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Methodological contributions for urban tree census in medium-sized cities. Case study: Pigüé, Argentina

Aportes metodológicos para censos de arbolado urbano en ciudades medianas. Caso de estudio: Pigüé, Argentina

Contribuições metodológicas para os recenseamentos de árvores urbanas em cidades de média dimensão. Estudo de caso: Pigüé, Argentina

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ABSTRACT

Geographic Information Systems (GIS) are key methodological tools for land management and to have databases of urban trees that help to make better decisions about biodiversity in a built environment. The construction of urban models with quality information is of high scientific and management value for diagnosis, evaluation and decision making. The objective of the present work was to establish the steps for the realization, design and modeling of a GIS for the management of urban trees in the city of Pigüé and to provide the basis for a computerized system to support decision making. The GIS was planned in order to have a model of reality, establishing the geographic model, the representation model and the storage model. A tree census was carried out and updated, surveying 9,518 spaces. It was found that there is a high diversity of tree species. Of the total number of spaces with species, 7424 are in good health. Pigüé's urban trees have a high percentage of trees that obstruct or interfere with the wiring of public services.



Keywords: Urban trees; Management; Planning; Geographic information systems.

RESUMEN

Los Sistemas de Información Geográfica (SIG) son herramientas metodológicas clave para la gestión del territorio y para tener bases de datos de arbolado urbano que ayuden a mejores decisiones sobre la biodiversidad en un medio construido. La construcción de modelos urbanos con información de calidad es de alto valor científico y de gestión para el diagnóstico, evaluación y toma de decisiones. El objetivo del presente trabajo fue establecer los pasos para la concreción, diseño y modelación de un SIG para la gestión del arbolado urbano en la ciudad de Pigüé y brindar las bases de un sistema informatizado de apoyo a la toma de decisiones. Se planificó el SIG a fin de tener el modelo de la realidad estableciendo el modelo geográfico, el modelo de representación y el modelo de almacenamiento. Se realizó un censo de arbolado y actualización del mismo relevando 9518 espacios. Se obtuvo que el arbolado presenta alta diversidad de especies. Del total de espacios con especies 7424 presentan buen estado sanitario. El arbolado urbano de Pigüé tiene un alto porcentaje de árboles que obstruyen o interfieren en el cableado de servicios públicos.

Palabras clave: Arbolado urbano; Gestión; Planificación; Sistemas de información geográfica.

RESUMO

Os Sistemas de Informação Geográfica (SIG) são ferramentas metodológicas chave para a gestão do território e para ter bases de dados de árvores urbanas que ajudam a tomar melhores decisões sobre a biodiversidade num ambiente construído. A construção de modelos urbanos com informação de qualidade é de alto valor científico e de gestão para diagnóstico, avaliação e tomada de decisões. O objectivo deste trabalho era estabelecer as etapas para a realização, concepção e modelação de um SIG para a gestão de árvores urbanas na cidade de Pigüé e fornecer a base para um sistema informatizado de apoio à decisão. O SIG foi planeado de modo a ter um modelo de realidade, estabelecendo o modelo geográfico, o modelo de representação e o modelo de armazenamento. Foi realizado e atualizado um censo de árvores, levantando 9518 espaços. Verificou-se que a população de árvores tem uma grande diversidade de espécies. Do número total de espaços com espécies, 7424 estão em bom estado de saúde. As árvores urbanas de Pigüé têm uma elevada percentagem de árvores que obstruem ou interferem com a cablagem dos serviços públicos.

Palavras-chave: Árvores urbanas; Gestão; Planeamento; Sistemas de informação geográfica.

INTRODUCTION

Geographic Information Technologies (GIT) are complements the different tools and methods to achieve adequate resource management. They allow the integration of relevant variables in order to achieve certain dynamism in decisions (Barragán, 2014). Geographic information is a fundamental component in territorial planning and management, with Geographic Information Systems (GIS), as part of GIT, being the basic and fundamental methodological tools for carrying out strategic plans and short,



medium and long term decision making. The different administrative levels invest resources in the development and implementation of plans that provide information on what, where and when (Zurita Espinoza, 2011). One of the requirements in the elaboration of these plans is the simplification of the real world through the construction of models in GIS environments, which allow abstracting and modeling reality in a geo-referenced database through a system of geographic coordinates defined by the user (Geraldi, 2009; Geraldi *et al.*, 2010; Buzai, 2011; Barragán, 2014; Fuenzalida *et al.*, 2015; Olaya 2020).

The construction of urban models with quality information is of high scientific and management value for diagnosis, evaluation and decision making. Specifically, with regard to urban trees, the construction of models and censuses are of vital importance. Having geo-referenced information on species, sanitary status, health, among others, allows for efficient tree management at low cost. Within the city, trees are a vital element of the landscape and provide various environmental, aesthetic, landscape, recreational, social and economic benefits, which are used in various ways by the population, who enjoy their presence and make them an integral element of the urban landscape, to such an extent that they become one of the indicators of the vital and sociocultural aspects of cities (Tovar Corzo, 2007). Specifically, linear trees perform functions such as water and energy conservation, improve air quality and decrease storm runoff and flooding, reduce noise levels, and provide habitat for wildlife (Benedetti and Campo, 2007; Kowarik and Körner 2005; Duval and Benedetti, 2017). Optimization of tree-generated benefits is directly related to tree characteristics such as cover, composition, density, distribution, and their health status (Abell *et al.*, 2008; James *et al.*, 2009).

In spite of fulfilling all these functions, trees in a city develop in a hostile environment dominated by man, where constructions, cables and lighting poles, drainage, asphalt, garbage, among others, predominate (Núñez, 2001). This environment highlights the importance of working with geographic information systems essential for the rapid availability of information, to solve problems and answer questions immediately. Then, the maintenance and proper functioning of urban ecosystems is the basis for the sustainable development of cities, being trees one of the most important elements to achieve this good functioning (Apud and Commons, 2020), which is more efficient and effective having geo-referenced information available. The objective of this work was to establish the methodological steps for the realization of a database of urban trees, design and modeling in a GIS environment as a contribution to the management of medium-sized cities and to provide the basis for a computerized system to support decision making.

MATERIALS AND METHODS

The case study was the town of Pigüé, located in the district of Saavedra, in the southwest of the province of Buenos Aires, at an altitude between 280 and 300 meters above sea level (Figure 1). This locality is a representative case of medium-sized cities, due to its population, functioning and structure. The area falls within the limit of the dry pampas, with a mean annual precipitation value of 702 mm and a mean annual temperature of 14°C (Benedetti *et al.*, 2016). It is located within the pampean phytogeographic region represented mainly by grasslands, a region that is totally modified by man. Thus, the sectors of the plains where agricultural activity has not



prospered are populated with species that make up the Pampean grassland, such as *Cortaderia selloana*, some grasses of the genus *Festuca* and different varieties of *Stipa brachychaeta*, *Stipa neesiana*, *Paspalum quadrifarium*, among others.

The implementation and design of a Geographic Information System (GIS) involves planning a series of strict steps to achieve a model of reality with quality information that can be extrapolated and even used by managers and decision makers. Olaya (2020) argues that a GIS must consist of three basic stages: A. the establishment of a geographic model; that is, a conceptual model of the geographic reality and its behavior, B. the establishment of a representation model; that is, a way of collecting the previous conceptual model and its own characteristics, reducing it to a finite series of elements and C. the establishment of a storage model; that is, a scheme of how to store the different elements of the representation model.

For the present work, a geographic model of discrete entities was used, which conceives of a geographic environment as an empty space in which different elements (entities) fill it. Each of these entities has its own characteristics, constant for all of them (Olaya, 2000).

The representation model was based on a vector model, which does not divide the space completely, but defines it by means of a series of geometric elements with associated values, the arrangement of which is not systematic (Olaya, 2000). The spatial component consists of a series of points with different degrees of complexity depending on the detail to be worked. This set of points is related to a series of values, which define the properties of the entity (Olaya, 2000).

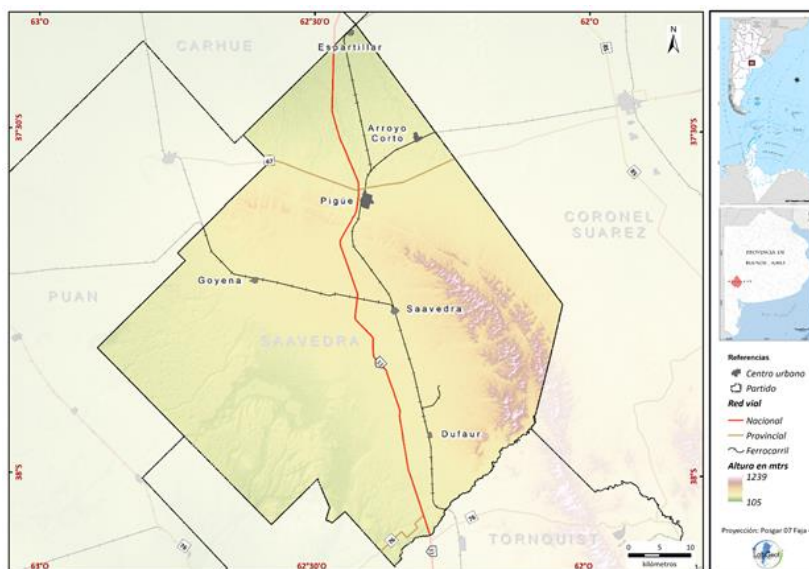


Figure 1. - Location of the study area.

Source: Barragan 2019.

The storage model used was the arc-node defined by two fundamental units, the nodes, which are points where several lines are connected; and the arcs, which are lines between two nodes (Olaya, 2000).



Once the models to be used were defined, the work was divided into different phases or stages.

Stage 1: Preparation

a. Systematic review of the available documentation oriented to the urban trees of the city and cartographic bases of the urban area. The consultation of both bibliography and cartography revealed some problems. Related to the first one, there were few census documents specified by individuals; and as for the cartographic base, digital parceling with spatial geo-referencing of the parcels was necessary.

b. Interview with local agents: In this interview the immediate needs of the municipality were defined. The need for infrastructure information was expressed, such as enclosure sidewalks, cables in relation to the tree, enclosures. Given that the objective of an urban tree census is to determine the current state of the trees in a locality and this implies answering two basic questions: what species are there and where are they located, it was decided to incorporate variables that respond to these needs.

c. Preparation of the survey form: Municipal inventories of urban trees should include information on the number of trees, species or varieties, dimensions, approximate age, health status and location of the trees with reference to specific elements of the urban space. Given the municipal requirements, a form was prepared with the data to be collected and defined with the following data: scientific and common name, height in meters (0-2, 2-4, 4-6, 6-8 or more than 8 meters), DBH (diameter at breast height), health conditions (good, diseased, decrepit and dead). It was also noted whether it should be removed directly because of its condition. The condition of the enclosures or pots was reported, specifically taking into account their size and whether they had garbage, dry grass or debris. Another item in the survey was linked to the conditions of growth in terms of its inclination and other observations of the urban environment such as interference of cables, damage to sidewalks, interference in lighting fixtures, interference in roofs or walls, among others (Benedetti *et al.*, 2014).

d. Standardization of data for inclusion in the geo-database. Setting up a geographic database is a complex task, even more so if the data to be loaded come from different sources or from surveys in which several people participate. For this reason, when designing and implementing a GIS it is extremely necessary to establish guidelines to complete the attribute tables, that is, to standardize the geographic information. The most common problems are the modifiable spatial units, which consists of having different results depending on how the spatial units used to collect information are defined, especially when working with non-natural delimitations. It is well known that GIS attribute tables are alphanumeric and sensitive to alterations, which, when incorrectly loaded, lead to failures in the model. Thus, for example, a period, a comma, a space, and the use of upper or lower case letters are considered as different attributes. For this reason, it was decided that each census taker should carry out the survey with numerical codes as shown in Table 1 (Table 1).



Table 1. - Numerical codes adopted for urban tree censusing

Height in meters	Circumference	Health conditions	Enclosure	Growth conditions
It is listed in ascending order from left to right, that is: 0-2 = 1 2-4 = 2 4-6 = 3 6-8 = 4 + 8 = 5	0-20 = 1	Healthy = 1	Garbage, burned dry grass = 1 With grass or green material = 2 Gravel concrete cement=3 No enclosure=4	Not inclined = 1
	20-40 = 2	Sick = 2		Slightly inclined = 2
	40-60 = 3	Decrepit = 3		Very steep = 3
	60-80 = 4	Dead = 4		
	+ 80 = 5	Remove = 5		

e. Workshop: The survey of trees should be carried out by trained people, since one of the steps is to recognize the species to be surveyed, or to correctly establish the health conditions of the species. It is also necessary to hold small diagnostic workshops. The purpose of these workshops is to agree on how to complete the forms and carry out the survey. It was agreed in this workshop to survey all the addresses even if there are no trees and to survey the condition of the sidewalks. It was also agreed on how to define the state of health of the species surveyed.

f. Field work: As with all field work, prior planning is required. On the one hand, it is necessary to coordinate the form of data collection and the role of each member. In this sense, each census taker was assigned certain blocks. The survey was carried out from the central blocks to the periphery. On the other hand, it is essential for the GIS specialist to be informed about who took the census in each block. The first tree survey was carried out among all the census takers to avoid errors. At the end of each day, a meeting was held to discuss the problems encountered.

g. Design phase of the logic model: 1. Cadastre (provided by the municipality and based on photogrammetric flights of the National Geographic Institute). For the design of the logic model it is necessary to have the spatial base, in this case the geo-referenced cadastre. Since most of the cadastres are in CAD format, it was necessary to convert DraWinG (dwg), which is a computerized drawing file format, to Shape (shp), which is a computerized spatial data file format. Then, it was then necessary to define the projection and the coordinate system, which in this case was the World Geodetic System 84 (WGS84). The trees were worked on the basis of a layer of points associated with the cadastre 2. The construction of the attributes is a complex task, even more so if there are several agents carrying out the census. Each agent completed the table following the protocol designed by the GIS specialist. The latter assigned an identifying code to each person and the metadata was completed. It was necessary to define the fields and task in charge of the GIS specialist.



Table 2. - Table attributes and number of characters used

Block ID	Species ID	Address	Height in meters	Circumference	Health conditions	site
Alphanumeric	Numeric	Alphanumeric	Numeric	Numeric	Numeric	Text
3 characters	8 characters	10 characters	3 characters	3 characters	3 characters	3 characters

Growth conditions	Interference cables	Damage to sidewalks	Luminaire interference	Interference ceilings and walls	Dirt sidewalk - cement - tile - other	Remarks
Numeric	Text	Text	Text	Text	Text	Alphanumeric
	3 characters	10 characters	3 characters	10 characters	10 characters	50 characters

RESULTS AND DISCUSSION

Geographic information systems are theoretical-methodological tools that allow thinking, acting and making decisions spatially. The possibility of combining information is substantial in land management. Decision-making about it requires having a model, with standardized and quality geographic information, that adapts to the needs of the territory and management purposes (Barragán *et al.*, 2019).

From the tree census, 9581 spaces were surveyed, of which 1417 corresponded to empty spaces, i.e., there are no trees and the enclosures are present, but empty, or the sidewalks of the plots do not have enclosures. The number of trees and shrubs amounts to 7000 trees and shrubs (individuals) (Benedetti *et al.*, 2014). Of the 1417 vacant spaces recorded (Figure 2) 439 are located in the northern sector, 483 in the southern sector and the rest in the city center. The town has two perpendicular avenues that are the structuring axes of the city, Mitre and Casey avenues. Both avenues have individuals on the boulevard and on the sidewalks, however, towards the ends of both avenues there are more empty spaces, mainly at the end of Mitre Avenue towards the south (Figure 2). It should be noted that the planned neighborhood in the eastern sector has very few empty spaces and the species are young. The spaces without species could be easily occupied since many of them have enclosures made and are empty. The planting of individuals in these spaces would lead to a more functional urban architecture and would help to break the monotony of the urban landscape, especially in the planned neighborhoods.



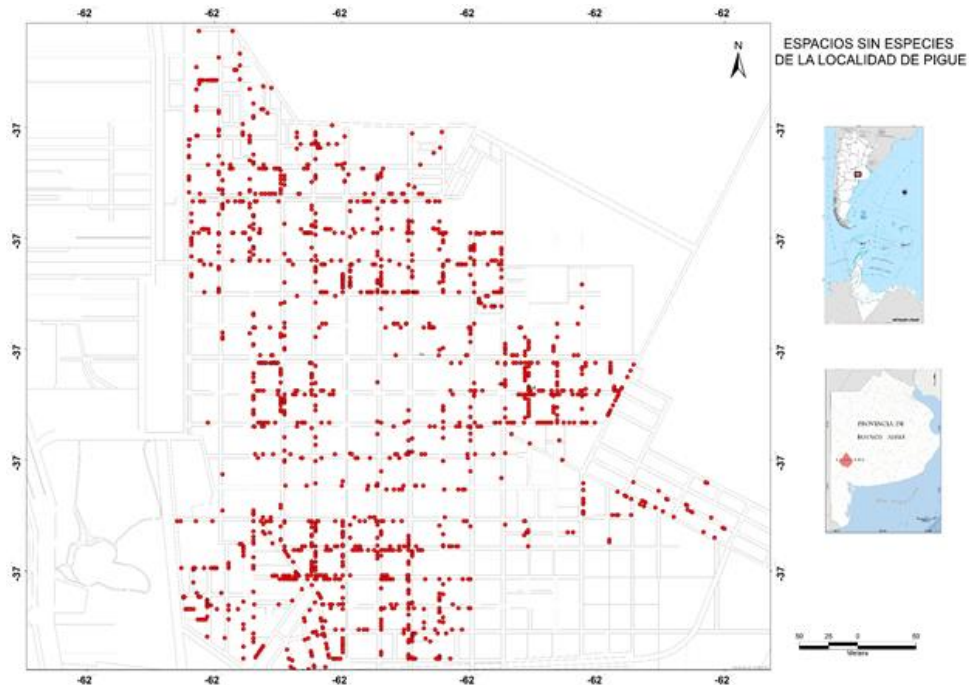


Figure 2. - Spaces without individuals in the locality of Pigüé

Figure 3 shows the number of tree species in Pigüé. The species that dominate the local tree population are *Robinia pseudoacacia L.*, *Fraxinus americana L.* and *Lagerstroemia indica*. The *Lagerstroemia indica* has a total of 800 individuals, followed by *Fraxinus americana L* (559) and *Robinia pseudoacacia L* (520). Although, these are the species that dominate the woodland, it presents an important specific diversity (Figure. 3) (Benedetti et al., 2014), with different types of acacias, walnut trees, willows, lindens, among others. Table 3 presents the representative genera of the alignment woodland. It is highlighted that most of the species have deep roots and are horizontally anchored, which is why sidewalk breaks do not reach a significant percentage.

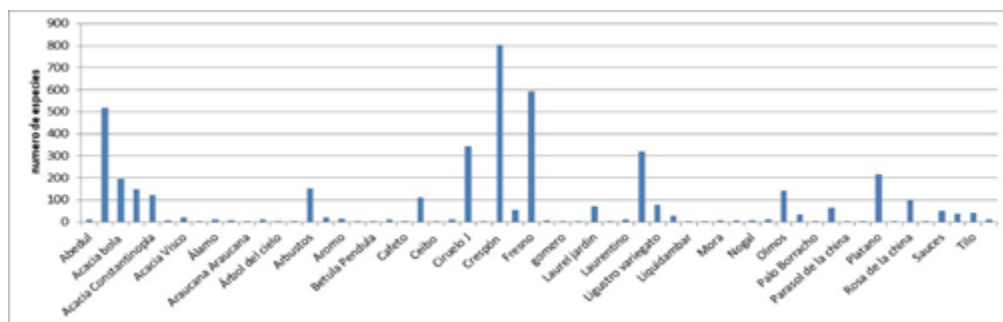


Figure 3. - Species diversity in Pigüé's urban woodland

The height of the trees and their diameter are indicators of the age of the species. In general, it is a locality with young trees. Forty-nine percent of the species are between 0 and 4 meters in height with diameters of less than 60 cm. Twenty-six percent of the species are older and have a height of 8 meters or more (Figure 4). Of the total dominant



Lagerstroemia indica, 518 are 0 to 2-meter species (Figure 5), i.e. the youngest species which are found in the north. There are 580 individuals from 2 to 4 meters that are located south of Casey Ave. 173 species are from 4 to 6 meters and 112 from 6 to 8 meters. The latter are located mainly in the center of the city and coincide with the historical sectors. In tree management, it is important to control adult species between 6 and 8 meters, as these require intensive care, for example, pruning to avoid weakening their structure.

Table 3. - Most representative genera of the alignment trees

Genera				
Abelia	Cercis	Gingko	Morus	Broom
Acacia	Chorisia	Hebe	Nerium	Rhus
Acer	Cutter	Hibiscus	Olea	Robinia
Ailanthus	Crataeus	Jacaranda	Phitolacca	Rosa
Araucaria	Cupressuss	Juglans	Phitosporum	Salix
Bauhinia	Eriobotrya	Lagerstroemia	Photinia	Schinus
Betula	Erythrina	Lavandula	Pinus	Sofora
Brachychiton	Eucalyptus	Ligustrum	Platanus	Syringa
Buxus	Ficus	Liquidambar	Populus	Thuya
Callistemon	Firmiana	Manihot	Prunus	Tilia
Catalpa	Fraxinus	Melia	Quercus	Ulmus
				Viburnum
				Yucca



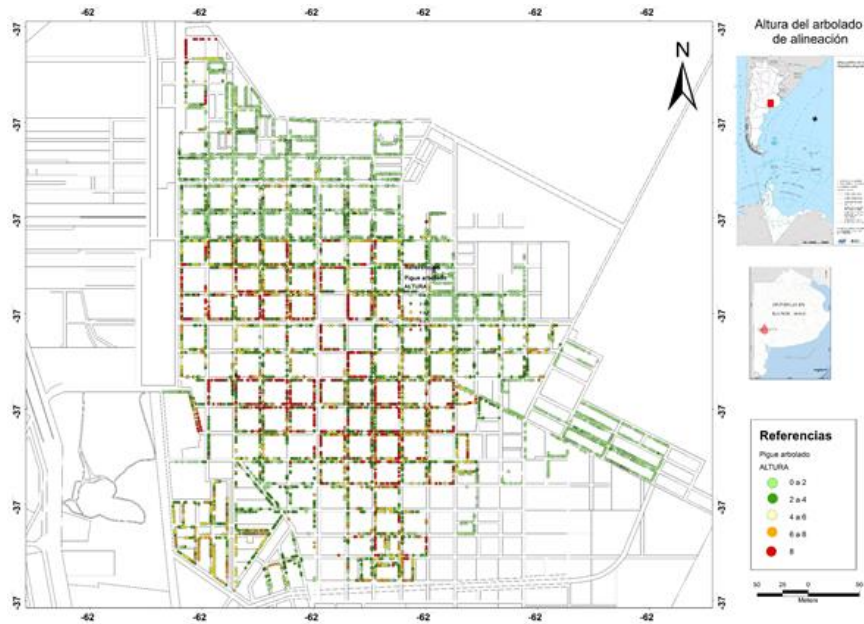


Figure 4. - Alignment tree height without considering shrubs

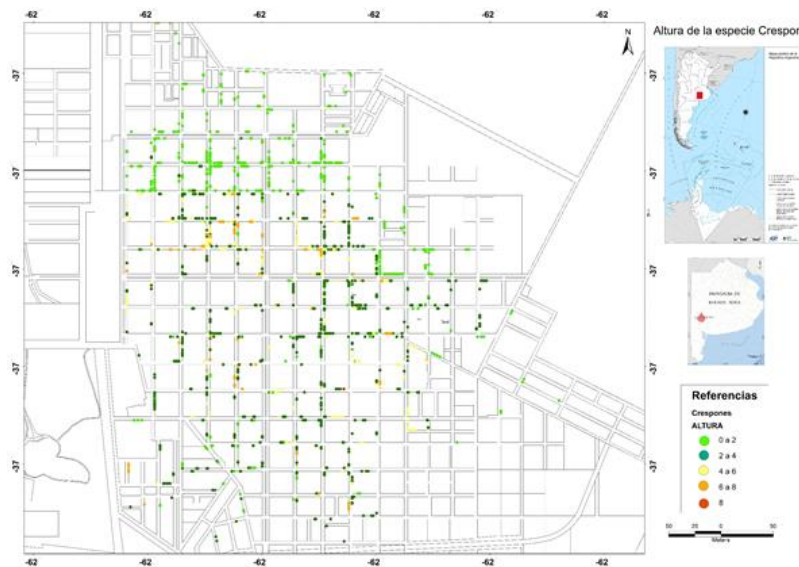


Figure 5. - Height of the dominant species *Lagerstroemia indica*

The state of health of the tree is a key to management. The also called phytosanitary status of the tree refers to the presence or absence of pests, diseases and the state of vigor.

Of the total number of areas with species, 7424 are in good health, that is, free of pests and diseases, and most of them have good vigor. However, 224 are sick and 123 are in a decrepit state. Ants, eaten leaves, aphids, fungi and others have been observed. These individuals do not have a specific distribution pattern (Figure 6). However, it is observed



that there are several continuous individuals with some type of affection, which would indicate situations of infection. In this regard, it is important to note that there are 88 individuals that should be removed due to poor sanitary conditions or danger of falling. It should also be noted that there are 6 dead individuals, which, although they are not in danger of falling, do not fulfill any function.

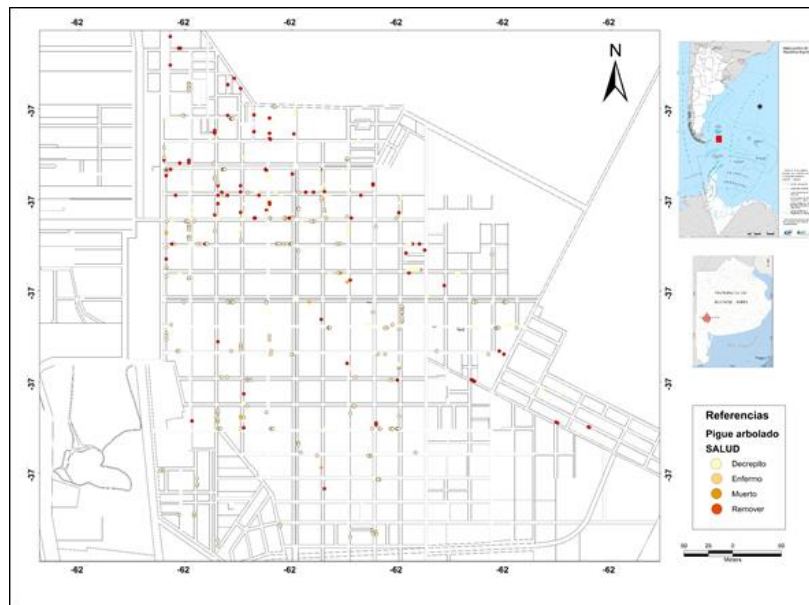


Figure 6. - Health status of the species without taking into account species with good health status

Monitoring, maintenance and pruning of the species must be on the agendas of the municipalities. The lack of planning and management in these matters could lead to serious consequences, such as accidents or death of specimens. It should not be forgotten that pruning is an aggression to the tree, which produces wounds in the bark tissues and leads to greater vulnerability to the presence of pests or weeds. Pruning, if necessary, should be carried out by technical specialists, since if it is done incorrectly, the individual will decay from the branches involved to the trunk and thus, an irreversible process that leads to the death of the specimen.

Pruning should be limited to what is strictly necessary and without altering in any way, except in cases that is needed, the characteristic shape of the plants. In other words, the morphology of the tree should be maintained in order to maintain a balance between the root system and the aerial part of the plant at the moment of its implantation, to adapt the crown to vehicular and walker traffic, overhead wiring, street lighting, and to maintain the shape and health of the tree (Núñez, 2001). Pigué's urban trees have a high percentage of trees that obstruct or interfere with the wiring of public services. Figure 7 shows that most of them are located south of Casey Avenue, which corresponds to the historic center of the town.

In the urban fabric, the condition of the sidewalks is a fundamental element for the management and planning of trees. According to the survey carried out, 23% of the town's sidewalks are made of clay. Most of these sidewalks are located in three distinct sectors of the city, the first with the largest number is to the north (Figure 8), and area



with planned housing that is no more than 20 years old. The other sector is located to the south of the town (Figure 8). It is towards this area where occupation has occurred in recent years. The third sector is located to the east and, as in the previous case, is an area of planned housing, being an expansion zone of the city.

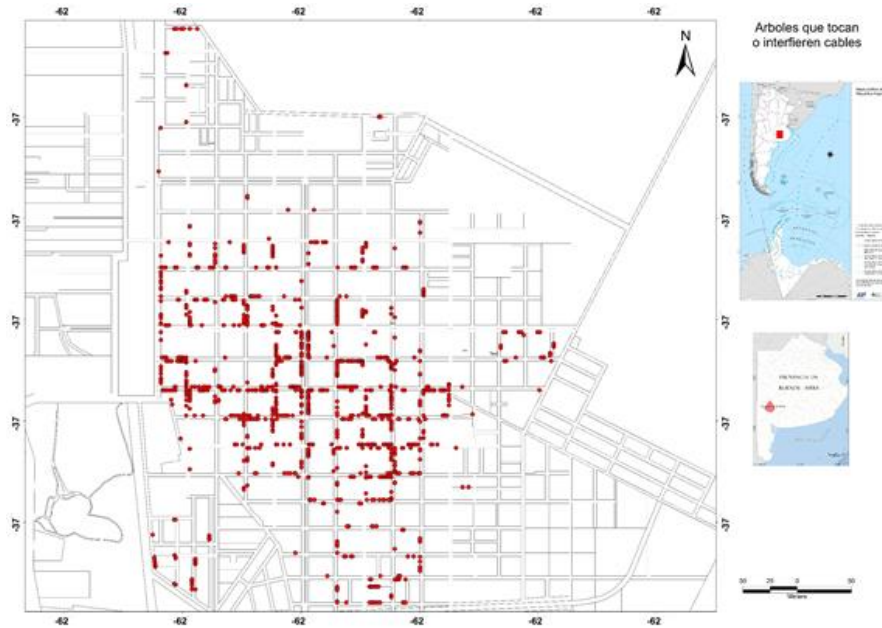


Figure 7- Trees obstructing and/or interfering with public cabling



Figure 8. - Clay sidewalks in the town of Pigüé



CONCLUSIONS

Urban tree management plans are fundamental in the management of public spaces. Having a census that helps to identify characteristics of diversity, health, height and others allows decision makers to manage them efficiently. The urban tree census carried out in the town of Pigüé made it possible to establish the state of the vegetation in terms of health and conservation, and to determine the places where it should be replaced, as well as the selection of the necessary species. The database obtained from the census and systematized in the GIS will allow the corresponding authorities to make decisions according to the needs of the trees. The town of Pigüé has a high diversity of tree species. In general, the state of health is good, and a continuous management plan is proposed that will allow appropriate decisions to be made, for example, to remove species in poor condition, replace individuals, manage empty spaces and, mainly, a pruning plan for the specimens.

The good management of trees will allow obtaining key benefits for the locality achieving a configuration and management of public spaces that allow improving the landscape beautification, regulating temperatures, improving air quality, enhancing properties, and increasing cultural contributions, among others.

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The authors declare not to have any interest conflicts.

Authors' contribution:

Alejandra Mabel Geraldí: Conception of the idea, literature search and review, instrument making, instrument application, compilation of information resulting from the instruments applied, statistic análisis, preparation of tables, graphs, and images, database preparation, general advice on the topic addressed, drafting of the original (first version), review and final version of the article, article correction, authorship coordinator, translation of terms or information obtained, review of the application of the applied bibliographic standard.



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