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DESIGNING SAMPLE PLOTS FOR THE INVENTORY OF URBAN AFFORESTATION IN THE CITY OF CURITIBA, PARANÁ STATE, BRAZIL

Everaldo Marques de Lima Neto[1], Daniela Biondi[2 3]

ABSTRACT

Inventories of urban trees performed by sampling methods are often complex because they need a delineation of the sites for data collection and the structure of the city can be a barrier to carry out the inventory. This study compared the area of plots measured conventionally with areas calculated in the GIS environment. We used three plots of an inventory conducted in the square-shape (500 x 500 meters) in 1984. We used the map of streets of Curitiba City, containing streets, blocks, and neighborhoods in a vector format. The areas of the plots were stored the polygon type in the GIS environment and measured in the filed with a measuring tape. The differences in the measurement of three parcels in the GIS environment with those found in conventional inventory were 0.005, 0.638 and 0.723 hectare. These differences occurred due to limiting factors in field measurements related to systematic and random errors of observation in conventional inventories, such as the topography and malfunctioning of equipment. We found that GIS programs greatly facilitate the fieldwork, especially in the delineation of plots.

Key-words: Geographic information system; Sampling; Inventory costs.

DELINEAMENTO DE UNIDADES AMOSTRAIS PARA O INVENTÁRIO DA ARBORIZAÇÃO DE RUAS EM CURITIBA, PR

RESUMO

Os inventários de arborização urbana feitos por métodos de amostragem são, muitas vezes, complexos porque necessitam da delimitação de parcelas para as coletas de dados e a estrutura da cidade pode ser uma barreira para o caminhamento da parcela. O objetivo desta pesquisa foi comparar as áreas das parcelas medidas em inventário convencional com áreas calculadas em ambiente SIG. Foram utilizadas 03 parcelas de um inventário realizado em 1984 com forma de um quadrilátero (500 x 500 m). Utilizou-se o mapa de arruamento de Curitiba, contendo ruas, quadras e bairros em formato vetorial. As áreas das parcelas foram armazenadas com o tipo polígono em ambiente SIG e mensuradas em campo com trena. As diferenças na medição das três parcelas em ambiente SIG com as encontradas no inventário convencional foram: 0,005, 0,638 e 0,723 ha. A obtenção destas diferenças foi devido aos fatores limitantes para medições que ocorrem em campo relacionado com os erros sistemáticos e aleatórios de observação em inventários convencionais, tais como: a topografia do terreno e defeitos em equipamentos. Constatou-se que os programas de SIG facilitam muito a execução dos trabalhos de campo, principalmente na delimitação de parcelas a serem inventariadas na forma convencional.

Palavras-chave: Sistema de informações geográficas; Amostragem; Custos do inventário.

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[1]Engenheiro Florestal, Doutorando em Engenharia Florestal, Universidade Federal do Paraná. Curitiba – PR, everaldo.limaneto@gmail.com
[2]Drª. Professora Associada, Universidade Federal do Paraná. Departamento de Ciências Florestais, Curitiba – PR, dbiondi@ufpr.br
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INTRODUCTION

Inventorying urban afforestation is the best way to know the arboreal heritage of a city, providing information about priorities of actions concerning the use pesticides, removal of trees and/or planting and replanting, as well as needs for maintenance.

The conventional inventory of urban forests requires the measurement of a large number of variables and it is costly, as it requires walking around the streets, a minimum number of people to facilitate data collection, besides the long time to measure the variables.

The use of geographic information systems (GIS) has been a good tool in several urban studies to minimize the difficulties in collecting data of the site. However, its use in inventorying urban afforestation is still scarce. For Lima Neto et al. (2010), the GIS integrates the number of trees with large storage capacity and spatial data representation in various levels of detail. Thus, it is important to have satellite images and/or aerial photographs of high spatial resolution and quality to measure the area and the dendrometric variables in inventories of urban forests.

In addition, it is important to delineate the areas to be inventoried. The first step is to identify the sampling unit and the tree population structure. The sampling unit can be a street, block, parts of streets, a group of blocks, or may be the result of a division process of areas using city maps of the area to be inventoried (SILVA et al., 2005).

Schreuder et al. (1993) state that the sampling unit must have a size that includes a representative number of trees, but small enough that the time used in data collection is not too long and too costly.

The accuracy of the inventory depends on the variability of the tree population represented in the sampling units and the intensity of sampling employed. Among the sampling units are the sample sizes, shapes, and arrangements that better represent the various conditions of population variation, allowing to inventory each unit with greater precision and reduced costs (SOARES, 1980). In terms of shape, the most common sampling units are square and rectangular.

Inventories require large amounts of resources, and the greater the number of variables studied, the greater the costs to carry out the inventory (SILVA et al., 2007).

Thus, when planning the inventory of urban forests, we must avoid the super sizing of sampling units. For that, it is necessary to establish a sampling pilot to ensure that the final product is not measured beyond its representativeness. Another problem is to establish objective criteria for the delineation of sampling units, that is, the sampling units must have its vertices well defined and accessible during the fieldwork. Access to sampling units is relevant because of the walk around to carry out the inventory. Urban areas have corners and vertices of the parcels located inside lots and/or residences, which hinder carrying out an efficient inventory.

The study of sampling units is also important for the proper planning of human and financial resources in the qualitative and quantitative inventories of urban afforestation (SILVA et al., 2005). This is important because of the need to increase the likelihood of better distribution of sampling units, decreasing the time to conduct inventories, providing greater efficiency of the works, among others (MILANO et al., 1992).

In this sense, the objective of the current study was to compare the area of sampling units measured in a conventional inventory, with areas calculated in the

GIS environment to facilitate the inventory of urban forests and reduce the time used for measurements with higher accuracy and smaller errors of area delineation.

MATERIAL AND METHODS

Location and characterization of the study site

The municipality of Curitiba, capital of the Paraná State, Brazil, is located in the southern region of the country and in the eastern region of state (25^o25'40"S lat; and 49^o16'23"W long) (Ground Zero – Tiradentes Square) (Fig. 1).

According to Köppen classification, the city has type Cfb climate, defined as temperate (or subtropical) humid, mesothermal (no dry season), with mild summers, and winters with frequent frosts and occasional snow precipitations. Temperature average 20.87 ºC in summer (period 2000-2009) and 14.77 ºC in winter (period 2000-2009). The average elevation is 934.6 m above sea level and the municipality covers an area of 435 km^2, with extension of 35 km North to South, and 20 km in the East-West direction (IPPUC, 2009).

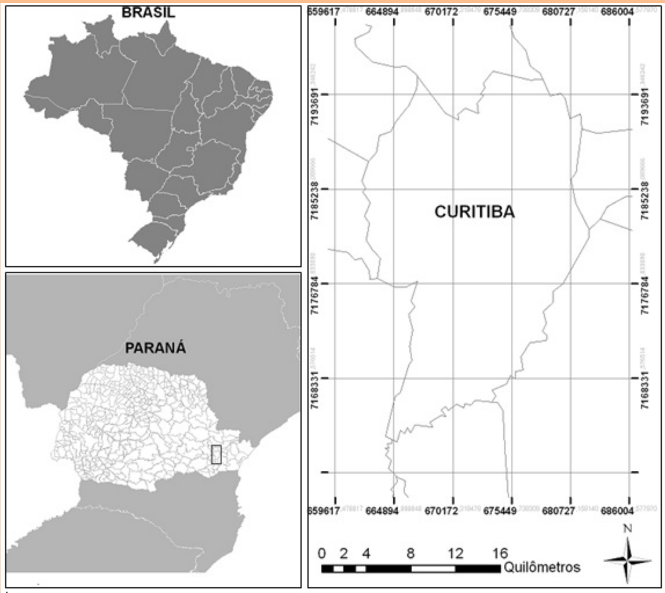

FIGURE 1 – Location the municipality of Curitiba, Paraná State, Brazil.

Methods

The selection of sampling units (SU) was based on the qualitative and quantitative analysis of afforestation of Curitiba directed by Milano (1984). The author divided the city map, with a scale of 1:20.000, using 15 SU with dimension of 500 x 500 meters. Based on the 15 SU used by Milano (1984), we selected three for this study (FIGURE 2).

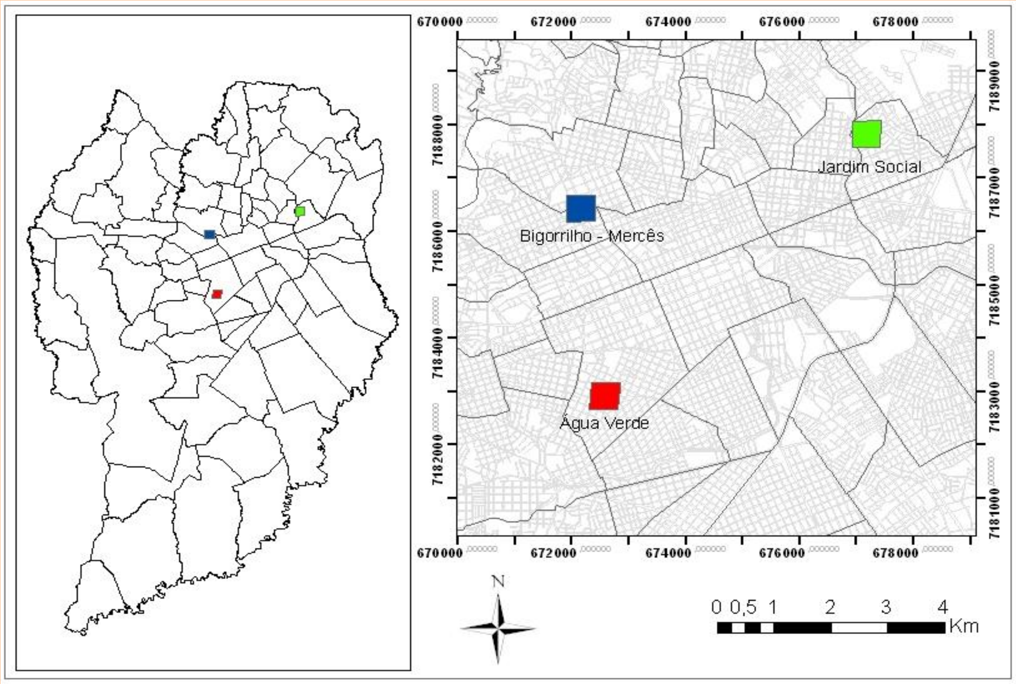

Figure 2 – Location of sampling units used for the construction of cartographic databases and analysis of street trees.

We chose the SU that showed increased number of trees and greater species diversity in the inventory conducted by Milano (1984), and the units are Bigorrilho, Água Verde, and Jardim Social.

Delineation of the Sampling Units

With the sketch of the area of parcels prepared by Milano (1984), we used the GPS *Garmin* to obtain the geographical coordinates at the vertices of the SU analyzed by the author. The data provided by the GPS were plotted in the geoprocessing software *ArcGIS* 9.2, adopting the system of Geographical Projection System UTM (*Universal Transverse Mercator*) and *Datum* SAD 69 (*South American Datum*), 22S.

From the obtained coordinates, we used the street map of Curitiba, which contains streets, blocks, and neighborhoods in a vector format provided by the Institute of Urban Planning and Research of Curitiba (IPPUC) to delineate the areas of the SU. The areas of the SU were stored in a vector format. The *shapefile* is an *ArcGIS* file format, which can store a point, line, or polygon. For the vector representation, the type polygon was defined as the area representation of the selected SU.

Sequentially, we imported the vector data (.*shp*) containing the streets, neighborhoods, and blocks to their respective information plans, allowing to define the plots analyzed and the assessed trees. Next, the vector representation was carried out for the delimitations of the SU, grouping under layers with orthophotographs, establishing the classification of street afforestation of the area.

After defining the SU, we carried out the vectorization of the trees on the streets in the program ArcGIS 9.2. To vectorize the trees, we created polygon-type vectors that corresponded to the geo-objects (trees) on every street.

For OLIVEIRA FILHO et al. (2006), a geo-object is a geographical entity unique and indivisible, characterized by its identity, borders and attributes. Depending on the entity considered, this object can be, for example, the individual tree crown, a forest fragment, an agricultural stall, or even a conservation unit. Each polygon allowed the spatial location and quantification of trees that compose the tree cover of the SU.

Subsequently, we compared the number of vectorized trees in the GIS environment with the trees inventories in 1984 collection and in 2010. According to SILVA et al. (2007), the accounting and registration of urban trees are of fundamental importance for the inventory of urban afforestation, otherwise, it is not possible to analyze any damage or evaluate the needs for maintenance of the trees.

RESULTS AND DISCUSSION

Bigorrilho Sampling Unit

This sample unit covers two neighborhoods, Bigorrilho and Mercês (Fig. 3) both located in central region. The Bigorrilho neighborhood covers an area of 350.30 hectares with a population of 30,065 inhabitants, while the Mercês neighborhood covers 327.60 hectares with 14,191 inhabitants (IPPUC, 2010).

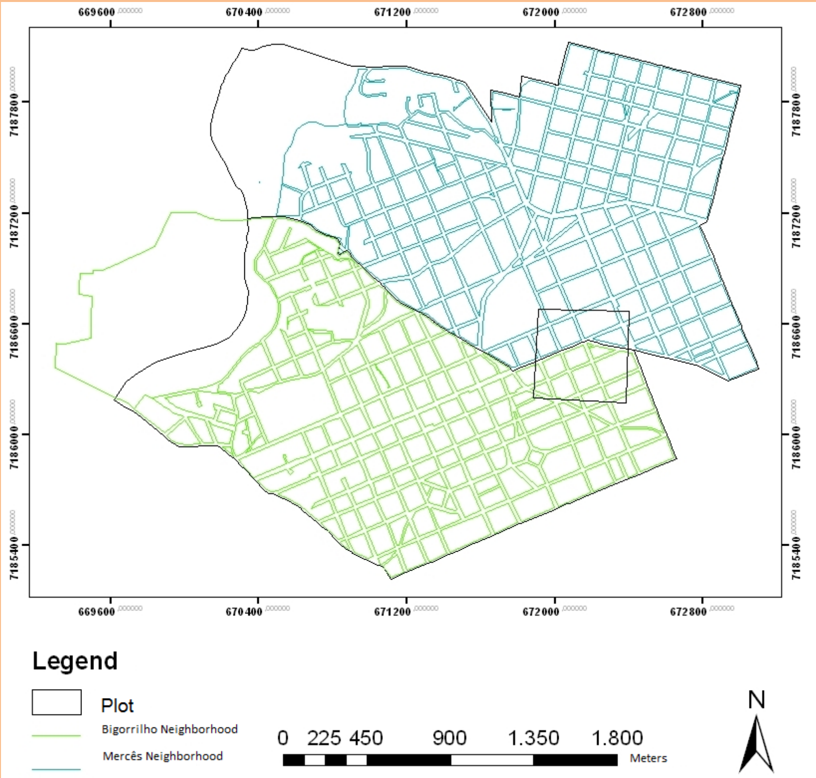

Figure 3 – Representation in GIS environment of the area of Bigorrilho Sampling Unit, Curitiba City, Paraná State, Brazil.

The Mercês neighborhood is located in the residential area of Mercês (ZR-M). This area shows the city growth axes, characterized as expansion areas of the traditional downtown and as trade corridors of transport and services, using a trinary system of circulation (IPPUC, 2010).

The buildings are tall, alternating constructions of two or three floors. There are no limits for the height of the buildings, but they must comply with restrictions imposed by the Ministry of Aeronautics and the Protection Plan of the Microwave Telecommunications Channels of Paraná State.

In the Bigorrilho SU, Milano (1984) found 24 species (Table 1), represented by 381 tree and shrubby sized individuals.

Água Verde Sampling Unit

This SU is located in the Água Verde neighborhood (Fig. 4) situated in the Portão region. It covers an area of 476.40 hectares with 53,228 inhabitants, which denotes the highest population density of the city.

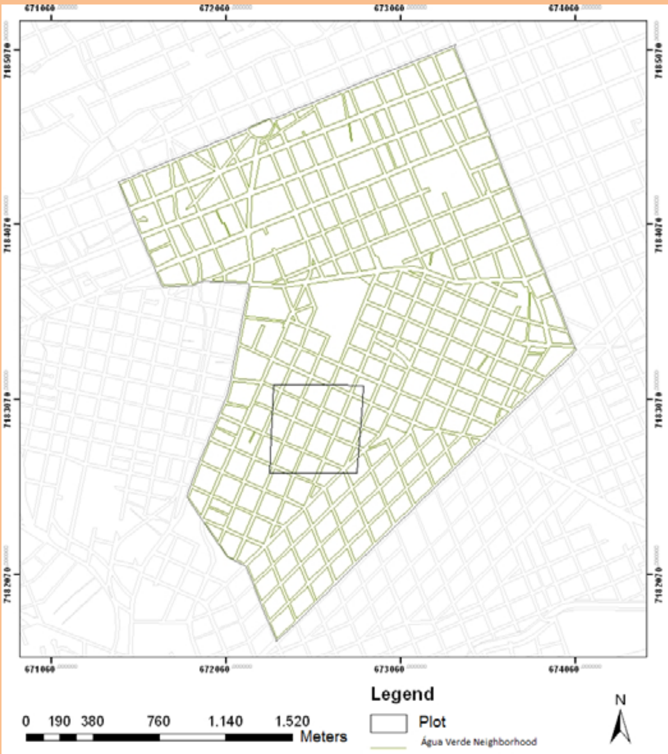

Figure 4 – Representation in GIS environment of the area of Água Verde Sampling Unit, Curitiba City, Paraná State, Brazil.

This SU is a Residential Zone 4 (ZR-4), where buildings are limited to six floors (IPPUC, 2010). The use is predominantly residential and there are houses and apartment buildings.

Jardim Social Sampling Unit

This SU is located in the Jardim Social Neighborhood (Fig. 5) that is located in the central region. According to IPPUC (2009), this neighborhood has 6,113 inhabitants and covers an area of 188.5 hectares.

Figure 5 – Representation in GIS environment of the area of Jardim Social Sampling Unit, Curitiba City, Paraná State, Brazil.

This SU is a residential area considered of type ZR-1 according to the criteria for the use and

Milano (1984) 35 different species (Table 1) corresponding to 341 tree and shrubby sized individuals.

occupation of the soil. The profile of buildings is predominantly residential and buildings are permitted to have up to two floors (IPPUC, 2010).

In his study, Milano (1984) found 46 species in this SU, represented by 554 tree and shrubby individuals. We can observe a slope tilt in the plot size, which may have occurred by the topographical unevenness in the region.

Comparison between the methods of data collection

The SU were selected based on research developed by Milano (1984) with size of 500 x 500 meters. In the relocation of the SU in the GIS environment, we observed difference sizes of the SU outlined as compared to the images collected in 1984 (Table 3).

Table 3 – Area of the SU obtained in GIS environment compared to the data collected in the inventory of afforestation of 1984 in Curitiba City, Paraná State, Brazil.

Sampling Units	(1) Area measured in 1984 (m²)	(2) Area measured in GIS (m²)	Difference between (1) and (2) (m²)
Jardim Social	250,000	249,950	50
Água Verde	250,000	256,830	6,830
Bigorrilho	250,000	257,230	7,230

The Jardim Social SU showed a smaller size than in 1984, and the difference was 50m². The other two SU presented a larger size (Table 3).

The differences that occurred in the Bigorrilho and Água Verde SU can be considered high. These differences could embed many street trees that were inventoried, which shows an extrapolation of results and, consequently, a change in representativeness of the inventory.

The imprecision in the delineation of the SU in the inventory of 1984 may be due to the shortage of resources on a massive scale, with cartographic information of topographical relief, contour lines, detailed maps of streets, public roads, squares, and sidewalks.

In addition, the mapping was carried out manually with graph paper in inches with measurement errors by the user in the field. Currently, the GIS programs make it easier to carry out the fieldwork of inventories through the demarcation of SU in the GIS environment.

In projects developed with the GIS, it is very important to measure the data representativeness. Between spatial data, there is always uncertainty and error. In the GIS environment, it is essential to carry out tests to ensure the data accuracy, since it is virtually impossible for the GIS to work with fully accurate data (Scott, 2003).

Despite the errors, the use of GIS techniques to delineate geo-objects in images offers a better performance than delineating areas in the field (OLIVEIRA, 1980; LOBÃO, 1996; DISPERATI and OLIVEIRA FILHO, 2002; DISPERATI et al. 2007a; DISPERATI et al., 2007b).

Oliveira Filho et al. (2005) used the GIS in a forest experiment in the FLONA of Irati City, Paraná State, Brazil, and implemented a spatial database oriented two distinct objects: trees and plots and, noted that the geo-objects provided the greater combinations, which enriches the results of the research.

Comparison between trees identified in the sampling units

Milano (1984) found 46 species in the three SU (Table 1) totaling 1,276 trees (Table 2).

Table 1 – Species inventoried in the streets trees of Curitiba City in 1984

Scientific name	Popular name	A. Verde	Bigorrilho	J. Social
Acacia mearnsii	Acácia-negra		X	X
Acacia podalyriaefolia	Acácia-mimosa	X		X
Acacia polyphyla	Monjoleiro	X	X	
Acer negundo	Acer	X		X
Araucaria angustifolia	Araucária			X
Caesalpinia peltophoroides	Sibipiruna		X	X
Cassia leptophylla	Cassia-fastuosa	X		X
Cassia macranthera	Cassia-manduirana	X	X	X
Cassia multijuga	Cassia-multijuga	X		X
Chorisia especiosa	Paineira	X	X	X
Citrus reticulata	Limoeiro			X
Cryptomeria japônica	Cedro-japonês	X		
Cunninghamia lanceolata	Pinheiro-chinês		X	X
Cytharexylum myrianthum	Pau-de-tamanco	X	X	
Enterelobium contortisiliquum	Tamboril		X	X
Eryobotrya sp.	Nêspera	X		X
Erythrina sp.				X
Erythrina falcata	Corticeira-da-serra		X	X
Eucalyptus cinerea	Eucalipto-prateado	X		X
Eucalyptus viminalis	Eucalipto	X		X
Eugenia sp.	Pintangueira-do-brava			X
Eugenia uniflora	Pitangueira	X		X
Euphorbia cotinifolia	Leiteiro-vermelho	X	X	X
Ficus elastica	Ficus	X	X	X
Hibiscus rosasinenses	Hibisco	X	X	X
Jacaranda mimosifolia	Jacarandá	X		X
Jacaranda purberula	Carobinha	X	X	X
Lafoensia pacari	aaaaaaaaaDedaleiro			X
Lagerstroemia indica	Extremosa	X	X	X
Ligustrum lucidum	Alfeneiro	X	X	X
Magnolia gradiflora	Magnólia	X		
Melia azedarach	Cinamomo	X	X	X
Hovenia dulcis	Uva-do-japão	X		
Nerium oleander	Espirradeira	X	X	X
Palmeira sp.	Palmeira	X		X
Paraptadenia sp.			X	
Pinus eliottii	Pinus			X
Populus sp.				X
Prunus persica	Pessegueiro			X
Psidium cattleyanum	Araçá-rosa	X		X
Salix babylonica	Chorão		X	X
Schinus terebentifolius	Aroeira			X
Sebastiana klotzchiana	Branquilho		X	
Sesbanea punicia	Acácia-vermelha	X		X
Spathodea campanulata	Tulipeira	X		X

Tabebuia sp.			X	X
Tabebuia alba	Ipê-amarelo	X		X
Tabebuia avellanedae	Ipê-roxo	X	X	X
Tabebuia chrysotricha	Ipê-amarelo-miúdo	X		X
Tibouchina sp.				X
Tibouchina granulosa	Quaresmeira		X	
Tibouchina pulchra	Manacá-da-Serra	X		X
Tibouchina sellowiana	Quaresmeira	X		X
Tipuana tipu	Tipuana	X	X	X
Taxodium distichum	Pinheiro-do-brejo	X		
TOTAL		35	24	46

Source: Adapted from MILANO (1984)

The quantitative analysis shows the dynamics of afforestation in 26 years (1984-2010) (Bobrowski, 2011). A continuous inventory of the street afforestation in the city of Curitiba showed differences of 55.06% for the number of trees (BIONDI and LIMA NETO, 2011).

In Table 2, we observe the differences for the number of trees in distinct analyses. The first refers to the collection conducted by Milano, the second by Bobrowski (2011) and the third with the plots in GIS environment.

Table 2 – Comparison between the number of trees inventoried in the field and in GIS.

Sampling Units	Number of trees		
	Inventory in 1984	Inventory in 2010	GIS environment
Bigorrilho	381	348	297
Água Verde	341	483	376
Jardim Social	554	437	382
TOTAL	1,276	1,268	1,055

The number of trees may be linked to differences in delimitation of the size of the SU in the field.

In the 2010, 348 trees were inventoried in the Bigorrilho SU. In the GIS environment, 297 trees were identified, showing a smaller number of trees compared to the inventory in 1984.

The number of trees inventoried in the Água Verde SU in the 2010 inventory totaled 483 trees. In the GIS environment, 376 trees were outlined. The detection of the trees in the SU in the GIS environment was 75.85% more accurate in relation to the 2010 inventory. The inventory of 1984 showed a larger numbed of trees than the others (Table 2).

In the Jardim Social SU, the inventory of 2010 showed 437 trees (Table 2). In the GIS environment, 87.41% of trees inventoried in the field were vectored (Table 2).

For the SU studied, the quantification of trees in GIS environment resulted in smaller numbers of trees than in the field inventories of 2010 and 1984.

The difference in the number of trees cannot exclusively attributed to the plot size, once removals and replacements of tree individuals may have occurred due to vandalism or environmental stress.

Urban afforestation undergoes constant plantings, deaths, replacement, and removal of trees. According to Biondi and Lima Neto (2011), this sequence of facts, simultaneous and constant, represents the dynamics of the vegetation cover. In addition, silvicultural, urbanistic and socio-cultural factors can affect the number trees.

CONCLUSIONS

The vectorization of street trees in GIS environment supports the conventional inventorying method. One method does not replace the other, only supports the implementation and eliminates variables measured in the field that are costly to be assessed.

The differences between the values obtained in the collection methods are related to the quality of cartographic bases used and/or observation and measurement errors in inventories.

It is recommended the creation and use of reliable cartographic bases in studies on urban afforestation. Besides, the use of the imaging interpretation techniques can assist or enhance the exact delineation of the areas of sampling units.

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