

Green infrastructure and ecosystem services to tackle climate change in Chilean cities.

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1. Introduction

According to Benedict and McMahon (2002) green infrastructure can be defined as an interconnected network of green spaces that preserve the functions of natural ecosystems and provides benefits to the population, and although this idea dates back to 1900 the term green infrastructure has only strongly emerged during the last decade (Benedict and McMahon, 2006) when it began to be used in the design and planning of urban and peri-urban environments (Eisenman, 2013).

In general, green infrastructure can help to address climate change in two forms (1) increasing overall resilience levels of the urban ecological system and therefore improving their preparedness for scenarios of high uncertainty, and (2) through the provision of ES contributing to face specific aspects of climatic change (Gill *et al.* 2007).

This second approach is what is preferred and developed in this research given its greater possibility of operationalisation and be empirically evaluated.

This research aims to present analytical approaches for urban green spaces and their functions, based on green infrastructure and ecosystem services concepts. This study provide an adequate conceptual-analytical framework for planning and the evaluation of green spaces as a strategy to address climatic change in urban environments.

2. Methodology

2.1 Study area

Santiago is the 7th major city of Latin America with nearly 8 million inhabitants and is situated in a very closed watershed, surrounded to the east by the Andean mountain chain with altitudes close to 5000 meters and to the west is the Coastal mountain chain with lower altitudes. From the Andean mountains, the Mapocho river and a set of large and small streams transport water and sediment, often torrentially.

Furthermore, Santiago has tripled its size in the last thirty years due to rapid expansion that has meant the replacement of agricultural land, native forests and shrubs and occupying river beds and streams. These changes in cover and land use have had dramatic environmental consequences.

For this study the area under analysis is operationally defined as a 200 meter buffer surrounding the Mapocho river as it passes through the city of Santiago, with over 2000 meters before entering the built-up area and 2000 meters downstream after leaving the city.

2.2 Methods

This research is based on the assessment of ecosystem services related to mitigation and adaptation to climate change (1) temperature regulation (mitigation – adaptation), (2) flood mitigation (adaptation) and (3) non-motorized transport routes (mitigation).

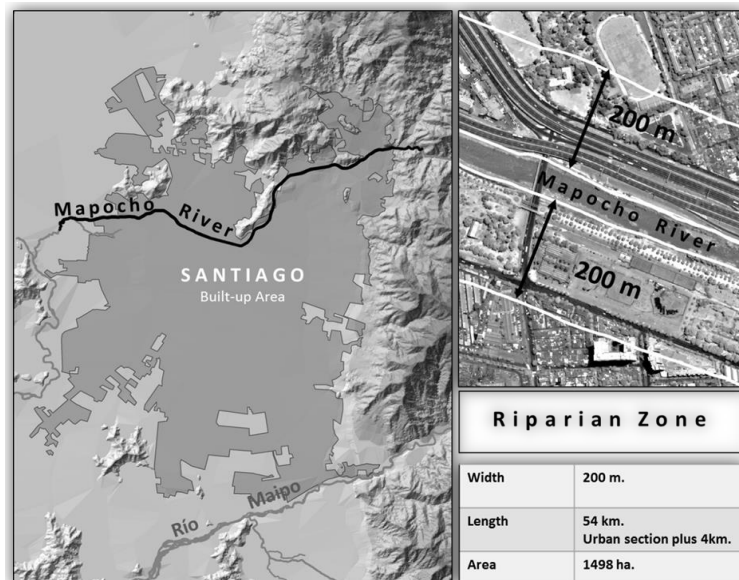


Figure 1: Santiago and riparian zone.

2.2.1 Temperature regulation:

There are two complementary types of measurements; while the first one is related to the use of fixed temperature data loggers, the second one is based on the use of mobile transects.

Fixed temperature data loggers

12 HOBO® Pendant® Temperature Data Loggers were installed in three transects along the Mapocho River during February, 2011. The three selected areas contain public parks and are distributed from east to west (1 in the east, 1 in the center and 1 the west) (Figure 2).

Each transect was provided with four HOBO® installed on each riverbank —100 and 200 meters away from the watercourse — within specifically designed weather-shelters (Figure 2). These devices were programmed to record the air temperature on an hourly basis and collected for analysis every four months.

Despite the efforts undertaken to camouflage these devices and the coordination with the park staff, the HOBO® loggers installed in the western transect (T3) were stolen twice. For that reason, there were no data available and the area was discarded.

The transect located in the downtown area (T2) generated the largest amount of information with all HOBOs® operating for almost a year.

The collected data was collected using a HOBO® Optic Base Station. Then, data was subject to consistency tests in order to identify and remove anomalous information derived from sensor damage or third-party actions. This procedure produced a table containing information regarding hourly air temperatures.

Mobile Transects

On January 11, 2011, 16 transects were performed along the Mapocho River and distributed according to land uses and the presence of bridges (Figure 2). Each transect consisted of five measuring points —one located over the river and two on each bank 100 and 200 meters away from the main watercourse.

Manual measurements of air temperature were performed three times a day (morning, afternoon, night). Properly calibrated thermo-anemometers were used.

Measurements were performed in the shade at an altitude of 1.5 meters and recorded in field data sheets, which were then digitalized and organized in tables for further analysis.

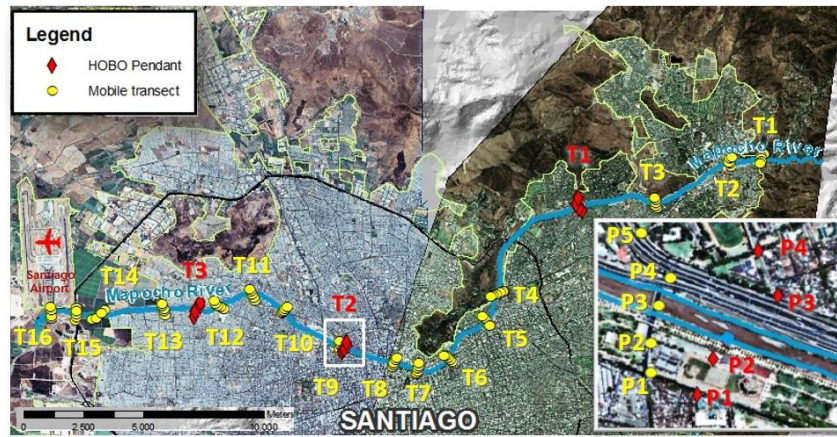


Figure 2: Mobile transects and HOB0® pendant distribution.

Due to the availability of staff and thermo-anemometers, teams of two people had to perform three or four transects; this meant that the measurement of the 16 transects was not performed simultaneously. However, measurement of four to five transects were taken simultaneously during each measurement session.

2.2.2 Flood mitigation

Initially, flood prone areas were mapped using flood hazard assessment information from the Bases para un Ordenamiento Territorial Ambientalmente Sustentable en la Región Metropolitana de Santiago (OTAS) project.

Next, how much of the riparian zone is threatened by floods as well as demographics of residents was calculated. The flood prone areas used for this analysis are those affected by flooding events every 2 years. Finally, the number of inhabitants living in flood prone areas was calculated.

2.2.3 Non-motorized transport routes

The transport network map was developed on the basis of information provided by Ministry of Public Works, which was previously amended and updated.

Firstly, the transport routes were classified into three types of main roads: streets, highways and bikeways. Secondly, the transport network structure was analyzed by calculating the percentage of transport network used by each road. These analyses prioritized the identification and study of riparian segments dominated by the presence of highways and bikeways.

Finally, the percentage of highways and bikeways of 50m and 200m riparian zones and the municipality was analyzed. Such an exercise was intended to examine whether there are spatial preferences for locations near the river.

3. Results

3.1. Temperature regulation

The air temperature measured in the Mapocho's riparian zone does not differ from the temperature recorded in the urban matrix during summer ($p < 0.05$), which is the season of the year where the maximum difference of air temperatures between a watercourse, including its riparian zone, and the urban matrix can be expected.

Figure 3 shows the air temperature for the two hottest days registered in summer 2011 in one of the three cross transects implemented in Mapocho River and the nearest official meteorological station. Although the points 4 and 5 are 0.5°C cooler than Independencia Station located in the urban matrix, this difference of temperature is not significant in statistical terms ($p < 0.05$). In other words, Mapocho's riparian zone is not providing a cooling effect to the city.

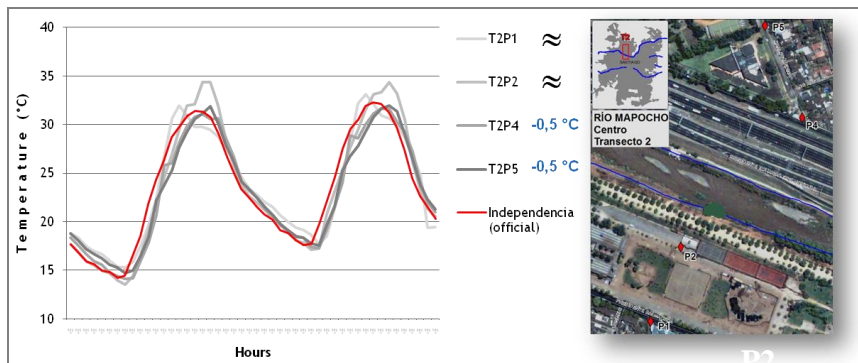


Figure 3: Air temperature for the two hottest days registered in summer 2011. T2=cross transect 2, Pn°= measurement point

Mobile transects performed on of November 11, 2011 allow to analyze the patter exhibited by cross sections along the river. Figure 6.15 shows the complexity of air temperature variation in relation to the distance to the river (P3) in the afternoon (Figure 4).

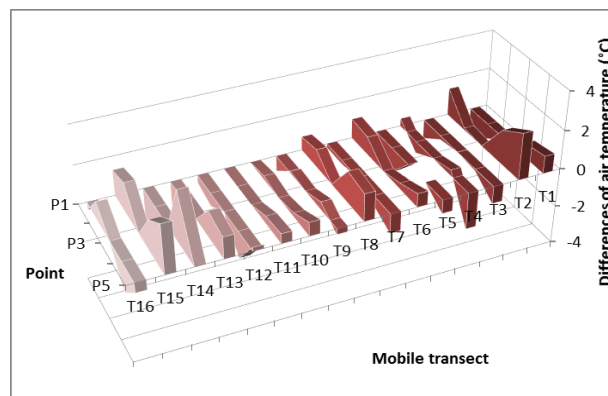


Figure 4: Mobile transects of air temperature, noon 11/01/2011.

Only transects 2, 6, 8, and 15 display the characteristic decreasing of air temperature from the river to the surrounding areas in both directions. Transect 15 is the most notable case, since those points located 100 m (2 and 4) and those located 200 m (1 and 5) from the riverbed are an average of 1.65°C and 1.9°C, respectively, warmer than point 3 located above the river (Figure 4). In contrast, temperatures registered above the river in transect 3, 5 and 7 are warmer than those recorded at 100 m and 200 m from the river.

The other (remainder) transects do not present patterns clearly recognizable, since air temperatures differences between the river and the surrounding land depend on which riverside is being considered, or even which specific point within a transect.

3.2. Flood mitigation

The Mapocho's river riparian zone has been affected by the urbanization process. Currently, the riparian zone is covered by residential areas (36%), and industries and commerce areas (13%). However, a 46,1% of the riparian zone remain undeveloped (green areas, natural areas and bare land).

70% of population living within the Mapocho's riparian zone (around 40,000 people) is affected by floods every two years. Residential and especially dense residential areas have been built in Mapocho's flood prone area, remarkably in the western section. In this respect, the riparian zone does not act as a flood protection buffer in most of its course. Overall, the riparian zone does not act as a buffer to protect against flooding in most of its urban route.

3.3. Transport routes

The transport network of Mapocho's riparian zone consists of 72.2 % of streets (including small streets and avenues), 25.5 % of highways, and 2.3 % of bikeways. Transport infrastructure is clearly oriented toward motorized transport. Streets are the most predominant type of road, making up more than 50 % of the transport system in all municipalities.

To the west of Santiago, urban highways are especially important representing an average of 37 % of the transport infrastructure. Even though Vitacura has lower relative values than Pudahuel and Cerro Navia, the absolute value of linear meters of highway in Vitacura is much larger and almost equal to that existing in Renca.

The main urban highway in the Mapocho's riparian zone is the Costanera Norte, which runs along the northern riverside. Apart from the Costanera Norte there is a second highway that goes along the southern riverside: the Costanera Sur. The presence of both Costanera Norte and Sur to the west of Santiago produces a remarkable change in the transportation network composition along the river.

Bikeways are not common in the riparian zone and only in Providencia and Las Condes are they slightly better represented with more than 10 % of the route system. Although in relative terms Las Condes has the highest percentage of bikeways, these consist of 310 linear meters contrasting with more than 5 kilometers existing in Providencia.

Conclusions

The conceptual framework articulating green infrastructure, ecosystem services and adaptation / mitigation of climate change, can clarify how urban green spaces contribute to urban climate regulation. This approach help to evaluate and quantify the role of green infrastructure to tackle global warming and the negative effects of climate change.

Green infrastructure can contribute to tackle climate change, both for mitigation and adaptation, which can occur simultaneously due to the multifunctional character of green spaces. Therefore, any strategy to address climate change in cities focusing on conservation or development of green infrastructure can be considered highly efficient.

The case of Mapocho River in Santiago demonstrates how the analytical framework can be applied using an approach based on indicators to assess the actual contributions of existing green infrastructure to address climate change in cities.

Finally, the role of Mapocho River's riparian corridor is mainly on mitigation of greenhouse gas emissions by acting as a major route for bicycle travel within the city. The cooling effect of these can be improved by using alternative landscaping design and practices of green spaces.

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