Arboriculture & Urban Forestry 2020. 46(2):84–95

ARBORICULTURE & URBAN FORESTRY
Scientific Journal of the International Society of Arboriculture

Urban Trees and Environmental Variables: Relationships in a City of Central Chile

By Mauricio Ponce-Donoso, Oscar Vallejos-Barra, Benjamin Ingram, and Gustavo Daniluk-Mosquera

Abstract. We identified relationships between ecosystem services provided by trees and environmental variables, including temperature (°C at ground level and 1.5 m), relative humidity (%), particulate matter (PM_{10}, maximum and average), noise (dBA), and ultraviolet radiation (UV at 1.5 m). This study was carried out in Talca, Chile, a mid-sized city. Measurement locations were selected in three areas based along three main avenues in the center of the city during three different seasons and three different schedules of day, generating 15,515 data in total. In circular plots, with 8 meter radiuses, measurements were recorded at the center and at a point on the perimeter. A correlation matrix was calculated and an ANOVA was conducted with canopy cover, schedule of day, and season as variation sources. The results show a high dispersion, and the correlation matrix that canopy coverage has a weak relationship with variables was studied. The results of the ANOVA showed the least number of significant differences associated with the canopy cover, schedule of day, and season, which showed significant differences for all variables. Tree coverage showed significant differences for all variables using the Tukey Test, with the exception of minimum noise. Plots with greater coverage were associated with increases in the particulate matter and relative humidity and decreases in maximum noise, temperature, and ultraviolet radiation. During mornings, the highest measurements of particulate matter, noise, and relative humidity were reported, whereas temperature maximums occurred at mid-day. The results confirm the importance of urban trees, specifically the canopy coverage, in mitigating negative environmental aspects in urban areas.

Keywords. Ecosystems Services; Humidity; Noise; Solar Radiation; Temperature; Tree Canopy.

INTRODUCTION

As countries develop economically, the majority of the population becomes localized in urban areas. This is principally due to the availability of goods and services in these areas that provide a better quality of life (Escobedo et al. 2014). As well as this, population growth increases population density, and hence it is necessary to increase urbanization in terms of both urban expansion and reconstruction. As a result, cities are becoming complex systems of heterogeneous areas with interactions of economic, social, and ecological phenomena. These factors create a dynamic environment that presents challenges for decision makers who construct communal areas of coexistence where sustainable development is encouraged for the development of ecosystem functions and services. These functions and services are derived from chemical (Préndez et al. 2013), biological, and physical processes (Posada et al. 2009) which are the result of natural interactions between biotic and abiotic components (De Groot et al. 2002) and provide explicit value or benefits to the well-being of human populations.

In the context described above, trees and green areas in general appear to provide these functions and ecosystem services in cities (Nowak 2006; Hernández 2008; Ponce-Donoso et al. 2012; Northrop et al. 2013; Haase et al. 2014; Hamstead et al. 2016; Russo et al. 2016; Ponce-Donoso et al. 2017; Calquín et al. 2019) by contributing to sustainability from economic, environmental, and social perspectives. At the same time, trees provide ecosystem functions and services that negatively impact the lives of citizens, also referred to as disservices (Lyytimäki and Sipilä 2009; Escobedo et al. 2011; Delshammar et al. 2015; Reyes et al. 2018; Speak et al. 2018), that include allergies, infrastructure destruction, and fallen fruits and leaves.

The concept of the urban forest originated during the 1960s in North America and during the 1980s in Europe (Konijnendijk et al. 2005). Cordell et al. (1984) identified urban forestry in parks or squares, both commercial and residential pathways, green belts, and other urban sites. Urban forestry is also defined in terms of maintaining healthy and functional vegetation and associated systems that provide long term benefits desired by the community, with an emphasis on the role of people who manage and use the urban forest in providing for its sustainability (Dwyer et al. 2003).

In recent years, it has been recognized that the main contribution of urban forestry is the impact on human health. These benefits to human health include the shade that trees provide (Nowak et al. 2006; Smargiassi et al. 2009), the reduction of the effect of the so-called urban heat island (Li et al. 2013; Haase et al. 2014), and the reduction of ultraviolet radiation, among others. The urban heat island effect can be defined as the occurrence of higher temperatures in central areas of the city compared to the adjacent peri-urban and rural areas; urban heat islands even generate micro-climates as a result of the combination of urban morphology and the heat released by human activities (Colunga et al. 2015; Coronel et al. 2015). Furthermore, relative humidity converges to comfortable levels for human habitation (approximately 55% to 60%), even though the gradients and oscillations depend on grey infrastructure (number of buildings and their height) and the distribution of trees, bushes, grass, and pavement (Weng et al. 2004; Petralli et al. 2006; Hamstead et al. 2016). This is because materials like concrete and asphalt are unable to absorb and retain water like plants can; however, these materials can absorb and retain solar radiation (Bowler et al. 2010).

Another relevant variable linked to urban forestry is ultraviolet radiation (UV), especially in latitudes where there is a worrying reduction in the ozone layer as is the case for countries in the southern part of South America. Na et al. (2014) modeled functions to predict the mitigating effects of trees on UV radiation at ground level. Grant et al. (2002) developed a three-dimensional model to measure UV radiation for different tree canopy coverage, the results of which showed that cities located between latitudes 15° S and 30° S have identical exposures, while cities between latitudes 15° S and 60° S and with less than 50% coverage have an ultraviolet protection factor (UPF) lower than 2. For other latitudes with a 90% coverage, the UPF was 10. As a result, the mitigation of the temperature, convergence of relative humidity to comfortable levels, and the reduction of UV radiation in public spaces is relevant for public policy making, particularly in a climate change context.

Exposure to particulate matter is known to be associated with health problems in the population. Trees play an active role in the reduction of particulate matter as with other atmospheric contaminants common in cities (Scott et al. 1999; Escobedo et al. 2006; Nowak et al. 2006; Bealey et al. 2007; McDonald et al. 2007; Litschke and Kuttler 2008; Escobedo et al. 2011; Vos et al. 2013; Irga et al. 2015). Hence, trees contribute to improving the health of the population by reducing rates of respiratory illness (Escobedo et al. 2011). However, the role that each different component of the phenotype of the tree plays in these processes, such as leaf size, stoma, density, meteorological conditions, among others, has yet to be set out in detail. Tiwary et al. (2009) were able to estimate in a quantity of 0.009 tons per hectare/year the particulate matter (PM_{10}) retention capacity of grass, conifer, and broadleaf trees, which would be equivalent to a reduction of two deaths and two hospital admissions in the same time period. Currently, air quality is monitored in contaminated cities so that restrictive measures can be taken against the polluting sources. The most commonly measured particle sizes are PM_{10} and $PM_{2.5}$, as is the case in various cities in Chile (MMA 2011).

Urban noise, also referred to as environmental noise, produces effects on the health of the population and can be catalogued in three different ways: physiopathological, psychological changes, and physical harm. The effect of trees and green areas on reducing health and psychological well-being has been previously studied (Gidlöf-Gunnarsson and Öhrström 2007). Fang and Ling (2003) estimated the effect of a belt of evergreen trees, concluding that trees are able to reduce negative health effects and calling it effective reduction. Along highways, Pudjiwati et al. (2013) estimated a reduction of about 10% at a distance of 20 meters from the road, while Samara and Tsitsoni (2007) determined that the most appropriate distance was 10 meters, taking into account a pine plantation for the same effect. Van Renterghem et al. (2013) studied the effect of hedges on the reduction of noise that comes from vehicles in cities, finding that high and dense hedges provide a noise reduction from light or slow moving vehicles. Furthermore, it was noted that the noise reduction should also be increasingly associated with the effect of the road surface over which cars are driven. However, Posada et al. (2009) found that vegetation did not fulfill the function of noise damping.

Furthermore, there are another set of services that a tree provides that must be recognized. Ulrich (1984) reported that hospital patients with a view of green areas were hospitalized for fewer days. Also, it was found that working environments that provide contact with vegetation also improve the well-being of employees and their efficiency (Kaplan 1993), including reducing the fear levels of people living in cities (Kuo and Sullivan 2001).

The modeling of quantitative data is frequently used to determine urban ecosystem services, as the heterogeneity in these contexts require both complex and multifunctional fitting (Pataki et al. 2011). The objective of this article is to link variables such as temperature, relative humidity, ultraviolet radiation, noise, and particulate matter variables measured in a mid-sized city with a Mediterranean climate, with different levels of forest canopy cover in three different seasons of the year. Our hypothesis is that canopy coverage will positively affect the value of variables linked to the quality of life of those who live in cities.

MATERIALS AND METHODS

This study considers the public urban forests in three areas in the commune of Talca, Chile, a city with a continental Mediterranean climate located in the Maule Region (35°25’59” latitude South and 71°40’00” longitude West), 102 meters above sea level, with an area of 232 km^2 and 201,800 inhabitants (BCN 2013). The average rainfall per year is 676.2 mm, with 75% of this rainfall between the months of May and August. Average monthly minimum and maximum temperatures range from 4.2 °C to 30.3 °C. Relative humidity varies in the range of 58.2% in summer to 89.5% in winter; Figure 1 shows the distribution of monthly precipitation and temperature (DGA 2004).

The data was collected in urban spaces, where 30 plots were defined and distributed in a circuit of streets in the center of the city, being located in places of public use and high pedestrian circulation (Figure 2). The criteria for the sampling distribution were to select 1 to 2 plots per block of street located on different sides of the road. Circular plots with a radius of 8 meters, equivalent to 200 m^2, were chosen per plot. The scale used was considered appropriate based on comparisons of similar studies such as Escobedo and Nowak (2009) and improved the representativeness of this type of study as indicated by Haase et al. (2014).

The street configuration is a typical Spanish colonial design based on street blocks measuring 125 meters, which translates to a separation distance between plots of approximately 100 meters on average. The selected areas were based on the representativeness of the trees in the center of the city. The first area is the main avenue, called Alameda, which has a major central reservation with trees (T01 – T12); the second area is the Isidoro del Solar Avenue (also called Diagonal), which has a diverse range of trees and a small central reservation with trees, as well as a section composed of *Platanus orientalis* L. that forms a dome over the vehicular area and includes two plots from the main

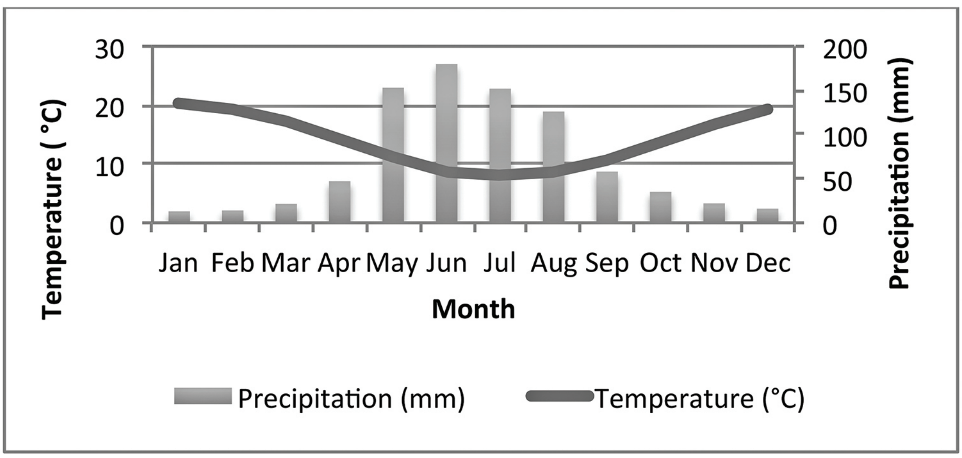

Figure 1. Distribution of monthly climate variables in Talca (DGA 2004).

Figure 2. Location of plots. Source: Google Maps.

square (also called Plaza de Armas)(T13 – T20). The third area is the street named 1st South (Uno Sur), which is the principal commercial zone of the city and has the least densely populated area of trees of the three areas considered (T21 – T30)(Figure 2).

For each plot, the percentage of tree coverage was obtained by horizontally projecting the tree crown from the trees inside the plot. During autumn 2016, the tree coverage was measured, showing that leaf loss in deciduous trees accounted for a 40% reduction in tree coverage on average. The percentage tree coverage (C) was found and split into five classes from 0% to 100%: 20% if $C \leq 20\%$, 40% if $20\% < C \leq 40\%$, 60% if $40\% < C \leq 60\%$, 80% if $60\% < C \leq 80\%$, and 100% if $C > 80\%$. This discretization was performed so that the ANOVA could be used with the data.

Environmental variables were recorded at two points in each plot, at the center and at the edge, corresponding to: (a) particulate matter PM_{10} (10.0 µm) at a height of 1.5 meters and measured in mg/m^3, recording maximum PM_{10} (PM_{10} max) and average PM_{10} (PM_{10} avg), using the measurement instrument DustTrak II Model 8532, TSI; (b) temperature at ground level (T° ground) and at a height of 1.5 meters (T° 1.5 m) was measured with a thermo hygrometer JT-07CRL in degrees Celsius; (c) relative humidity at a height of 1.5 meters, measured as a percentage (%) and using the same instrument as was used for measuring the temperature; (d) levels of noise measured in decibels at a height of 1.5 meters (dBA), maximum (Max noise), and minimum (Min noise), measured with a sound level meter using the measurement instrument LUTRON SL-4012; and (e) ultraviolet radiation at a height of 1.5 meters and measured in nanometers (nm) using the measurement instrument Light meter UV340B. The measurements were recorded during three different times of day: (i) between 8:00 and 9:00 am; (ii) between 2:00 and 3:00 pm; and (iii) between 7:00 and 8:00 pm, corresponding to times of day: morning, midday, and evening, respectively. In each hourly period mentioned, the 10 sites in each block were visited to measure the different variables.

The season when measurements were made corresponds to the date ranges: November 2014 to January 2015, April to May 2015, and September to November 2015, which we have termed summer, autumn, and spring, respectively. The total number of records was 1,968, which is equivalent to 15,515 points of data. To record the data, two ad hoc data collection forms were created, one for the measurements of

Table 1. Measurements of environmental variables by seasons and area.

		Maximum PM_{10} (mg/m^3)			Average PM_{10} (mg/m^3)		
Season	Block	Coefficient of variation	Average	Amplitude	Coefficient of variation	Average	Amplitude
Autumn	I	0.064	0.080	0.005 – 0.532	0.044	0.061	0.003 – 0.175
	II	0.120	0.127	0.013 – 0.750	0.043	0.086	0.009 – 0.234
	III	0.143	0.107	0.011 – 0.850	0.050	0.066	0.001 – 0.240
Spring	I	0.060	0.041	0.003 – 0.800	0.016	0.022	0.002 – 0.089
	II	0.054	0.042	0.006 – 0.502	0.023	0.024	0.004 – 0.125
	III	0.015	0.022	0.002 – 0.106	0.011	0.014	0.001 – 0.126
Summer	I	0.027	0.026	0.002 – 0.161	0.006	0.012	0.002 – 0.036
	II	0.038	0.025	0.003 – 0.363	0.010	0.012	0.002 – 0.043
	III	0.023	0.022	0.005 – 0.211	0.010	0.012	0.001 – 0.048
		Maximum noise (dBA)			**Minimum noise (dBA)**		
Season	**Block**	**Coefficient of variation**	**Average**	**Amplitude**	**Coefficient of variation**	**Average**	**Amplitude**
Autumn	I	0.09	76.7	60.4 – 94.7	0.10	58.5	3.6 – 73.0
	II	0.08	74.4	60.3 – 112.9	0.07	57.7	48.0 – 71.8
	III	0.12	72.2	2.0 – 91.2	0.08	58.1	49.6 – 72.4
Spring	I	0.13	77.3	57.4 – 106.5	0.09	59.3	47.5 – 80.5
	II	0.11	73.6	27.7 – 111.7	0.10	58.3	10.2 – 77.2
	III	0.08	72.5	59.4 – 98.5	0.08	58.0	25.7 – 72.5
Summer	I	0.12	75.4	47.7 – 112.9	0.12	58.7	41.8 – 79.3
	II	0.10	73.1	54.7 – 99.4	0.08	54.5	42.9 – 69.5
	III	0.09	70.1	45.9 – 89.2	0.08	54.5	45.6 – 66.8
		Ground-level Temperature (°C)			**Temperature at 1.5 m (°C)**		
Season	**Block**	**Coefficient of variation**	**Average**	**Amplitude**	**Coefficient of variation**	**Average**	**Amplitude**
Autumn	I	0.27	15.8	9.4 – 23.2	0.27	15.8	9.3 – 25.2
	II	0.42	14.4	3.4 – 31.9	0.42	14.3	1.5 – 28.9
	III	0.36	17.1	4.9 – 33.9	0.34	16.7	4.7 – 28.0
Spring	I	0.29	19.4	9.3 – 35.5	0.28	18.9	2.4 – 30.4
	II	0.32	19.7	7.7 – 34.7	0.32	19.4	6.9 – 34.7
	III	0.32	19.6	2.8 – 35.5	0.30	19.0	9.7 – 33.4
Summer	I	0.28	24.6	11.8 – 41.1	0.25	23.2	11.4 – 34.2
	II	0.33	22.8	9.8 – 42.8	0.33	22.2	6.5 – 37.4
	III	0.25	28.5	13.1 – 45.1	0.26	25.5	9.4 – 36.9
		UV (nm)			**RH (%)**		
Season	**Block**	**Coefficient of variation**	**Average**	**Amplitude**	**Coefficient of variation**	**Average**	**Amplitude**
Autumn	I	1.55	51.1	0.0 – 330.3	0.22	70.3	47.8 – 98.0
	II	1.34	57.2	0.0 – 400.0	0.27	69.5	41.9 – 97.6
	III	1.51	69.4	0.0 – 363.4	0.27	66.0	0.85 – 96.0
Spring	I	3.48	327.5	1.0 – 8,820.0	0.32	55.7	23.3 – 87.5
	II	2.11	200.9	0.1 – 3,800.0	0.32	58.3	25.2 – 96.0
	III	2.10	331.8	0.9 – 5,400.0	0.37	48.0	19.8 – 82.4
Summer	I	3.12	529.7	2.3 – 9,620.0	0.25	50.1	28.1 – 75.8
	II	3.07	283.5	0.9 – 7,600.0	0.39	52.3	25.8 – 93.1
	III	2.69	715.3	3.5 – 9,340.0	0.32	43.9	12.8 – 71.6

variables related to the tree and the other for environmental data. The data was recorded in an Excel worksheet before analysis was then performed.

A correlation matrix was calculated using the measurements so that relationships between the variables could be observed. As well as this, an ANOVA was calculated for each of the recorded variables using sources of variation such as percentage of tree coverage, the time of day, and the season. Average values were used for the statistical analysis. The implicit hypothesis used was that there are no statistically significant differences between the sources of variation.

ANOVAs were used to determine if there were statistically significant differences between the sources of variation and the interaction added between the sources of variation.

RESULTS

The sampling performed identified 75 trees with 23 different species, with a large abundance of *Liquidambar styraciflua* L. The diameter at breast height (dbh) fluctuated between 2.3 and 90.2 cm, and the diameters of the crown between 0.36 and 15.23 m. The greater percentage of tree coverage was found in the Alameda block (T01, T03, and T06) and in the Diagonal (T11, T16, T19, and T20), whereas in the Uno Sur block there were fewer trees, and hence the tree coverage was reduced.

The results for the environmental variables showed a large spread, which is due to the influence of the different sources of variance (time of day and season) used in the study (Table 1). The maximum percentage fluctuation of each variable (defined as the difference between the maximum value and the minimum value and then divided by the minimum value) gives an idea as to the magnitude of the fluctuation according to the source of variance considered. Particulate matter has the largest fluctuation of 494.2% when considering season (summer vs. autumn), followed by the fluctuation in the time of day (morning vs. midday) which was 135.0%. The fluctuation of noise was the lowest, with a variation between 1.2% and 11.6%. Temperature, ultraviolet radiation, and the relative humidity showed the largest fluctuation in the time of day, followed by season, contrary to what was observed with particulate matter. The largest fluctuation observed was the ultraviolet radiation, with a maximum fluctuation of 4,021.8% when considering times of day (midday and morning), followed by the fluctuation of the season (2,099.0%) considering summer vs. autumn.

The correlation matrix showed the relationship between the different variables (Table 2). The majority

Table 2. Relationship between variables. Correlation coefficient (probability).

Variables	PM_{10} (mg/m^3)		Noise (dBA)		Temperature (°C)		UV (nm)	RH (%)
	Max	Avg	Max	Min	Ground	1.5 m		
PM_{10} Avg (mg/m^3)	0.73 (0.00)							
Noise max (dBA)	0.11 (0.00)	0.10 (0.00)						
Noise min (dBA)	0.11 (0.00)	0.14 (0.00)	0.26 (0.00)					
T° ground (°C)	-0.40 (0.00)	-0.53 (0.00)	-0.09 (0.00)	-0.30 (0.00)				
T° 1.5 m (°C)	-0.40 (0.00)	-0.52 (0.00)	-0.07 (0.00)	-0.30 (0.00)	0.97 (0.00)			
UV (nm)	-0.09 (0.00)	-0.14 (0.00)	-0.03 (0.13)	-0.12 (0.00)	0.39 (0.00)	0.32 (0.00)		
RH (%)	0.39 (0.00)	0.51 (0.00)	0.07 (0.00)	0.25 (0.00)	-0.85 (0.00)	-0.86 (0.00)	-0.27 (0.00)	
Coverage (%)	0.00 (0.97)	0.03 (0.22)	-0.06 (0.01)	0.02 (0.33)	-0.11 (0.00)	-0.07 (0.00)	-0.08 (0.00)	0.12 (0.00)

The data with significant differences are marked in grey.

of the variables show a linear relationship between themselves (grey cells), however, weak relationships ($r < 0.60$) dominate the results, the exceptions being the relationship between temperatures ($r = 0.97$), followed by relative humidity with temperature at 1.5 m ($r = -0.86$) and with temperature at ground level ($r = -0.85$), and finally between particulate matter. The variables that didn't show a linear relationship with tree coverage are maximum PM_{10} ($r = 0.00$), average PM_{10} ($r = 0.03$), and minimum noise ($r = 0.02$), and also maximum noise with ultraviolet radiation ($r = -0.03$).

The ANOVA results showed significant differences from various sources of variation (Table 3). Tree coverage and time of day showed significant differences in the variables, with the exception of the noise level data. Season showed significant differences for all variables.

Maximum noise and ultraviolet radiation did not show any interactions between the sources of variation, such that the results from the Tukey multiple comparison test for these variables indicate that these variables can be analyzed separately, depending on the source of variation (Table 4). In the remaining variables, any interactions evident are merely for reference. For example, if maximum PM_{10} is analyzed according to tree coverage, time of day, and season of year, it was observed that the maximum values for canopy coverage of 20%, 100%, and 40% were found in autumn, spring, and summer, respectively. In autumn as in spring, the maximum values are reached in the morning, whereas in summer the maximum values were recorded at midday (Table 4).

The Tukey multiple comparison test showed the differences detected by the ANOVA. In the case of canopy coverage, significant differences were found for noise, temperature at ground level, and ultraviolet radiation, showing that larger tree coverage can be characterized by lower average values. This tendency is likewise visible in the remaining variables, even though there is no evidence of significant differences with the exception of relative humidity (RH), which has an inverse relationship (Table 4). This result confirms that tree coverage has a role in reducing the amplitude of these recorded variables, making cities more habitable by reducing the undesirable effects of these negative variables.

The time of day showed significant differences for all variables except for maximum noise. The behavior of the variables that showed significant differences was dissimilar. The highest values were observed in the mornings for maximum and average particulate matter, minimum noise, and relative humidity, whereas temperatures reached maximums at midday. Analyzing the season variable established that maximum values, with the exception of temperature and ultraviolet radiation, were recorded in autumn.

DISCUSSION

Even though the particulate matter values show significant differences (Tables 3 and 4) when considering the tree coverage, no clear tendency is visible in the relationship between particulate matter and tree coverage. According to Liu et al. (2015), the canopy coverage directly influences the concentration of particulate matter. This relationship was also confirmed in this study, even though canopy coverage did not necessarily lead to a reduction in particulate matter. Another aspect that justifies these results is the spatial extent of the study. The distance between the furthest pair of spatially separated points was no more

Table 3. Probability of ANOVA by variable and source of variation.

Source of variation	PM_{10} (mg/m^3)		Noise (dBA)		Temperature (°C)		UV (nm)	RH (%)
	Max	Avg	Max	Min	Ground	1.5 m		
A: Coverage	0.0176	0.0008	0.0000	0.3973	0.0000	0.0000	0.0012	0.0000
B: Time of day	0.0000	0.0000	0.1133	0.0000	0.0000	0.0000	0.0000	0.0000
C: Season	0.0000	0.0000	0.0448	0.0000	0.0000	0.0000	0.0000	0.0000
Interaction								
ABC	0.0055	0.0001	0.8636	0.0207	0.0157	0.0000	0.2861	0.0011

The data with significant differences are marked in grey.

Table 4. Tukey multiple comparison test for variables mean and source of variation.

Source of variation	Level	PM$_{10}$ (mg/m^3)		Noise (dBA)		Temperature (°C)		UV (nm)	RH (%)
		Max	Mean	Max	Min	Ground	1.5 m		
Coverage	20	0.053_{ab}	0.033_{a}	73.4_{b}	57.5_{a}	21.3_{b}	20.1_{b}	377.0_{b}	54.4_{a}
	40	0.062_{b}	0.037_{ab}	77.1_{d}	57.6_{a}	19.6_{a}	19.0_{a}	275.0_{ab}	59.6_{bc}
	60	0.064_{b}	0.039_{b}	75.7_{c}	57.8_{a}	19.2_{a}	18.8_{a}	234.0_{ab}	60.2_{bc}
	80	0.045_{a}	0.032_{a}	71.6_{a}	58.2_{a}	19.3_{a}	18.9_{a}	153.0_{a}	58.5_{b}
	100	0.06_{b}	0.041_{b}	71.1_{a}	57.1_{a}	18.8_{a}	18.5_{a}	144.0_{a}	61.2_{c}
Time of day	Morning	0.079_{b}	0.045_{b}	74.5_{b}	59.0_{c}	13.1_{a}	12.7_{a}	50.2_{a}	79.0_{c}
	Midday	0.040_{a}	0.026_{a}	73.4_{a}	56.4_{a}	23.7_{c}	22.6_{c}	632.0_{b}	45.9_{a}
	Evening	0.053_{b}	0.038_{b}	73.4_{a}	57.5_{b}	22.1_{b}	21.9_{b}	28.1_{a}	51.4_{b}
Season	Autumn	0.110_{c}	0.076_{c}	73.5_{a}	57.8_{b}	15.0_{a}	15.0_{a}	41.2_{a}	71.0_{c}
	Spring	0.037_{b}	0.021_{b}	74.5_{b}	58.6_{c}	19.4_{b}	19.0_{b}	230.0_{b}	55.3_{b}
	Summer	0.025_{a}	0.012_{a}	73.3_{a}	56.5_{a}	24.4_{c}	23.2_{c}	439.0_{c}	49.9_{a}

Results with significant differences are colored grey. Subscripts with different letters indicate significant differences (probability < 0.05).

than 2.5 kilometers. With a larger spatial extent and point pair separations, it's likely that significant differences would be found. On the other hand, it must be taken into consideration that a quantity of particulate material is raised from ground level by the passage of different types of automobiles, for which raised-level readings could be expected in times of greater traffic.

In numerical terms, if the percentage reduction between the smallest and largest tree coverage is compared, a decrease in PM_{10} of 6.4% and 0.3% for maximum and average measurements respectively can be observed (Table 1). According to the studies carried out by McDonald et al. (2007) and Vos et al. (2013), the reduction of PM_{10} associated with canopy coverage can fluctuate between 2% and 26%, which coincides with the maximum value of the variable recorded in this study.

For the season of year, the largest values of particulate matter and relative humidity were recorded in autumn, followed by spring, and then summer (Tables 1 and 4). The high values in particulate matter are explained by two reasons: one is the climatic conditions (known as thermal inversion phenomenon), and the second is the use of firewood as a fuel to heat homes and the relative humidity of summer conditions in a continental Mediterranean climate (MMA 2011). On the other hand, regarding the time of day when measurements were recorded, maximum values of particulate matter and relative humidity were recorded in the morning and the evening, whereas at midday lower values were recorded.

The temperature and ultraviolet radiation measurements showed maximum values in summer, followed by spring, and then autumn (Tables 1 and 4). When time of day is considered, the maximum value was observed at midday, followed by evening, and then morning, similar to the result found by Scott et al. (1999). The measurements for these variables, as with particulate matter and relative humidity, showed a decreasing tendency as the tree coverage increased. However, with the measurements of the noise, no tendency related to season, time of day, or canopy coverage was observed. This finding is consistent with the studies of Posada et al. (2009) and Pudjiwati et al. (2013), which state that tree and vegetation coverage must be significant so as to reduce noise levels, a situation that is not present in this study.

The analysis of the season when measurements were made showed maximum values for all variables in the autumn season, with the exception of temperatures and ultraviolet radiation.

Even though the presented results confirm existing studies and our hypothesis, the challenges encountered in finding the relationships between the variables require that the study should be enhanced to include more plots, other areas within the city, and other times of day and months of year. This is especially important in cities where there have been insufficient numbers of these types of studies carried out; these studies enable developing countries to improve conditions in cities by putting in place environmental policies.

The study has limitations to take into consideration, which are: (a) the territory studied, which corresponds to a part of a city with a continental Mediterranean climate; (b) no repeat measurements longer than one year were made; (c) a census was not carried out that characterized the trees; and (d) the vehicular flow of the streets and avenues studied was unknown. For this reason, the results must be considered in the space and conditions in which the research was conducted.

CONCLUSION

Statistically significant differences were found between the averages of studied variables (PM_{10}; Max Noise; Min Noise; Time of Day and Season; Temperature; UV; and RH) for all sources of variation. The exception was for noise, which didn't present significant differences in tree coverage.

As canopy coverage increases, a decreasing tendency with particulate matter, temperature at 1.5 m, and relative humidity was observed; however, no significant differences were identified. Significant differences were found in noise, temperature at ground level, and ultraviolet radiation, and in general supports the idea that as canopy coverage increases, a reduction in the unwanted effects of these variables can be observed.

The time of day showed significant differences for all variables with the exception of maximum noise. This would be explained by working hours and vehicle paths within the city. Maximum and average particulate matter, minimum noise, and relative humidity showed significant differences in the mornings, which would be due to atmospheric phenomena. However, as would be expected, both temperature and ultraviolet radiation reached their maximums at midday. Significant differences present for all variables during the season when the data was recorded is taken into consideration. Autumn and spring showed maximum particulate matter, noise, and relative humidity values, and summer showed high temperature and ultraviolet radiation values.

The theory that canopy coverage is able to reduce some of the effects of the recorded variables in this study has been reinforced, thus making cities more comfortable as the undesirable effects of the variables studied are reduced.

LITERATURE CITED

Bealey WJ, McDonald AG, Nemitz R, Donovan R, Dragosits U, Duffy T, Fowler D. 2007. Estimating the reduction of urban PM10 concentrations by trees within an environmental information system for planners. *Environmental Managements*. 85:44-58.

Biblioteca del Congreso Nacional (BCN, CL). 2013. Reportes Estadísticos Distritales y Comunales 2013. [Accessed 2014 Jan 10]. http://reportescomunales.bcn.cl

Bowler D, Buyung-Ali L, Knight TM, Pullin AS. 2010. Urban greening to cool towns and cities: a systematic review of the empirical evidence. *Landscape and Urban Planning*. 97:147-155.

Calquín F, Ponce-Donoso M, Vallejos-Barra O, Plaza E. 2019. Influence of urban trees on noise levels in a central Chilean city. *Revista de la Facultad de Ciencias Agrarias*. 51(1):41-53.

Colunga ML, Cambrón-Sandoval VH, Suzán-Azpiri H, Guevara-Escobar A, Luna-Soria H. 2015. The role of urban vegetation in temperature and heat island effects in Querétaro city, México. *Atmósfera*. 28:205-218.

Cordell H, Anderson L, Berisford C, Berisfrod Y, Biles L, Black P, Degraaf R, Deneke F, Dewers R, Gallaher J, Grey G, Ham D, Herrington L, Kielbaso J, Moll G, Mulligan B. 1984. Urban Forestry, Section 16. In: Wenger K, editor. *Forestry handbook*. 2nd Edition. Washington (USA): Wiley Interscience. p. 887-983.

Coronel AS, Feldman SR, Jozani E, Facundo K, Piacentini RD, Dubbeling M, Escobedo FJ. 2015. Effects of urban green areas on air temperature in a medium-sized Argentinian city. *Environmental Science*. 2:803-826.

De Groot R, Wilson MA, Boumans RM. 2002. A typology for the classification, description and valuation of ecosystem function, goods and services. *Ecological Economics*. 41:393-408.

Delshammar T, Östberg J, Öxell C. 2015. Urban trees and ecosystem disservices—a pilot study using complaints records from three Swedish cities. *Arboriculture & Urban Forestry*. 41:187-193.

Dirección General de Aguas (DGA), Ministerio de Obras Públicas (CL). 2004. Diagnóstico y clasificación de los cursos y cuerpos de agua según objetivos de calidad. Cuenca del río Maule. 152 p.

Dwyer JF, Nowak DJ, Noble MH. 2003. Sustaining urban forests. *Journal of Arboriculture*. 29:49-55.

Escobedo FJ, Nowak DJ, Wagner JE, de La Maza CL, Rodríguez M, Crane DE, Hernández J. 2006. The socioeconomics and management of Santiago de Chile's public urban forest. *Urban Forestry & Urban Greening*. 4:105-114.

Escobedo FJ, Nowak DJ. 2009. Spatial heterogeneity and air pollution removal by an urban forest. *Landscape and Urban Planning*. 90:102-110.

Escobedo FJ, Kroeger T, and Wagner J. 2011. Urban forest and pollution: analyzing ecosystem services and disservices. *Environmental Pollution*. 159:2078-2087.

Escobedo FJ, Adams D, Timilsina N. 2014. Urban forest structure effects on property value. *Ecosystem Services*. 12:209-217.

Fang C, Ling D. 2003. Investigation of the noise reduction provided by tree belts. *Landscape and Urban Planning*. 63:187-195.

Gidlöf-Gunnarsson A, Öhrström E. 2007. Noise and well-being in urban residential environments: the potential role of perceived availability to nearby green areas. *Landscape and Urban Planning*. 83:115-126.

Grant RH, Heisler GM, Gao W. 2002. Estimation of pedestrian level UV exposure under trees. *Photochemistry and Photobiology*. 75:369-376.

Haase D, Larondelle N, Andersson E, Artmann M, Borgström S, Breuste J, Gomez-Baggethum E, Gren A, Hamstead A, Hansen R, Kabish N, Kremer P, Langemeyer J, Lorance E, McPhearson T, Pauleit S, Qureshi S, Schwarz N, Voigt A, Wurster D, Elmqvist T. 2014. A quantitative review of urban ecosystem service assessments: concepts, models, and implementation. *Ambio*. 43:413-433.

Hamstead Z, Kremer P, Larondelle N, McPherson T. 2016. Classification of the heterogeneous structure of urban landscapes (STURLA) as an indicator of landscape function applied to surface temperature in New York City. *Ecological Indicators*. 70:574-585.

Hernández J. 2008. La situación del arbolado en Santiago. *Revista de Urbanismo*. 18:1-8.

Irga PJ, Burchett MD, Torpy FR. 2015. Does urban forestry have a quantitative effect on ambient air quality in an urban environment? *Atmospheric Environment*. 120:173-181.

Kaplan R. 1993. The role of nature in the context of the workplace. *Landscape and Urban Planning*. 26:193-201.

Konijnendijk C, Kjell N, Randrup T, Schipperijn L. 2005. *Urban Forest and Trees*. Amsterdam (Holland): Springer Verlag. 520 p.

Kuo FE, Sullivan WC. 2001. Environment and crime in the inner city: does vegetation reduce crime? *Journal of Environment and Behavior*. 33:343-367.

Li X, Zhou W, Ouyang Z. 2013. Relationship between land surface temperature and spatial pattern of greenspace: what are the effects of spatial resolution? *Landscape and Urban Planning*. 114:1-8.

Litschke T, Kuttler W. 2008. On the reduction of urban particle concentration by vegetation—a review. *Meteorologische Zeitschrift*. 17:229-240.

Liu X, Yu X, Zhang Z. 2015. PM2.5 Concentration differences between various forest types and its correlation with forest structure. *Atmosphere*. 6:1801-1815.

Lyytimäki J, Sipilä M. 2009. Hopping on one leg—the challenge of ecosystem disservices for urban management. *Urban Forestry & Urban Greening*. 8:309-315.

McDonald AG, Bealey WJ, Fowler D, Dragosits U, Skiba U, Smith RI, Donovan RG, Brett HE, Hewitt CN, Nemitz E. 2007. Quantifying the effect of urban tree planting on concentrations and depositions of PM10 in two UK conurbations. *Atmospheric Environment*. 41:8455-8467.

Ministerio del Medio Ambiente (MMA, CL). 2011. Capítulo 1: Contaminación del aire. Informe del Estado del Medio Ambiente 2011: Riesgo para la Salud y Calidad de Vida de la Población. 47 p.

Na HR, Heisler GM, Nowak DJ, Grant RH. 2014. Modelling of urban trees' effects on reducing human exposure to UV radiation in Seoul, Korea. *Urban Forestry & Urban Greening*. 13:785-792.

Northrop RJ, Beck K, Irving R, Shawn M, and Andreu I. 2013. City of Tampa Urban Forest Management Plan. November 2013. City of Tampa, Florida. 64 p.

Nowak D, Crane D, Stevens J. 2006. Air pollution removal by urban trees and shrubs in the United States. *Urban Forestry & Urban Greening*. 4:115-123.

Pataki DE, Carreiro MM, Cherrier J, Grulke NE, Jennings V, Pincetl S, Pouyat RV, Withlow TH, Zipperer WC. 2011. Coupling biogeochemical cycles in urban environments: ecosystem services, green solution, and misconceptions. *Frontier in Ecology and the Environment*. 9:27-36.

Petralli M, Prokopp A, Morabito M, Bartolini G, Torrigiani T, Orlandini S. 2006. Ruolo delle aree verdi nella mitigazione dell' isola di calore urbana: uno studio nella cittá di Firenze. *Rivista Italiana di Agrometerologia*. 1:51-58.

Ponce-Donoso M, Vallejos-Barra O, Daniluk-Mosquera G. 2012. Comparación de fórmulas chilenas e internacionales para valorar el arbolado urbano. *Bosque*. 33:69-81.

Ponce-Donoso M, Vallejos-Barra O, Escobedo FJ. 2017. Appraisal of urban trees using twelve valuation formulas and two appraiser groups. *Arboriculture & Urban Forestry*. 43:72-82.

Posada M, Arroyave M, Fernández L. 2009. Influencia de la vegetación en los niveles de ruido urbano. *Revista EIA*. 12:79-89.

Préndez M, Carvajal V, Corada K, Morales L, Alarcón F, Peralta H. 2013. Biogenic volatile organic compounds from the urban forest of the Metropolitan Region, Chile. *Environmental Pollution*. 183:143-150.

Pudjiwati UR, Yanuwiyadi B, Sulistiono R, Suyadi. 2013. Estimation of noise reduction by different vegetation type as a noise barrier: a survey in highway along Waru-Sidoarjo in East Java, Indonesia. *International Journal of Engineering and Science*. 2:20-25.

Reyes J, Ponce-Donoso M, Vallejos-Barra O, Daniluk-Mosquera G, Coelho AP. 2018. Comparación de cuatro métodos de evaluación visual del riesgo de árboles urbanos. *Colombia Forestal*. 21:161-173.

Russo A, Escobedo FJ, Zerbe S. 2016. Quantifying the local-scale ecosystem services provided by urban treed streetscapes in Bolzano, Italy. *AIMS Environmental Science*. 3:58-76.

Samara TH, Tsitsoni TH. 2007. Road traffic noise reduction by vegetation in the ring road of a big city. *Proceedings of the International Conference on Environmental Management, Engineering, Planning and Economics*. June 24-28. Skiathos (Greece). p. 2591-2596.

Scott KI, Simpson JR, McPherson RG. 1999. Effects of tree cover on parking lot microclimate and vehicle emissions. *Journal of Arboriculture*. 25:129-142.

Smargiassi A, Goldberg MS, Plante C, Fournier M, Baudouin Y, Kosatsky T. 2009. Variation of daily warm season mortality as a function of micro-urban heat islands. *Journal of Epidemiology and Community Health*. 63:659-664.

Speak A, Escobedo FJ, Russo A, Zerbe S. 2018. Na ecosystem service-disservice ratio: using composite indicators to assess the net benefits of urban trees. *Ecological Indicators*. 95:544-553.

Tiwary A, Sinnett D, Peachey C, Chaladi Z, Vardoulakis S, Fletcher T, Leonardi G, Grundy C, Azapagic A, Hutchings R. 2009. An integrated tool to assess the role of new planting in PM10 capture and the human health benefits: a case study in London. *Environmental Pollution*. 157:2645-2653.

Ulrich R. 1984. View through a window may influence recovery. *Science*. 224:224-225.

Van Renterghem T, Attenborough K, Maennel M, Defrance J, Horoshenkov K, Kang J, Bashir I, Taherzadeh S, Altreuther B, Khan A, Smyrnova Y, Yang H. 2013. Measured light vehicle noise reduction by hedges. *Applied Acoustics*. 78:19-27.

Vos PEJ, Maiheu B, Vankerkom J, Janssen S. 2013. Improving local air quality in cities: to tree or not to tree? *Environmental Pollution*. 183:113-122.

Weng Q, Lu D, Schubring J. 2004. Estimation of land surface temperature-vegetation abundance relationship for urban heat island studies. *Remote Sensing of Environment*. 89:467-483.

ACKNOWLEDGMENTS

The authors thank Fondo de Protección Ambiental of Ministerio del Medio Ambiente, Chile, project NAC-I-035-2014 for funding this project.

Mauricio Ponce-Donoso (corresponding author)
Facultad de Ciencias Forestales
Universidad de Talca
P.O. Box N° 747
Talca, Chile
mponce@utalca.cl

Oscar Vallejos-Barra
Facultad de Ciencias Forestales
Universidad de Talca
Talca, Chile

Benjamin Ingram
Cranfield University
Bedfordshire, United Kingdom

Gustavo Daniluk-Mosquera
Facultad de Agronomía
Universidad de la República
Montevideo, Uruguay

Conflicts of Interest:
The authors reported no conflicts of interest.

Résumé. Nous avons cerné les liens entre les services écosystémiques fournis par les arbres et diverses variables environnementales dont la température (°C au niveau du sol et à 1.5 m), l'humidité relative (%), les particules en suspension (PM_{10}, maximum et moyenne), le bruit (dBA) et le rayonnement ultraviolet (UV à 1.5 m). Cette étude fut effectuée à Talca, Chili, une ville de moyenne dimension. Les points de mesure furent choisis dans trois secteurs situés le long de trois avenues principales dans le centre de la ville durant trois saisons différentes et selon trois moments distincts de la journée, générant 15,515 données au total. Dans des parcelles circulaires d'un rayon de 8 mètres, les mesures furent enregistrées au centre ainsi qu'en un point sur le périmètre. Une matrice de corrélation fut calculée et un test ANOVA fut réalisé avec l'indice de canopée, le moment de la journée et la saison comme sources de variation. Les résultats montrent une dispersion élevée tandis que la matrice de corrélation selon laquelle l'indice de canopée a un lien faible avec les variables fut étudiée. Les résultats du test ANOVA montrèrent le moins de différences significatives lorsqu'associés avec l'indice de canopée et le moment de la journée, tandis que la saison montrait des différences significatives pour toutes les variables. Le couvert d'arbres montra des différences significatives pour toutes les variables lorsque le test d'additivité de Tukey était utilisé, à l'exception du bruit minimal. Les parcelles avec une plus grande couverture étaient associées avec des augmentations pour les particules en suspension et l'humidité relative mais des diminutions pour le bruit maximal, la température et le rayonnement ultraviolet. Les mesures les plus élevées pour les particules en suspension, le bruit et l'humidité relative furent enregistrées lors de la matinée tandis que les températures maximales se produisirent en milieu de journée. Les résultats confirment l'importance des arbres urbains, particulièrement l'indice de canopée, afin d'atténuer les impacts environnementaux négatifs dans les zones urbaines.

Zusammenfassung. Wir identifizierten Beziehungen zwischen Ökosystemleistungen, die von Bäumen und anderen Umweltvariablen geliefert werden, einschließlich Temperatur (°C auf Bodenniveau und in 1.5 m h), relative Humidität, Feinstaub (PM_{10}, Maximum und Durchschnitt), Lärm (dBA) und ultraviolete Strahlung. Die Messorte wurden in drei Arealen ausgewählt entlang von drei Hauptverkehrsstraßen im Zentrum der Stadt während drei verschiedenen Jahreszeiten und drei verschiedenen Zeitplänen über den Tag, wobei insgesamt 15,151 Daten erhoben wurden. In runden Messbereichen mit 8 m Radius wurden Daten im Zentrum und an einem Punkt auf dem Perimeter aufgezeichnet. Eine Korrelationsmatrix wurde kalkuliert und ein ANOVA mit Kronenbedeckung, Zeitplan des Tages und der Jahreszeit als Quellen für Variationen durchgeführt. Die Ergebnisse zeigen eine hohe Dispersion und die Korrelationsmatrix, daß Kronenbedeckung nur eine schwache Beziehung zu den Variablen hat, wurde untersucht. Die Ergebnisse aus dem ANOVA zeigten die geringste Anzahl von signifikanten Unterschieden in Kombination mit der Kronenbedeckung, dem Zeitplan des Tages und der Jahreszeit, welche von allen Variablen signifikante Unterschiede zeigte. Die Baumbedeckung zeigte für alle Variablen unter Verwendung von dem Tukey Test signifikante Unterschiede bis auf den minimalen Lärmpegel. Messbereiche mit größerer Bedeckung wurden verbunden mit Anstieg von Feinstaub und relativer Luftfeuchtigkeit und Abstiege bei maximalem Lärm, Temperatur und ultravioletter Strahlung. Vormittags wurden die höchsten Messungen von Feinstaub, Lärm und relativer Luftfeuchtigkeit aufgezeichnet, wobei die Temperaturmaximale um die Mittagszeit auftraten. Die Ergebnisse bestätigen die Bedeutung von urbanen Bäumen, insbesondere die Kronenbedeckung zur Minderung von negativen Umweltbedingungen in urbanen Bereichen.

Resumen. Identificamos las relaciones entre los servicios del ecosistema proporcionados por los árboles y las variables ambientales, incluida la temperatura (°C a nivel del suelo y 1.5 m), la humedad relativa (%), las partículas (PM_{10}, máximo y promedio), el ruido (dBA) y la radiación ultravioleta (UV a 1.5 m). Este estudio se realizó en Talca, Chile, una ciudad mediana. Las ubicaciones de medición se seleccionaron en tres áreas a lo largo de tres avenidas principales en el centro de la ciudad durante tres estaciones diferentes y en tres horarios del día, generando 15,515 datos en total. En parcelas circulares, con radios de 8 metros, las mediciones se registraron en el centro y en un punto del perímetro. Se calculó una matriz de correlación y se realizó un ANOVA con cobertura de dosel, horario del día y temporada como fuentes de variación. Los resultados muestran una alta dispersión; se estudió la matriz de correlación de que la cobertura del dosel tiene una relación débil con las variables. Los resultados del ANOVA mostraron la menor cantidad de diferencias significativas asociadas con la cubierta del dosel, el horario del día y la temporada, lo que mostró diferencias significativas para todas las variables. La cobertura de los árboles mostró diferencias significativas para todas las variables que utilizan la prueba de Tukey, con la excepción del ruido mínimo. Las parcelas con mayor cobertura se asociaron con aumentos en las partículas y la humedad relativa y disminuciones en el ruido máximo, la temperatura y la radiación ultravioleta. Durante las mañanas, se reportaron las mediciones más altas de partículas, ruido y humedad relativa, mientras que las temperaturas máximas ocurrieron a medio día. Los resultados confirman la importancia de los árboles urbanos, específicamente la cobertura del dosel, para mitigar los aspectos ambientales negativos en las áreas urbanas.