytacazes. During our field work, we uncovered that drastic trimming and tree removal were widespread practices in all sampled neighborhoods. Given that *Caesalpinia peltophoroides* has been chosen as one of the most favored species for clear-cutting by the Municipal Secretariat of Environment, the process of environmental impoverishment associated with trimming and clear-cutting is more strongly felt by Class 2 neighborhoods where this species is dominant.

Conclusion

The results of this study indicate that tree abundance and diversity is not evenly distribution amongst neighborhoods with different economic standards. Our results show that while high-income neighborhoods contain pockets of high environmental standards, most middle- and low-income neighborhoods show just the opposite. Therefore, while high-income neighborhoods have access to the better environmental services provided by trees (e.g., lower temperatures, landscape diversity, ecological dynamism), middle- and low-income neighborhoods are left with more arid landscapes which leads to higher annual temperatures and more degraded environments.

The practical result is that wealthier neighborhoods that already have access to better public and private infrastructure also have an advantage in terms of the environmental amenities provided by trees. We argue that the social and environmental distortions uncovered by this study are not casual but result from policy decisions made by the local government. The local government has not yet recognized the existence of unequal ecological quality in Campos dos Goytacazes and as a result continues to reinforce environmental segregation by focusing its tree planting efforts in high-income neighborhoods. Distinct wealth levels may also result in different levels of residential involvement in tree plantings and maintenance efforts, reinforcing social and spatial segregation in Campos dos Goytacazes. We suggest that the solution for achieving social equity would be a participatory planning process that recognizes the existence of spatial and environmental segregation in cities like Campos dos Goytacazes. Finally, we suggest that there is a clear need for forestry programs targeted at increasing tree abundance and species diversity as a means of enhancing the environmental quality of urban areas located in the tropics.

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