Vegetation diversity in the Santiago de Chile urban ecosystem[1]

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Summary

This study included urban and periurban areas of Santiago, Chile. The 967km^2 metropolitan area is composed of approximately six million inhabitants in various social and economic situations. The purpose of this paper was to assess alfa (α) and beta (β) vegetation diversity in the 36 metropolitan boroughs, and analyze the relationship of the assessed biodiversity to social and economic indices. Preliminary results showed tendency to increased vegetation diversity when the social and economic statuses of a borough increase.

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1. Introduction

Chile, located in the southwest part of the South America, is a developing country that has a growing industry and increasing urban activity. Its area occupies about 760.000 km^2 and stretches from the border with Peru to near to the Antarctic Circle. In contrast with its considerable length, Chile's width averages no more than 176 km. Santiago, the capital city, is located in the Metropolitan Region at the central zone of the country between the parallels 32º 55' and 34º 17' latitude south and the meridians 69º 47' and 71º 43' west longitude (figure 1).

Santiago city is located upon a basin originated from tectonic phenomena combined with erosive processes. This basin has been filled with fluvial and glacial fluvial sediments coming from the two main rivers of this area: The Mapocho and the Maipo rivers. This basin, in turn, is surrounded by mountains that mainly belong to the coastal range (towards the south /west) and to the Andes Mountains (to the north/east). The altitude of urban mountains ranges from 1,500 to the 3,200 meters above the sea level. This complex orographic situation of this city makes it closed for air renewal producing high levels of air pollution and other phenomenon knowed as "thermal inversion" during the winter season.

This geographic situation coupled with a mediterraneum and semiarid climate (average maximum temperature in January is 28.2ºC and average minimum temperature in July is 4.4ºC and average rainfall of 400 mm), makes very important to know the diversity of urban vegetation as well as its distribution for management purposes. In addition, the

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967km^2 metropolitan area is composed of approximately six million inhabitants in various social and economic situations. Santiago is a developing city, with high social contrast. Biologically based development constitutes an important part of sustainable development and should be explicitly included in urban planning (Lovejoy, 1996). Aditionally, the general assuption that human influence on the landscape is negative is not always true. In some cases the value of a site decreses, but in others, human activities are neccesary to maintain biodivesity (Gotzmark, 1992).

Therefore, the purpose of this paper was to assess alfa (α) and beta (β) vegetation diversity in the 32 metropolitan boroughs, and analyze the relationship of the assessed biodiversity, using indices of richeness, dominance and eveness, to social and economic levels (high, middle, and low income). These three levels conform diferents microclimatic conditions related to the differerent structural materials within the urban environment and affect the amount and arrangement of vegetation (Quattrochi and Rowntree, 1988).

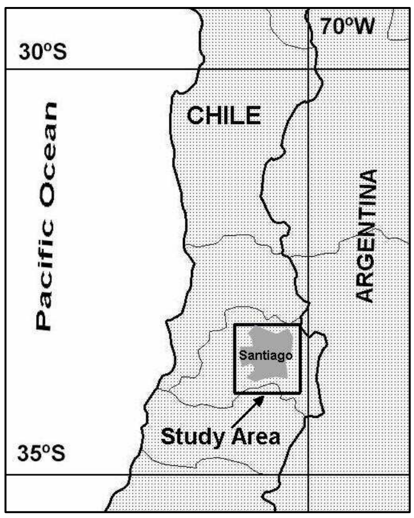

Figure 1: Location of the study area in Chile.

2. Data and methods

The study area covers 967 km^2 of Santiago, including both urban and periurban zones, and a total of 36 metropolitan boroughs (figure 1). To perform a better sampling of the vegetation diversity it was necessary to consider the high variation in social and economical statuses throughout the city. Each one of them was included in one stratum according to two criteria, social-economic level and average tree area cover (%). By this means three strata were defined for both variables together: high (H), middle (M) and low (L). The reason for considering the tree cover was its close relationship to potential richness of species.

Social and economical data was acquired from the 1992 National Census data base, projected to year 2000 (ICCOM Novaction, 2000). Tree area covers were obtained through photointerpretation on B/W 1:10.000 orthophomosaic (1998), using ramdom dot sampling over the study area. Every sampling point was classified with or without tree cover. Consequently, a total of 4,355 points were processed and the statistics for every borough were calculated. After applying the two criteria the high, middle, and low strata have 6, 11 and 19 boroughs, respectively.

The data collection for biodiversity assessment corresponds to a ramdom stratified sampling. According to Nowak et al. (2001), the sampling error became stable before rising to 200 sampling plots independent of the size of the city. Thus, a total of 200 sampling circular plots were set as sampling size (*n*). The proportion assigned to each stratum was calculated as a function of its size and tree cover, according to the following formula:

$$n_i = n * \frac{w_i c_i}{\sum_{i=1}^{3} w_i c_i} \qquad n = \sum_{i=1}^{3} n_i = 200$$

Where, n_i is the number of plots per stratum, w_i is the area of the stratum and c_i is the average tree cover in the stratum. Inside each stratum, the physical allocation of the plots was performed considering landuse distribution classes and its areas (figure 2).

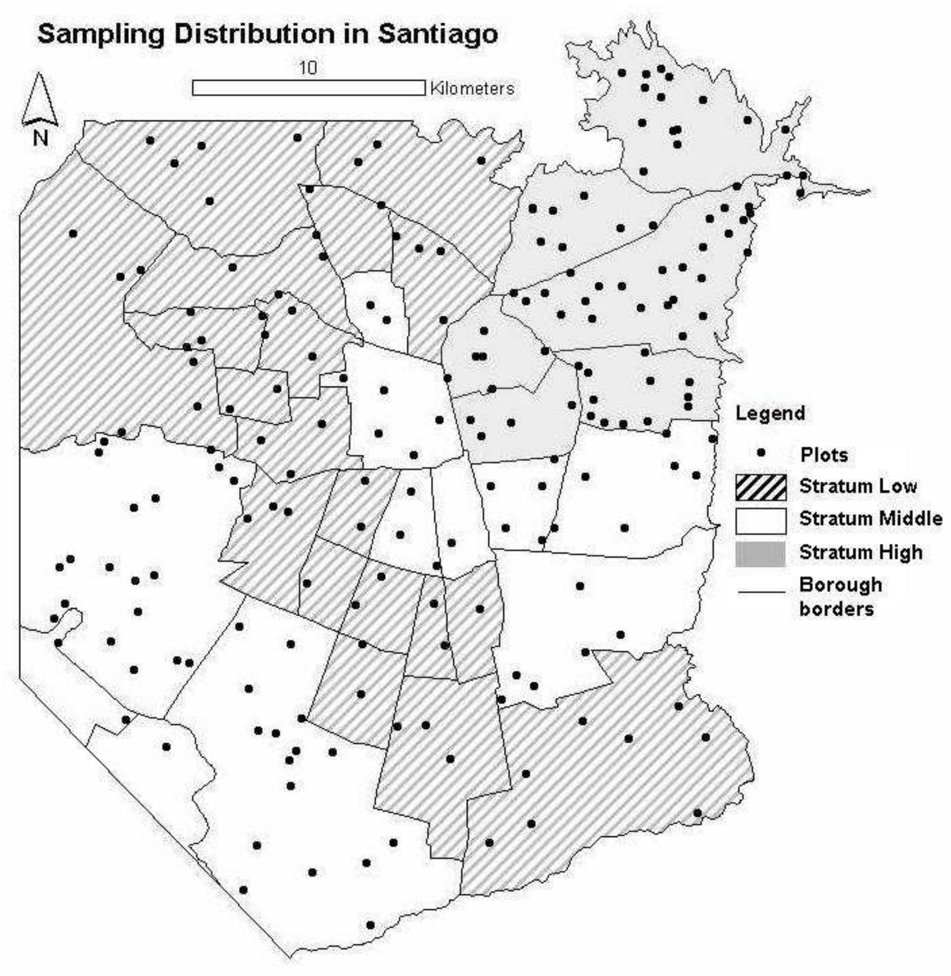

Figure 2: Distributions of sampling plots.

Each plot is a circular area of 11 meters radii, inside which a high number of variables were measured using the methods described in details by Nowak et al. (2001). Each plot was georeferenced and general information and ground pictures were acquired. All cover types were registered as percentage of the plot area, and for vegetation types all the tree and shrub species were identified and measured in order to assess their size, condition, and frequency.

Several indices were used to assess the biodiversity among strata: Shannon, Menhinick, Simpson and Shannon evennees (Magurran, 1988). Shannon diversity index and Shannon evenness index assume that all species within landuse type or city have been sampled. The first is mainly an indicator of species richness while the second is an indicator of species evenness. Both have a moderate sensitivity to sample size and therefore landuses and/or cities may not be comparable. Menhinik index is an alternative indicator of richeness and Simpson diversity index an indicator of species dominance, both have a low sensitivity to sample size; therefore, may be more appropriate for comparison between landuse types.

3. Results

The concept of biodiversity comprises two components, namely variety and relative abundance. Research in ecological diversity is often restricted to species richness, which means a straightforward count of the number of species in a specified area. However, relative abundance is also very important to understand how species weigh in a specific environment.

On first inspection diversity appears to be a very simple and unambiguous term. However, the difficulty lies in the fact that diversity measures takes into account both species richness and evenness (that is how equally abundant species are).

Species diversity measures can be grouped into three main categories, namely a) species richness indices, b) species abundance models, and c) indices based on the proportional abundance of species. The firs group, species richness indices, are basically a measure of the number of species in a defined sampling unit. The second group, species abundance models, essentially describes the distribution of species abundance. The third group, indices based on the proportional abundance of species, seek to combine richness and evenness in a single figure, such as Shannon's or Simpson's diversity index.

Table 1 shows sampling specifications and measures of biodiversity for each landuse in the city of Santiago. The total area of Santiago is 96,715 ha split in three land tenures: High Income (17%), Middle Income (38%) and Low Income (45%).

LANDUSE	TOTAL AREA (ha)	SAMPLED AREA (ha)	NO. PLOTS	SAMPLED TREES	MEASURES OF BIODIVERSITY					
					S	SPP/HA	SHANNON	MENHINICK	SIMPSON	EVENNESS
High Income	16493	2.99	74	301	84	28.05	4.01	4.84	46.07	0.91
Middle Income	37034	2.51	62	146	45	17.93	3.36	3.72	24.00	0.88
Low Income	43188	2.59	64	144	41	15.83	3.24	3.42	19.21	0.87
CITY TOTAL	96715	8.09	200	591	108	13.34	4.06	4.44	40.05	0.87

Table 1. Species diversity indices for each landuse in the city of Santiago.

A total of 108 vegetal species were identified for the city of Santiago. The species richness showed to be correlated to the land tenure, increasing as income grows. In the High Income tenure, 84 species were identified for the collection area with a species density of 28 species per hectare. In the Middle Income tenure, 45 species were identified for the collection area with a species density of 18 species per hectare. In the Low Income tenure, 64 species were identified for the collection area with a species density of 16 species per hectare. This fact is confirmed by Menhinick's index which is a measure of numerical species richness (Number of species divided by the square root of the number of individuals) which also increases as income grows.

Indices based on the proportional abundance of species provide an alternative approach to the measurement of diversity. These indices are based on the rationale that diversity in a natural system can be measured in a similar way to the information contained in a code or message.

Probably the most widely used index, in spite of its drawbacks, is the Shannon's diversity index. Shannon's index assumes that individuals are randomly sampled from an indefinitely large population and that all species area represented in the sample. Shannon's diversity index is calculated from the following equation:

$$H' = -\sum p_i \, Ln \, p_i$$

where p_i is the proportion of individuals found in the i^{th} species.

Even though Shannon's diversity index takes into account evenness and species richness, it is considered to be weighted towards species richness as opposite to the Simson's Index which is considered to be weighted towards species dominance. Shannon's diversity index showed to be correlated with land tenure, increasing as income grows. The values for the city of Santiago are found between 3.24 for the low income tenure to 4.01 for the high income tenure. Magurran (1988) reports that the value of the Shannon's diversity index is usually found between 1.5 to 3.5 and only rarely surpasses 4.5, which coincides with the values found for this study.

Simpson's index provides a measure of biodiversity weighted towards the abundance of the commonest species while being less sensitive to species richness. Simpson's index has a low sensitivity to sample size and therefore is more appropriate for comparison between land use types than Shannon's. Simpson's comes from the following formula:

$$D = \sum \frac{n_i (n_i - 1)}{N (N - 1)}$$

where n_i is the number of individuals in the ith species and N is the total number of individuals.

Usually Simpson's index is expressed as 1/D to provide a measure that increases as biodiversity grows. Simpson's diversity index showed to be correlated with land tenure, increasing as income grows. The values for the city of Santiago are found between 46.07 for the high income tenure to 19.21 for the low income tenure.

Shannon's evenness index is a measure of how equally distributed are species within a collection area. Shannon's evenness index is based in the same assumptions as the Shannon's diversity index as it is partially derived from it. It has a moderate sensitivity to sample size and therefore land tenures may not be comparable. Shannon's evenness index comes from the following formula:

$$E = \frac{H^{'}}{Ln\ S}$$

Shannon's evenness index moves in a range from 0 to 1. The lower values show that individuals are concentrated in a few species, while the higher values show that individuals distribute equally among species. Evenness showed to be correlated with land tenure, increasing as income grows. The values for the city of Santiago are found between 0.87 for the low income tenure to 0.91 for the high income tenure. This behaviour is also shown in table 3, where the proportion of the 20 most common species over the total number of individual change dramatically with land tenure. While this 20 species represents the 72,7% of the total in the lower stratum, they fall to just 48,3% in the high stratum. The middle stratum shows a intermediate value of 62,8%.

Stratum A		**Stratum B**		**Stratum C**	
Scientific names	**%**	**Scientific names**	**%**	**Scientific names**	%
Acacia caven	4,5	Acacia caven	7,0	Robinia pseudoacacia	7,2
Kageneckia oblonga	4,1	Prunus dulcis	6,0	Citrus limon	6,2
Prunus ceracifera var. pisardii	3,7	Prunus ceracifera	5,6	Ligustrum vulgare	5,3
Liquidambar styraciflua	3,5	Robinia pseudoacacia	4,2	Rosa sp.	4,8
Acer negundo	2,9	Citrus limon	4,2	Robinia pseudoacacia var. umbraculifera	4,8
Ligustrum japonicum	2,7	Populus deltoides	3,7	Acacia caven	4,8
Lithrea caustica	2,7	Prunus armeniaca	3,3	Populus deltoides	4,3
Quillaja saponaria	2,5	Grevillea robusta	3,3	Ligustrum japonicum	4,3
Acacia dealbata	2,5	Rosa sp.	3,3	Prunus ceracifera	3,8
Pittosporum tobira	2,2	Ligustrum japonicum	2,8	Acacia karroo (A. horrida)	3,8
Acacia melanoxylon	2,0	Robinia pseudoacacia var. umbraculifera	2,8	Prunus ceracifera var. Pisardii	3,3
Prunus ceracifera	2,0	Acer negundo	2,3	Lithrea caustica	3,3
Ailanthus altissima	2,0	Liquidambar styraciflua	2,3	Ulmus campestris	2,9
Rosa sp.	2,0	Citrus aurantium	2,3	Cydonia oblonga	2,4
Platanus acerifolia	1,6	Cupressus macrocarpa	1,9	Vitis vinifera	2,4
Acacia saligna	1,6	Hibiscus rosa-sinensis	1,9	Melia azedarach	2,4
Ligustrum vulgare	1,6	Pyracantha coccinea	1,9	Cestrum parqui	1,9
Nerium oleander	1,4	Syringa vulgaris	1,4	Pinus radiata	1,9
Citrus limon	1,4	Prunus persica	1,4	Cupressus macrocarpa	1,4
Eriobotrya japonica	1,2	Ligustrum vulgare	1,4	Acacia saligna	1,4
TOTAL	48,3	TOTAL	62,8	TOTAL	72,7

Table 2: List of the 20 most common species. The percentage indicates the proportion over the total number of species in each strata.

4. Conclusions

This research was developed to compare biodiversity indices for different land tenures. These were divided in high, medium and low income comprising an area of 16, 37 and 43 thousands hectares respectively. The hypothesis that biodiversity relates to land tenure was assessed for the city of Santiago.

Species richness showed to be correlated to land tenure. In fact, 28, 18 and 16 species per hectare were estimated for high, medium and low income strata. The trend coincides with those showed by Menhinick's index which also increases as income grows.

Those measures based on the proportional abundance of species combining richness and evenness in a single figure, such as Shannon's or Simpson's diversity index showed to be also correlated to land tenure, increasing as income grows. The lowest value for the Shannon's diversity index was found to be 3.24 for the low income, while being 3.36 and 4.01 for the medium and high income land tenure. Magurran (1988) reports that the value of the Shannon's diversity index is usually found between 1.5 to 3.5 and only rarely surpasses 4.5, which coincides with the values found for this study.

Shannon's evenness index showed to be also correlated with land tenure, increasing as income raises. These values were 0.91, 0.88 and 0.87 for high, medium and low income land tenures respectively.

From our perspective, decision making in urban environments could be greatly enhanced through biodiversity measures. Thus, decision makers now could undertake decisions based not only on economic or social criteria but also on environmental indices in order to assess alternative courses of action regarding forest planning of urban environments.

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