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A Satellite and Ground Evaluation of Urban Vegetation and Infrastructure in the Landscape of a Tropical City: Heredia, Costa Rica

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A Satellite and Ground Evaluation of Urban Vegetation and Infrastructure in the Landscape of a Tropical City: Heredia, Costa Rica

Urban vegetation can have beneficial effects on biodiversity and human health and has been widely studied in temperate cities. The situation, however, is different in the tropics: there is a knowledge gap describing the influence of the growth and expansion of tropical cities on vegetation within the cities. There is also a scarcity of work discussing appropriate methods to quantify urban vegetation in the tropics, where financial resources for research are normally quite limited. Our objectives in this article were to measure the amount of urban vegetation in a tropical city, its relationship to population and infrastructure, and to determine if satellite results differ from those obtained on the ground. For these objectives we studied the city of Heredia, Costa Rica, during the rainy season, when vegetation was most developed. We sampled 91 sites from the ground (with 360 degree digital panoramic photographs) and compared the measurements with the corresponding satellite photographs. Satellite and ground estimates of vegetation and infrastructure differed significantly (Kruskal-Wallis ANOVA, $p=0.00002$). The satellite estimate of vegetation was nearly one third higher that the ground estimate. These finding illustrated that a significant part of the vegetation is hidden from the view, reducing the potential beneficial effects that a person's perception of plants has on their psychology. Conversely, the estimate of infrastructure cover was much higher from the ground than in the satellite photographs. In the ground estimate the dominant landscape component was vegetation (48%), followed by buildings (28%), roads (23%) and billboards (0.41%). We conclude that density of the human population, rather than its total size, is the best predictor of vegetation in this tropical landscape (multiplicative model regression, F Ratio 7.33, $p= 0.0081$).

Keywords
tropical urban ecosystems, landscape components, relative infrastructure cover, Central America

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Introduction

Landscape analysis is an important part of urban planning and has been widely applied in temperate cities under a variety of psychological, biological, and physical approaches that include urban vegetation and its psychological effect on humans of all ages, its relationship with city animals, and physical aspects, such as light pollution of the nocturnal landscape (Kaplan and Kaplan, 1989; McDonnell, Hahs, and Breuste, 2009). In contrast with temperate cities, very little is known about urban vegetation in the tropics (Barrientos, 2009; Monge-Nájera and Pérez-Gómez, 2010).

The scarcity of information about tropical urban vegetation is particularly regrettable because the tropics have the highest levels of terrestrial biodiversity in the world and because the biota of tropical cities is being affected by urbanization (Fournier, 1993; *Estado de la Nación*, 2007). The inhabitants of cities perceive vegetation in their landscape and are affected by it in significant ways that have health and even economic implications that are beneficial when vegetation is abundant and deleterious when it is scarce (Kaplan and Kaplan, 1989; Groenewegen, van den Berg, de Vries, Verheij, 2006; WHO, 2007).

Urban population growth is also a problem in the tropical country considered in this study, Costa Rica; in 1900 it had approximately 300,000 inhabitants, but by 2008 the population had increased to 4,500,000 of which 71% live in urban and peri-urban areas (INEC, 2008; *Centro Centroamericano de Población*, 2012). As a result, small towns, mostly established in colonial times, grew until they merged with their neighbors, forming a large metropolitan area in the geographic center of the country (Barrientos, 2010). There is, however, very little information about how this growth has affected urban vegetation in the country (Monge-Nájera and Pérez Gómez, 2010).

Traditionally, urban vegetation has been evaluated from high above the ground using aerial or satellite photographs (Solano, Robinson, and Morera, 1996; Savitsky, 1999) and this is the dominant type of data used by the Costa Rican government for defining its policies (e.g., www.minae.go.cr) but it has more recently been found that the vegetation perceived by humans on land (“ground perception”) can be different from what is perceived from airplanes and satellites, at least for a tropical region (Monge-Nájera and Gieseke, 2005). A recent article from a temperate habitat also found a difference in estimates and added that this depends on the type of vegetation (King and Locke, 2013). In a detailed review of methods, Kaplan and Kaplan (1989) concluded that a combination of ground and aerial methods can improve the overall analysis of the landscape. Based on these findings, we decided to combine ground-level photographic landscape analysis with satellite data for the city of Heredia, Costa Rica. Our objectives for this study were to measure the amount of urban vegetation in a tropical city and describe the relationship of urban vegetation to human population and city infrastructure (using a statistical regression), and to determine if satellite results differed from those obtained on the ground.

MATERIALS AND METHODS

Our study covers the main urban and suburban area in the city of Heredia in central Costa Rica. Costa Rica has seven provinces and these are divided into *cantones*, each with its own municipal government. Heredia is clustered with the other important Costa Rican cities, at mid-elevation in the geographic center of the country (Figure 1). Heredia province has ten *cantones* and we calculated satellite data for nine of them (Appendix 1); we excluded one *cantón* because it is not part of the urban area.

Figure 1. Costa Rica: distribution of original vegetation types and location of main cities (in red). White square: studied area (details in Figure 2). Map by Sergio Aguilar, based on http://darnis.inbio.ac.cr.

Originally, we tried to randomly select the sample sites, but many fell in places that were not accessible by road or were on private property where we could not obtain permission to enter. For that reason, we selected sites that met three criteria: they could be reached by public road, the vegetation was similar to vegetation in the surrounding area (judged visually by the main author, who is an ecologist), and it had a landmark, usually a large building, that could facilitate relocation in future studies (as a backup to the GPS location). We chose a total of 91 sites that covered the urban and suburban area within the city (Figure 2).

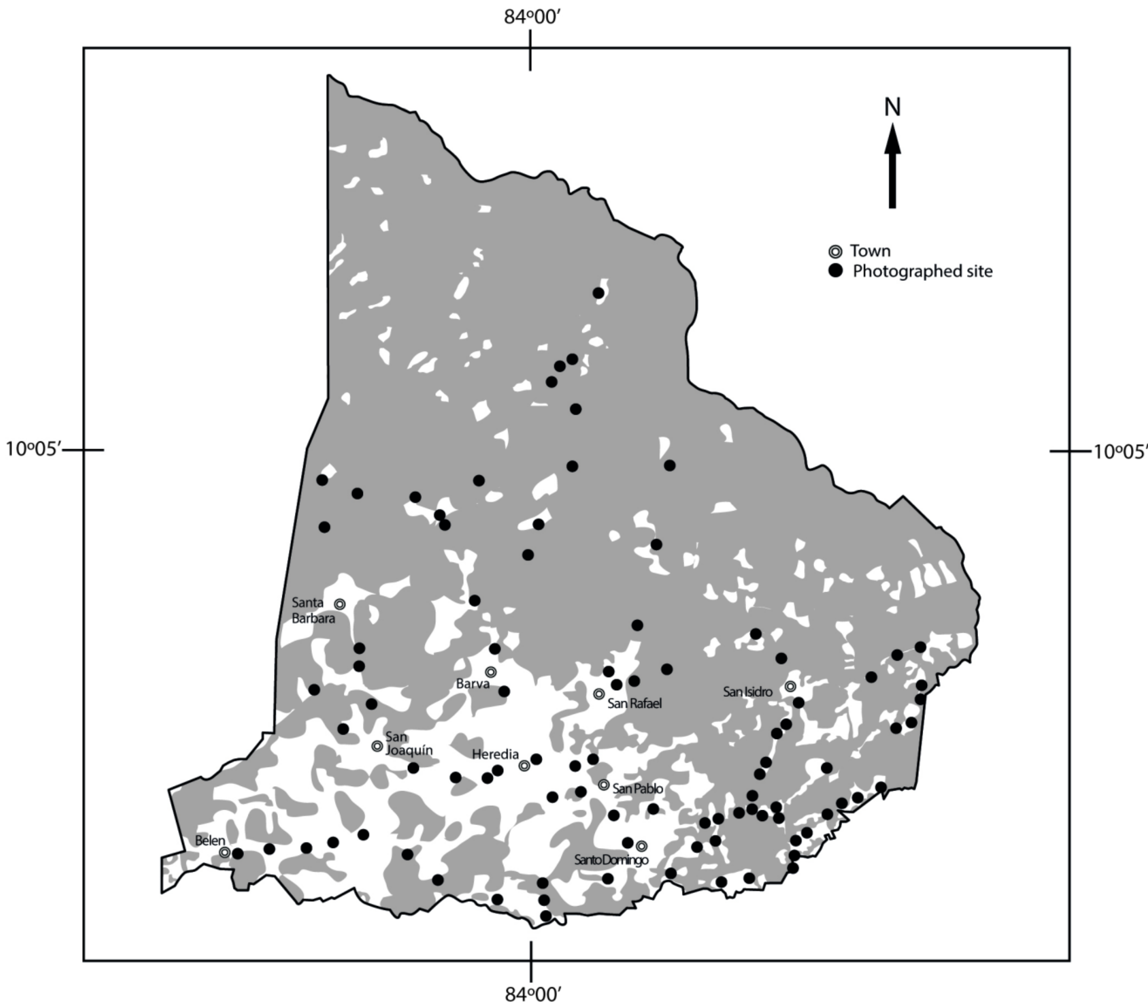

Figure 2. Study area: The province of Heredia is divided into 10 *cantones* (see main text) of which nine are part of the main urban zone of Costa Rica. These *cantones* were chosen for the study and appear in this map. White: more urbanized area. Gray: area covered by vegetation. The location of the sample sites (solid circles) shows how the urban and suburban areas were covered. Open circles represent the main towns within the more urbanized part of the study site.

In each site we made a GPS (Trimble Juno series, precision 3-4 m) reading for location and used a 14 megapixel Sony Alpha camera with a 18 mm lens (Sony SH0006) to take ten photographs that later were merged to produce a 360 degree panorama with Microsoft Laboratories Image Composite Editor 1.3. The camera was placed 1.5 m above the ground. All photographs were taken from July through September 2009, a period that was included in the period when the satellite images were taken (details below). GPS was measured to the 4 m so that the sites could be matched reliably with the high resolution (3420 X 4800 pixels) satellite images (details below).

The area is all tropical and the study was done in the rainy season to guarantee that full vegetation cover was included (vegetation may lose foliage during the dry season in some parts of this area). The panoramic images covered a varying amount of space according to the site characteristics, so we converted all values to percentages to account for this and to make comparisons meaningful.

A preliminary analysis of the resulting panoramas showed that the landscape basically had four types of component: buildings, roads, vegetation and billboards, so we measured the percentage of area in the photographs covered by each component. For this we used a technique traditionally used in botany and already analyzed for reliability (Monge-Nájera, González, Rivas Rossi , and Méndez, 2002) we counted grid points over each component in the image with the exception of the sky, which was not included in the counts (Figure 3). We used percentages to allow comparisons among images of different sites.

Figure 3. Cover was measured by counting the number of intersection points falling on each kind of element (vegetation, buildings, roads, billboards) in 360 degree panoramas of 91 sites. This example shows the increasing importance of vegetation in the landscape from the center of the city (top image) towards the suburban area (middle and bottom images).

Satellite Images

Satellite images were premium high resolution images from Google Earth Pro version 4.2; photographs were download between June and August 2010 (taken from February 2002 to January 2010; www.google.com/enterprise/mapsearth/products/earthpro.html). Satellite images do not allow a reliable identification of billboards, so in these images we only distinguished between vegetation and infrastructure (Figure 4). In the vegetation category we included mature and secondary forest, croplands and grasslands which could be recognized by the green or yellow-grass appearance and heterogeneous shapes (croplands look symmetric but color is green or green-yellow). In the infrastructure category we included houses, roads, green houses, buildings and bridges. Elements in the building category were recognized by their symmetric shape and homogenous color (mainly gray and clay red). Buildings or green areas 15m^2 or bigger were classified in the corresponding category. The small areas (less than $15m^2$) inside a matrix of the opposite category were ignored.

Costa Rica has seven provinces and these are divided into *cantones*; each *cantón* has its own municipal government. The satellite image data were calculated for a total of nine *cantones* (Appendix 1).

Human Population

Population size for each geographic unit (*cantón*) and density per unit were obtained from official records of the 2008 national census (INEC 2008).

Statistical Analysis

We used Statgraphics Plus 5.1 to calculate means and standard errors, Kruskal-Wallis ANOVAs (Figs. 4 and 5) and regression equations to estimate vegetation cover in the landscape with population density, buildings, roads and billboards as independent variables. A series of backward stepwise regressions with all variables indicated that only population density was required to estimate vegetation (here used as % vegetation in the landscape). For this reason we reanalyzed the data with a simple regression and found that the linear model was not the most appropriate among 27 calculated models (e.g. Reciprocal-Y square root-X, S-curve model and Reciprocal-Y logarithmic-X). We thus recalculated the regression with t Multiplicative model: $Y = a*X^b$ that had the best results.

The full dataset and statistical results are included in the electronic Appendices 1 and 2.

RESULTS

Ground and Satellite Results

Satellite and ground estimates of vegetation and infrastructure differed significantly (Kruskal-Wallis ANOVA, Test Statistic 23.68, $p=0.00003$). The satellite estimate of vegetation was nearly one third higher than the ground estimate (Fig. 4), suggesting that in this city a significant part of the vegetation is hidden from the view of its inhabitants, reducing the beneficial effects that perception of plants has on their psychology.

In agreement with the previous finding, the infrastructure estimate from the ground was more than double the estimate from satellite photographs (Fig. 4).

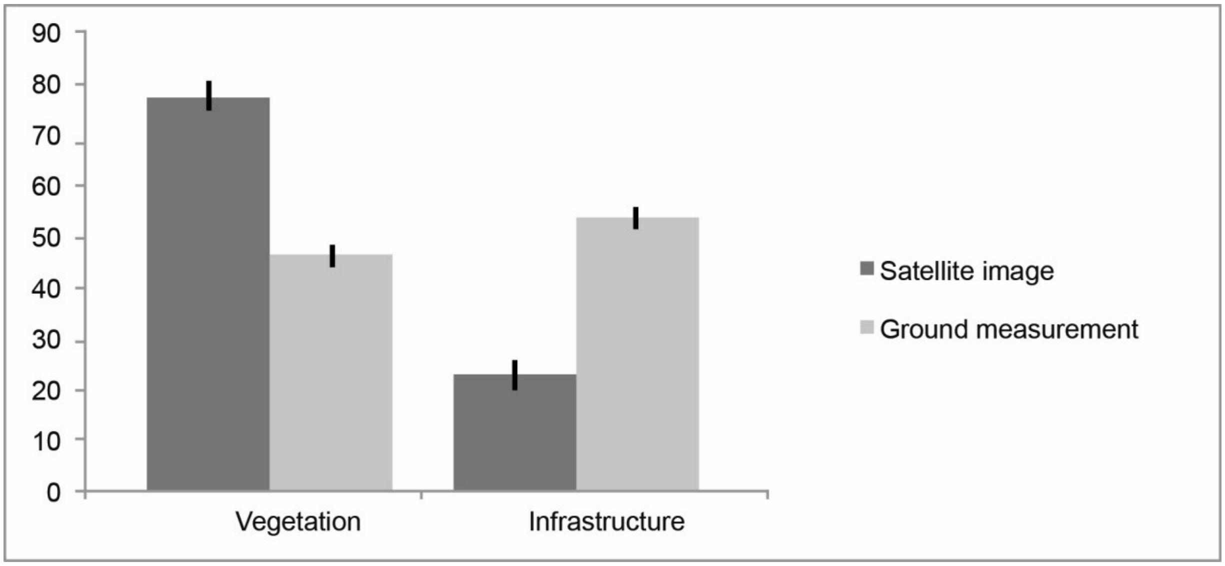

Figure 4. Relative (%) cover with vegetation and infrastructure according to satellite images and the ground survey in Heredia, Costa Rica. Infrastructure is the category composed of buildings and roads, merged in this analysis for reasons explained in the methods). Bars: standard errors.

Ground landscape components

At ground level, the dominant landscape component was vegetation (nearly half of the landscape area visible is composed of plants, including grass, bushes and trees); it was followed by similar proportions of buildings and roads which, when added together represent nearly the other half of the landscape. Billboards represented a very small percentage of the landscape (Fig. 5) and the pattern is statistically significant (Kruskal-Wallis ANOVA, Test Statistic 234.81, p=0.0). These results indicate that the inhabitants of Heredia perceive a landscape that is half vegetation and half infrastructure.

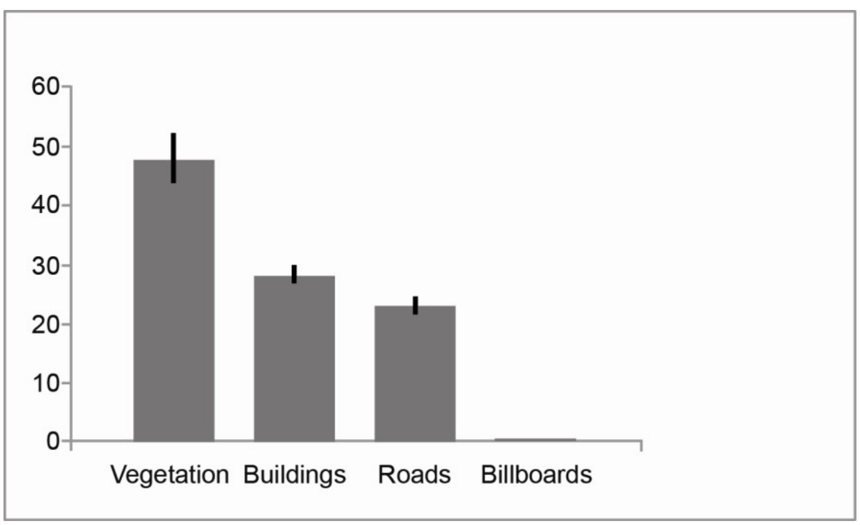

Figure 5. Relative (%) cover with vegetation and infrastructure according to the ground survey in Heredia, Costa Rica. Bars: standard errors.

Variable Associations

A total of 27 models were tested and appear in Appendix 2. The equation of the fitted multiplicative model that best describes the relationship between Vegetation and Population Density is:

(p=0.0081, r^2=7.6)

*Vegetation(%)= exp (5.29508 – 0.242817*ln (Population Density)*

The regression of infrastructure versus population density:

*Infrastructure(%)= sqrt(-460.176 + 242.419*ln(Population Density)*

was not significant (p=0.1556; r^2=2.25265 percent) and the possible reason for this is analyzed in the discussion. The need to use exponential values and logarithms indicates that the relationship between the density of the human population and the vegetation perceived in the landscape is complex and non-linear.

DISCUSSION

The only previous study focused on how satellite and ground images differ for Central American landscapes is that of Monge-Nájera and Gieseke (2005) who found that satellite images produced higher estimates of vegetation cover, which is consistent with the present study. This does not mean that satellites are better or worse than ground measurements, but that usually more infrastructure is visible from ground level, and thus, the perceived proportion of vegetation in the landscape is lower for the people who live in it (Monge-Nájera and Gieseke, 2005). A recent study in New York City found no statistically significant differences among geographic information system data, ground visual estimations and ground hemispherical photographs when measuring tree canopy, but the hemispheric photographs overestimated building coverage (King and Locke, 2013). These results cannot be directly compared with ours because they are from a temperate city and because King and Locke used a skyward-oriented fisheye lens while we used a horizontally oriented 18 mm lens, but they highlight the fact that ground perception is different from airplane and satellite images. We only recommend ground measurements when the objective is assessing landscape perception by urban inhabitants, an important element in their psychological condition according to Kaplan and Kaplan (1989). The finding that ground data are meaningful and acceptable when compared with more expensive high technology is particularly valuable for the tropics, where financial research resources are normally quite limited. Archaeological data show that humans have been adding natural specimens to their homes for more than 2,000 years and the proportion of natural versus artificial items in a landscape is of key importance to define how the landscape is perceived (Grinde and Patil, 2009), but filters are needed to properly define which elements are measured and which are excluded (Llobera, 2003). For our study we decided that the important elements were vegetation, buildings, roads and billboards because they could be reliably measured in the images and represent the “natural versus artificial” dichotomy of the landscape. A limitation of our study is that the classifications were not more detailed; other researchers may think of many further subdivisions for the vegetation (even to plant species) and of the infrastructure (for example, windows, doors, wood walls, concrete walls, traditional or modern constructions, and many others). However, such a fine subdivision was not within the scope of this study that had the vegetation versus infrastructure as a central objective.

Areas with a higher proportion of infrastructure may not have the largest population density because people live elsewhere and commute. More densely populated areas have less vegetation because humans tend to replace natural elements such as vegetation with infrastructure, sometimes with unexpected effects on their behavior (Antonson, Mårdh, Wiklund, and Blomqvist, 2009) and health (Sorensen, Barzetti, Keipi, and Williams, 1998). This intensive use of space is notable in tropical cities where land is expensive and funds scarce. For this reason, our finding that nearly half of the landscape seen by the inhabitants of Heredia is composed of vegetation is reassuring, considering that the only comparable published value that we found is "under 30 % vegetation" for the city of Sacramento, California (Akbari, Rose, and Taha, 1999). By selecting areas close to roads, we introduced a bias against areas that are hard to reach and even more vegetated. The effect of this bias, albeit possibly low, would be an underestimation of vegetation, and again, the implication is favorable: the vegetation in Heredia may be even higher than the 50 % that we found.

While the urban landscape of Heredia can be similar to those of many tropical Latin American cities, it is very different from tropical colonial cities such as Antigua in Guatemala and Guanajuato in México. Those cities have urban landscapes dominated by buildings and roads, with minimal billboards and street and park vegetation and our results cannot be extrapolated to them. These cities deserve a future study because even though they are poor in vegetation, the houses have large internal gardens (JMN and ZB personal observation).

Our study is, to our knowledge, the first to measure these landscape elements with ground panoramic images and satellites photographs for any Central American city. We found that Heredia has an important proportion of vegetation in its urban landscape, and that it needs to be measured from the ground in studies on how it affects its human inhabitants. We hope that this study will provide a baseline for follow up work on how this tropical landscape evolves in the years to come and that it will inspire similar research in other tropical cities.

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Appendix 1. Full dataset for the present study.
http://digitalcommons.lmu.edu/cgi/viewcontent.cgi?filename=0&article=1124&context=cate&type=additional

Appendix 2. Statistical results in detail.
http://digitalcommons.lmu.edu/cgi/viewcontent.cgi?filename=1&article=1124&context=cate&type=additional