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Uneven distribution of urban green spaces in a coastal city in northwest Mexico

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ABSTRACT
Extent and distribution of urban green spaces (UGS) in Mazatlan (Mexico) are analysed using remote sensing and GIS techniques. Vegetated areas (2,270 ha), a third of the urban area in 2015, were reclassified into green spaces (GS), urban tree (UT) and open spaces (OS), based in the normalised difference vegetation index, relating them with demographic and socioeconomic data. UGS allocation per capita amount 55 m^2, mainly represented by the UT class, with the largest patches associated with low developed and very high marginalised areas, and also with very low marginalised sectors, while the lowest allocation correspond to medium and low marginalisation, highly populated sector, without significant correlations. Despite the USG allocation, it is required a better urban planning to maintain public UGS and to protect the local flora, threatened by the introduction of exotic, ornamental species (64% of UT), to guarantee the provision of ecosystem services to the population.

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Urban green space; vegetation condition; NDVI; GIS; environmental equity

Introduction

Current trends in human population suggest that more than a half of the world's population is living in urban areas, and probably this figure will rise up to two thirds of the population to the year 2050 (United Nations 2014). The American continent and Europe are clearly the most urbanised regions, with >70% of the population living in cities smaller than 500,000, but also in megacities with more than 10 million people (United Nations 2014). On the other hand, Africa and Asia, remain basically as rural regions, but at the same time embracing the most populated cities in the world, displaying some of the highest urban growing rates in the recent years (Seto et al. 2011).

Cities and their regions are hubs for people, infrastructure and commerce, requiring extensive resources and putting intense pressure on the environment. The environmental impacts include the loss of biodiversity, air and water pollution, noise increasing, higher greenhouse gases (GHG) emissions and increasing runoff and flood potential (Wilson et al. 2003; Grimm et al. 2008; Poelmans and Van Rompaey 2009; Atu, Ayama, and Eja 2013; Derkzen, Teeffelen, and Verburg 2015). As the urban demographic growth demands resources and services, alterations in the availability and quality of natural resources occur, invading fertile soils, reducing biodiversity, modifying biogeochemical processes and the local climate, sometimes permanently (Ruiz-Luna and Berlanga-Robles 2003; Grimm et al. 2008). Thus, urban growth is considered responsible for some important

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environmental problems, especially in developing countries or regions (China, India, Africa), particularly threatening low elevation coastal zones and near protected areas (Seto et al. 2011; Seto, Güneralp, and Hutyra 2012).

Moreover, cities are seen as development poles, giving access to more opportunities than those offered by the rural areas for economic growth, jobs, and poverty reduction, which explains their high rates of growth, also bringing challenges to make cities sustainable at the long term. Thus, it is necessary to improve efforts to preserve existing natural or semi-natural habitats or to reconstruct habitats within or near cities to assure quality of life and resilience, therefore improving social cohesion (Kazmierczak 2013; Elmqvist et al. 2015).

Considering this, reduction of natural covers is probably the most distressing process associated to urban growth, because it changes the availability and quality of the goods and services delivered by the natural environments to the human population (ecosystem services), whose loss could involve severe economic, social and cultural impacts (Gómez Baggethun and Barton 2013).

Although ecosystem services (ES) are mainly linked to natural environments rather than anthropic, in recent years, the study of urban spaces for ES delivering is emerging as an important research frontier that incorporates the benefits of ecosystems for urban health and well-being (Gómez Baggethun and Barton 2013; Derkzen, Teeffelen, and Verburg 2015; Kremer et al. 2015), security (Whitford, Ennos, and Handley 2001), and as a tool for improving urban sustainability and resilience (McPhearson, Kremer, and Hamstead 2013; Elmqvist et al. 2015).

Regulating services such as air purification, soil quality, climate and water regulation, together with cultural services (non-material benefits such as recreation, aesthetic, educational), are the main ES offered by green and blue urban ecosystems (Bolund and Hunhammar 1999; Tzoulas et al. 2007). Such ES are produced in areas partly or completely covered by vegetation, including parks, community gardens, cemeteries, public plazas, and vacant lots, among others. Thus, the provision of urban ES in a city is related with the extent and quality of green coverage, the area available per capita, and the degree to which habitats are aggregated or fragmented, among other indicators (Fuller and Gaston 2009; Beninde, Veith, and Hochkirch 2015).

But despite the urbanisation degree, there is a need to maintain untouched green areas or to develop new, as they are important for recreation, sports, social links, besides many environmental benefits derived from them. For these reasons, green areas are an important issue for urban planning, and in agreement with the World Health Organization (WHO), it is considered a sustainable development goal by the United Nations Organization, to provide universal access to safe green and public spaces, particularly for children, women and other vulnerable people (WHO 2016).

With the above considerations, Badiu et al. (2016) mention that the WHO recommend a minimum of 9 m^2 of green areas per capita, with optimum values around 50 m^2, although some European cities aim to allocate between 6 and 10 m^2 of urban green spaces (UGS), evenly distributed according to the population density. There are also reports on green urban areas for countries in Asia and Latin America, but some of them only include total extension and dynamics of green areas, disregarding demographic data (Gupta et al. 2012; Wendel, Zarger, and Mihelcic 2012; Macedo and Haddad 2016). Even when demographic data are included for those regions (Mena et al. 2011; De la Barrera, Reyes Paecke, and Banzhaf 2016; You 2016; Richards, Passy, and Oh 2017), there are some problems defining urban areas boundaries (Cohen 2006), and consequently, it is not easy to detect when green spaces distribution is balanced, or when it is contravening social equity and environmental justice principles (Kabisch and Haase 2014; Wolch, Byrne, and Newell 2014).

Concerning their importance, allocation of UGS per capita and their accessibility only can be improved throughout urban planning based in the comprehensive analysis of UGS distribution, quality and structure, only affordable with the use of remote sensing tools, as proposed for present study, which provide with synoptic and continuous data, useful for decision makers.

Mazatlan, selected as case study, is a coastal city located in northwest Mexico, whose proximity to the sea, as well as the presence of wetlands and relics of dry forest, confer important environmental advantages to the people inhabiting there. However, the local natural landscape and physiography have significantly changed due the expansion of the urban area, particularly in the last decades, derived from the growth of some economic activities in the area, presumably changing the population quality of life.

Formerly, the local landscape was dominated by coastal wetlands (saltmarsh, mangrove and lagoons) and dry forest until the third quarter of the XX century, gradually reducing their area for agriculture purposes first, but later, as consequence of the urban growth, spreading on the area with different population densities (Ruiz-Luna and Berlanga-Robles 2003; Beraud, Covantes, and Beraud 2007). Since the early 1970s, a real estate boom in the city produced a differential growth, developing high and medium cost suburban residential areas, low cost housing, including apartment and condo apartment buildings, and even encroachments followed by informal settlements with few or none services or community facilities, later regulated to fit with political interest.

This rapid and disorganised urban development had impact on natural covers, mainly affecting coastal lagoons, mostly drained at the end of the XIX and the first half of the XX centuries, arguing public health issues (Beraud, Covantes, and Beraud 2007). In addition, dry forest and other natural vegetation disappeared incessantly, losing more than 50% in the urban polygon from 1973 to 1997 (Ruiz-Luna and Berlanga-Robles 2003).

Regarding the unplanned development, which is not exclusive for the study area, regulations at Federal, State and Municipality scale have been adopted to plan the Mazatlan's urban growth, considering zoning and land uses guidelines to make it sustainable (Ayuntamiento de Mazatlán 2017). However, as mentioned by Cohen (2006) although many developing cities include guidelines on land development and the future direction of urban growth, they have rarely been implemented.

In this regard and considering the urban growth projections, which estimate a fast growth because of tourism expansion, it is necessary to identify the distribution and availability of UGS, defining a baseline to analyse if the total extent meets the international standards or if they are deficient in some way. Thus, this knowledge contributes to support measures to improve population welfare, providing with technical elements to design public policies or to define specific goals to ensure social and environmental equitability in the near future.

Methods

Study area

Mazatlan is a coastal city, head of a municipality with the same name, located in northwest Mexico, at the Pacific Coastal Plain in Sinaloa state (Figure 1). Since its foundation in the XVI century, Mazatlán grew slowly, with sporadic economic pulses that encouraged the urban consolidation at the middle of the XX century, including land reclaimed from the sea (Beraud, Covantes, and Beraud 2007). Then, from the early 1970s, this city has grown from about 2,500 ha and slightly more than 150,000 population (Ruiz-Luna and Berlanga-Robles 2003), to reach nearby 8,000 ha (IMPLAN 2011), and 381,583 population counted in the last census (INEGI 2010).

Climate is warm-subhumid, with rains in summer, averaging 200 mm rainfall, with temperatures close to 30 °C and relative humidity around 80% from July to September, increasing the apparent temperature. Precipitation increases notably when tropical storms or hurricanes occur, mostly from August to November. Regarding this, the present study was achieved during the dry season, when cloud cover is negligible, allowing the analysis based in satellite imagery.

UGS estimation and distribution

Detection and extent assessment of UGS was obtained analysing SPOT 7 multispectral satellite imagery (1.5 m pixel resolution), recorded in 2015. Land covers classification was achieved using standard unsupervised classification techniques based in the Isoclust iterative algorithm, included in the Idrisi Selva 17.0 software. This algorithm allows the association of pixels in the multispectral bands, to

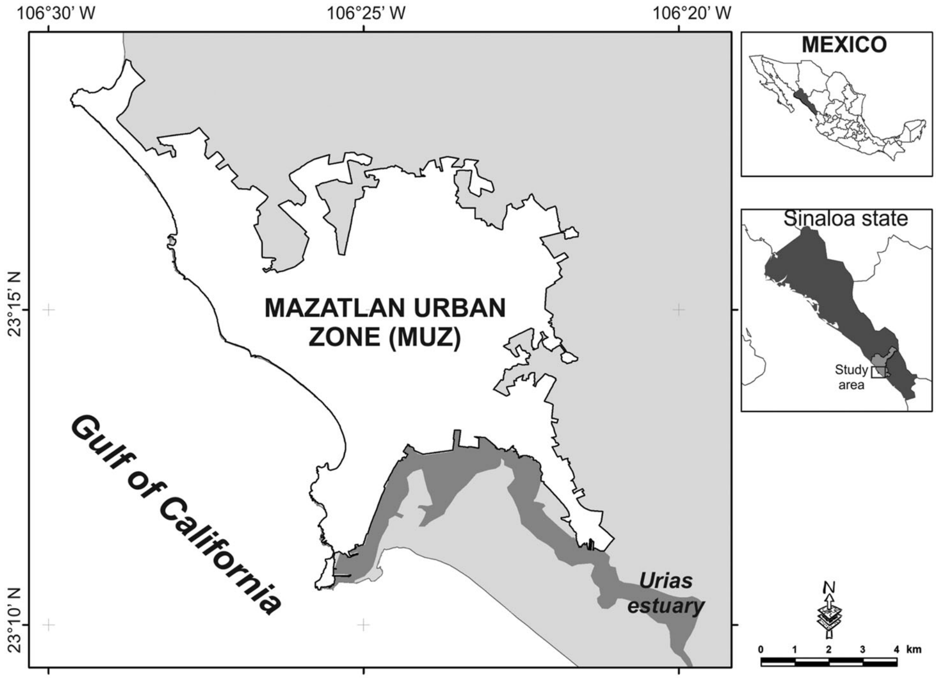

Figure 1. Location of the study area: Mazatlan urban zone in northwest Mexico.

a pre-determined number of clusters identified as informational classes, minimising the spectral distance among pixels, averaging classes in the radiometric space (Eastman 2012).

Previous to the classification process, the study area was isolated using the Mazatlan urban zone (MUZ) polygon provided by the cartographic service from the National Institute of Statistics and Geography (INEGI, by the Spanish acronym), on-screen updated with false colour compositions (RGB423 and RGB123), from the 2015 SPOT image, using ArcMap 10.1 software.

Three general informational/cover classes were defined: Vegetated area (Va), Water surface (Ws) and impervious surfaces/beach (Is/b). To integrate them, a set of ten spectral classes per cover were pre-defined, assigning every pixel of the multispectral image to one of those classes, based in their spectral signature using Isoclust algorithm. After this, the resultant spectral classes were combined into the three informational classes and the accuracy of the classification was assessed.

From an error matrix with the same classes in rows and columns, the overall accuracy, producer's accuracy and user's accuracy values were obtained, as well as the Kappa (K^) coefficient (Congalton and Green 2009). A total of 327 control points were obtained from field work, recorded with a Rino 120 Garmin GPS unit (± 5 m precision), and also derived from Google Earth Pro, allowing to measure the agreement between classification and reference data.

Using the output Va class as a mask, the Normalized Difference Vegetation Index (NDVI) was estimated with the original reflectance values for the red (0.625–0.695 µm) and near-infrared (0.760–0.890 µm) SPOT bands 3 and 4, respectively. The NDVI is a measure of vegetation quality and vigour, which relates the radiation in red (R) absorbed by chlorophyll, with the near infrared (nIR) reflected by the cell wall.

$$\mathrm{NDVI} = \frac{nIR - R}{nIR + R}$$

Thus, chlorophyll concentration and foliage amount define together the NDVI values, acquired in the −1 to 1 range. Lowest values (< 0.1) are obtained for non-vegetated covers, while moderate values

($0.1 < NDVI \leq 0.3$) are for barely covered surfaces, low photosynthetic activity or low vegetation biomass. Higher values correspond to sound vegetation areas, reaching up to 0.8, with the highest values for temperate and tropical forests (Weier and Herring 2000).

Following Ruiz-Luna, Escobar, and Berlanga-Robles (2010), the obtained NDVI values were ranked based in their quartile distribution (Qn), representing a vegetal condition gradation, later reclassified into three urban green categories, previously discussed for Latin America (Mena et al. 2011). Values under Q_1, associated with poor vegetation condition, were categorised as urban open spaces (OS), including diverse natural to highly maintained environments, free of buildings, areas outside city boundaries, and urban spaces commonly open to public access, but also privately owned, such as vacant lots. Values in the interquartile range ($Q_1 - Q_3$) are related with urban tree spaces (UT), mostly associated with tree planting in urban areas, including street lawns, tree pits, roadways, planters, and cluster plantings. Finally, NDVI values above the Q_3 are for green spaces (GS), which are relatively large spaces such as urban forests and public gardens, dominated by tree vegetation. The effectiveness of this re-classification was also evaluated estimating the overall, producer's and user's accuracies, following the same procedure as it was done with the SPOT image classification.

Vegetation cover indices estimation

Additionally to the UGS assessment, some vegetation cover indices relating the green urban spaces with population (m^2 per capita) and the urban extent (proportion of UGS to the urban area), which in some way reflect quality of life, societal behaviour and ecosystems health, were calculated to evaluate the Mazatlan urban greenness condition (Table 1). The indices values were estimated based on demographic data by the Municipal Institute of Urban Planning (IMPLAN 2011), which projected a total urban population of 413,883 for the year 2015, and the Mazatlan urban extent (MUZ) for the same year, previously estimated.

Moreover, the relationships among vegetation cover extent and types, with indicators of socioeconomic status, were defined based in the analysis of administrative municipality subdivisions, known as Basic Geostatistical Areas (AGEB, by its acronym in Spanish) and published by the National Population Council in Mexico (CONAPO 2010). The Mazatlan urban zone is organised in 207 AGEB, each representing a set of blocks, from one to fifty, delimited by urban features such as streets, avenues or similar, available in shapefile format. Each AGEB is identified with a unique code and includes data on population size and density, extent (m^2) and marginalisation degree.

Population density (people per hectare) was categorised in four classes: Very high density (108.3–218 per ha), High (67.4–108.2 per ha), Medium (33.8–67.3 per ha), and Low (<1–33.7 per ha). The marginalisation degree is directly calculated by CONAPO, measuring the impact of social deprivation in four dimensions (Education, Health, Adequate housing and Lack of basic needs), organised by the same institution in five categories (Very high, High, Medium, Low and Very low), representing a scale from high to low levels of poverty and shortcoming. The information was integrated to a Geographic Information System (GIS), using ArcMap 10.1.

Finally, an unstratified sampling was achieved in different sites in the MUZ, following the i-Tree Streets sampling protocol (https://www.itreetools.org/resources/manuals/Streets_Manual_v5.pdf), completing around 100 plots, to have a rough representation of the diversity and characteristics of the urban tree stratum. The species, total height, diameter at breast height (DBH) and crown

Table 1. Vegetation cover indexes. Area per inhabitant and proportion of vegetated area with respect to the Mazatlan urban zone (MUZ), estimated with data from the year 2015.

Vegetation cover	per inhabitant (m^2 per capita)	Proportion to the urban area (%)
Total Vegetated area (Va)	Va/Population	(Va*100)/MUZ
Green spaces (GS)	GS/Population	(GS*100)/MUZ
Urban tree (UT)	UT/Population	(UT*100)/MUZ
Open spaces (OS)	OS/Population	(OS*100)/MUZ

width (CW) were recorded, evaluating circular plots with around 400 m^2 or 1000 m^2 surface, up to complete 0.5% of the total area of the UT class. Selection of the sites was based on a previous photo-interpretation of high resolution images available in Google Earth Pro.

Results

Urban green space cover assessment and distribution

The updated polygon for the Mazatlan urban zone (MUZ) enclose an area around 7,400 hectares (74 km^2), defining the boundaries for the satellite data analysis. From the 327 control points recorded in the study area, a total of 286 points were positive, producing an overall accuracy value of 87.4% and a Kappa coefficient (K^) value of 0.76. In both cases, result point out that the classification is better compared with one produced by chance, and that it has a substantial agreement with the reference data (Landis and Koch 1977). By class, Va and Ws reached the highest producer's accuracy values (>95%), while Is/b obtained the lowest value (70.8%). Regarding the user's accuracy, all values were above 83% (Table 2).

Regarding the level of accuracy obtained with the image classification, the area covered by class was estimated, being the Is/b class the largest, with 4,890 ha, representing two thirds of the total surface. Around 31% of the MUZ is occupied by the Va class (2,270 ha) and only 3% of the total (250 ha), was classified as Ws (Figure 2).

Areas formerly classified as Va were later re-classified to the three defined types of UGS, based on their NDVI values distribution, that averaged 0.36 (desv. std. = 0.108), ranging from 0.05 to 0.66. Following this, the open spaces (OS) class was defined by NDVI values from 0.05 to 0.27, while urban tree (UT) class ranged from values above 0.27 and 0.43. Finally, the class green spaces (GS) representing vegetation with the best conditions, was defined by NDVI values above 0.43. The accuracy of the vegetation types classification, was also evaluated through an error matrix, similar to the previous evaluation process, but in this case, only 73 control points were included.

Values obtained for the overall accuracy (73%) and K^ (0.57), indicate a moderate agreement between the classification and ground data, with OS class as the responsible for most of the error, achieving only 44.4% for the user's accuracy, while UT was the less accurate (65.8%), regarding the producer's accuracy (Table 3).

The above results suggest a moderately accurate classification, which is still representative for the vegetation cover status. Considering this, the main urban vegetation type was represented by the UT class, with 1,146 hectares, 50% of the total evaluated vegetated cover. The GS (582 ha) and OS (541 ha) classes followed UT class in order of importance, each one representing around 25% of the total (Figure 3).

With the above results and regarding the 2015 population size, estimated at 413,883 people, and the MUZ extent, the Total vegetated area (Va) index reached an average of 54.8 m^2 of vegetated area per capita, corresponding to 30.7% of the total MUZ, as mentioned above. Also considering the vegetation types and assuming GS as the vegetation representative for the greenest condition or with the closest canopy, a value of 14.1 m^2 per capita was obtained. Other indices considering the population size are represented in Table 4, together with the denso-independent indices values, highlighting that UT, the less vegetated condition, doubles the GS and OS areas.

Table 2. Accuracy assessment for land cover classification in the Mazatlan urban zone.

	Va	Is/b	Ws	Total rows	User's accuracy
Vegetated area (Va)	**182**	35	0	217	**84**
Impervious surfaces/beach (Is/b)	6	**85**	0	91	**93**
Water surface (Ws)	0	0	**19**	19	**100**
Total Columns	188	120	19		
Producer's accuracy	**97**	**71**	**100**		

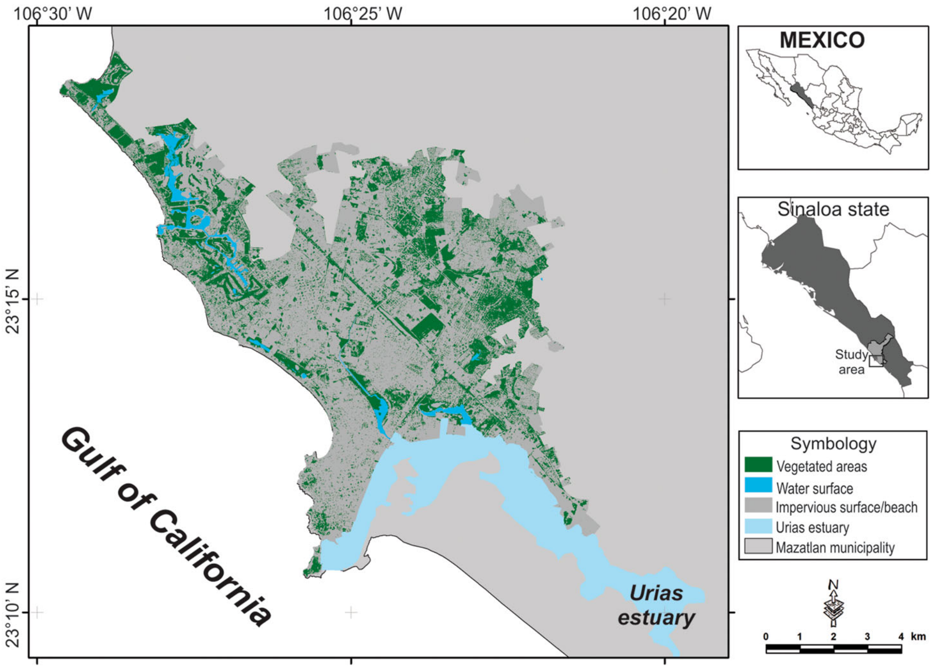

Figure 2. Main land use and covers of Mazatlan defined by unsupervised classification of SPOT imagery (2015).

Concerning the Basic Geostatistical Areas (AGEB), a total of 207 units integrate the MUZ, however, data about population size and degree of marginalisation are only available for 188 AGEB (91%). Those administrative units cover 97% of the total MUZ, ranging from 0.01 to 7.1 km^2 (mean = 0.37; s.d. = 0.57) in extent, with population densities from 43 to 21,769 people per km^2 by AGEB. The mean population density is around 7,970 people per km^2 (79.7 per hectare), ranging from 0.4 to 217.7 people per hectare.

At least two of the three vegetation categories are present by AGEB, with some exceptions for the GS class, which only was found in 179 AGEB, with the smallest and the largest cover by AGEB, mostly located to the north and periphery of the study area. The best distributed class was OS, evenly disseminated in multiple patches, with a mean area around 2.3 ha by AGEB, displaying the lowest variation in size (standard deviation = 2.9 ha). Considering the degree of marginalisation, Mazatlan seems to be characterised by low levels, with 83% of the AGEB categorised as Medium to Very low. In addition, around 80% of the vegetation was found in those administrative units (Figure 4). However, in average the Medium and Low levels display the lowest vegetation cover values by AGEB, with 7.5 and 5.6 ha of vegetation by AGEB, while those qualified as Very low marginalisation level have the highest values with more than 15.6 ha by AGEB.

It is important to highlight that areas corresponding to Very low level of marginalisation are mainly integrated by urbanised zones with residential-medium housing, with the highest real state price, as

Table 3. Accuracy assessment for the Mazatlan's urban vegetation types classification.

	GS	UT	OS	Total rows	User's accuracy
Green space (GS)	**20**	6	0	26	**77**
Urban tree (UT)	4	**25**	0	29	**86**
Open spaces (OS)	3	7	**8**	18	**44**
Total columns	27	38	8		
Producer's accuracy	**74**	**66**	**100**		

Overall accuracy (73%); Kappa Coefficient (^K = 0.57).

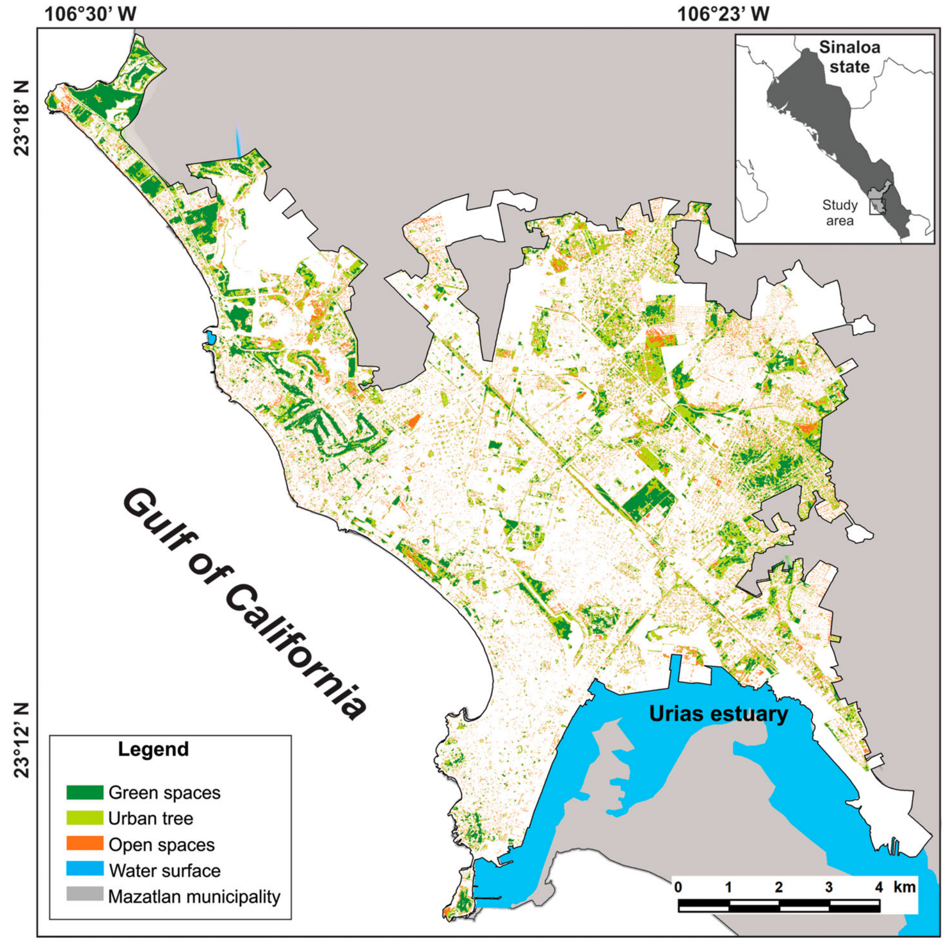

Figure 3. Classification of vegetated areas in Mazatlan city (2015) by vegetation types.

Table 4. Vegetation cover indices per inhabitant of Mazatlan city, and relative distribution regarding the Mazatlan urban zone (MUZ) extent.

Vegetation cover	per inhabitant (m^2 per capita)	Proportion to the urban area (%)
Total vegetated area (Va)	54.8	30.7
Green space (GS)	14.1	7.9
Urban tree (UT)	27.7	15.5
Open spaces (OS)	13.1	7.3

defined by the National Housing Commission (http://www.conavi.gob.mx:8080/Reports/Inv_Viv_Vig/Inv_x_TipViv.aspx). Also, includes many developing residential-medium areas, with green spaces in their facilities (golf courses, public and private gardens), as well as undeveloped zones close to the coastline, that are rapidly transforming.

By contrast, the Medium and High marginalisation levels are integrated by high to medium cost traditional-popular housing, which includes historic buildings (built before the XX century), and popular to economic (social interest) housing, normally including high population density levels (73–88 inhabitants per hectare). These marginalisation levels display reduced green areas per capita, most of them corresponding to the UT class and some public parks. Finally, High and Very high marginalisation areas include large green spaces averaging more than 4 ha by AGEB with

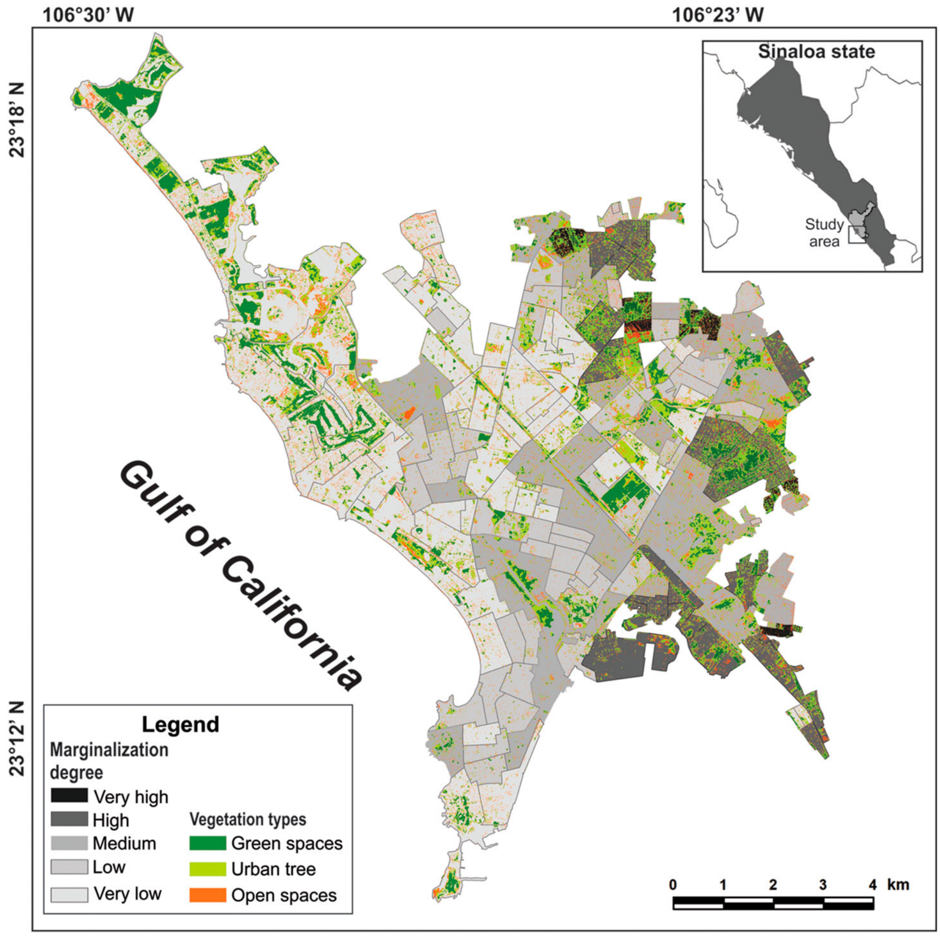

Figure 4. Marginalisation level by Basic Geostatistical Areas in Mazatlan city (Sinaloa, México), showing distribution of three vegetation types, Green spaces (GS), Urban trees (UT) and Open spaces (OS).

many of them larger than 10 ha, some of them located in undeveloped areas from the periphery, sometimes as irregular settlements, in unsuitable areas for living or previously used for agriculture activities.

UGS classified as open spaces (OS) were the most widespread in the MUZ, with patches equivalent to one pixel (2.25 m^2), up to 3.4 ha as the maximum. In AGEB with UGS larger than 10 ha, values from 12.1 to 26.5 ha, were found in the Very low marginalisation level. A similar situation was observed for the UT class, with areas from 10 to 85.1 ha in Very low levels of marginalisation. Finally, GS have the most irregular distribution in the MUZ, predominantly to the periphery and close to the coastline, corresponding mainly to dry forest relicts, with eleven AGEB with more than 10 ha of this vegetation type (11–124 ha by AGEB), mostly corresponding to Very low level of marginalisation. A summary of the total UGS as a function of the marginalisation classification is shown in Table 5.

With some exceptions, marginalisation levels were moderately or not significantly related with population or UGS extent indicators. Total or by vegetation type were negatively correlated with marginalisation, with R^2 values between 0.59 and 0.67. A similar value was obtained when population density by marginalisation level was related with the vegetated area by inhabitant. The lowest density values were observed in both extremes of the marginalisation scale, while UGS by inhabitant followed a different pattern, with the highest values related with High and Very high marginalisation

Table 5. Urban green spaces (UGS) distribution per Basic Geostatistical Areas (AGEB) in Mazatlan city, as a function of their level of marginalisation. Green spaces (GS), Urban trees (UT) and Open spaces (OS). Vegetation by types and total extent in hectares.

Marginalisation degree	Number of AGEB	GS	UT	OS	Total UGS	Pop	UGS per capita (m^2)
Very high	6	11.9	43.1	18.7	73.7	4654	158.3
High	26	57.0	193.0	68.8	318.8	35485	89.8
Medium	57	71.5	243.2	112.8	427.6	121406	35.2
Low	46	65.4	132.4	58.8	256.6	108532	23.6
Very low	53	284.5	375.1	169.7	829.3	108504	76.4
Total	188	490.3	986.9	428.8	1906.0	378581	

levels, and the lowest with Medium and Low marginalisation, with Very low marginalisation remaining in an intermediate position.

As mentioned above, most of the largest UGS by AGEB are represented by undeveloped areas that are rapidly changing with the growth of the urbanisation, but also there are important developed areas where the urban tree vegetation type has a good representation. As a result of the unstratified sampling, a total of 95 circular plots (400 and 1000 m^2 surface) where analysed for a total of 6.5 ha, equivalent to 0.57% of the estimated UT area.

From this sample size, 273 trees were identified, belonging to 19 species, almost half of them (9) recognised as native, while the rest correspond to exotic species, which almost doubled in number (174) the native species (99). In both cases, the three most abundant species amounted 65% (native) and 82% (exotic) of their respective total number (Table 6). Regarding their structure, the tree height and crown width obtained similar mean values, for both tree species groups, while the native species had a mean basal area of 0.011 m^2, slightly higher compared with that estimated for the exotic (0.008 m^2).

Discussion

Globally, urban areas are growing at an unprecedented pace. By 2030, urban areas are projected to house more than 60 per cent of people globally, and one in every three people will live in cities with at least half a million inhabitants (United Nations 2014). This process is one of the main drivers of landscape change that currently leads to a reduction in the environmental quality, as many

Table 6. Urban tree species and main structure parameters.

Species	Origin	Number	Basal area (m^2)	Height (m)	Crown width (m)
Byrsonia crassifolia (Malpighiaceae)	Native	1	0.006	7.0	4.0
Caesalpinia platyloba (Fabaceae)	Native	2	0.008	7.0	4.0
Ehretia anacua (Boraginaceae)	Native	28	0.006	3.7	2.4
Enterelebium cyclocarpum (Mimosaceae)	Native	10	0.004	3.0	2.1
Guazuma ulmifolia (Sterculiaceae)	Native	10	0.003	5.2	2.6
Pithecellobium dulce (Mimosaceae)	Native	8	0.009	7.1	3.5
Swietenia humilis (Meliaceae)	Native	26	0.031	6.5	3.1
Tabebuia donnell-smithii (Bignoniaceae)	Native	5	0.014	7.6	5.4
Tabebuia rosea (Bignoniaceae)	Native	9	0.014	8.6	8.0
Mean values		**11**	**0.011**	**6.2**	**3.9**
Albizia Lebbeck (Mimosaceae)	Exotic	10	0.002	5.5	3.1
Azadirachta indica (Meliaceae)	Exotic	70	0.003	6.1	3.1
Delonix regia (Fabaceae)	Exotic	5	0.008	5.2	3.1
Eucaliptus grandis (Myrtaceae)	Exotic	5	0.002	3.0	2.6
Ficus lyrata (Moraceae)	Exotic	52	0.002	3.7	2.5
Laburnum anagyroides (Fabaceae)	Exotic	20	0.010	3.7	3.7
Mangifera indica (Anacardiaceae)	Exotic	2	0.021	4.5	4.5
Terminalia catappa (Combretaceae)	Exotic	6	0.012	7.8	7.8
spp1	Exotic	3	0.009	5.0	5.0
ssp2	Exotic	1	0.010	3.0	3.0
Mean values		**17.4**	**0.008**	**6.0**	**3.8**

urbanizations have their origin in settlements located near to fertile soils and water sources. Particularly for coastal cities, besides the hydrologic and soil alterations, there also exist cumulative effects on the coastline and coastal ecosystems, such as saltmarshes and lagoons, which are transformed to adapt them to the urban design and growth.

Despite the landscape transformations, it is clear the importance of UGS for many ecosystem services delivery, existing a natural tendency to maintain green spaces, regarded as sources of well-being, areas for recreation, maintaining biodiversity and even increasing property value (Morancho 2003; Kong and Nakagoshi 2006; Melichar and Kaprová 2013).

Due the alterations to the natural ecosystems, some benefits and services provided by the UGS have been also modified, particularly those related with biogeochemical cycles and provisioning services, but they are still important for climate regulation, noise reduction, recreation and psycho-physical and social health (MEA 2005). In particular, the access to non-material benefits from the UGS has been regarded as a matter of environmental justice, with implications for the social coexistence (Wendel, Zarger, and Mihelcic 2012; Wolch, Byrne, and Newell 2014), relating the UGS availability with the income and other socioeconomic parameters, situation that must be tackled with a better spatial or urban planning (Tzoulas et al. 2007), and increasing public green spaces viewed as classless spaces (Wendel, Zarger, and Mihelcic 2012).

Therefore, it is important to identify the availability and distribution of UGS to preserve them and to improve the green infrastructure, looking for a better citizens' quality of life, through UGS planning. In the present study we used remote sensing techniques to evaluate green areas, classifying them depending on their vegetation quality, as a measure of their capacity to offer benefits and services to the Mazatlan community.

Considering a previous landscape evaluation of the MUZ by Ruiz-Luna and Berlanga-Robles (2003), since 1997 there has been an average increase of about 100 hectares per year, with most of this growth reducing green spaces previously occupied by rain-fed agriculture, deciduous forests and even secondary succession vegetation.

Despite that the partition of the NDVI values distribution into quantiles was not enough to separate vegetation types with more accuracy, the output classification system allowed to identify how vegetation with different condition is distributed in the city and by their administrative subdivisions (AGEB), allowing comparisons based in population parameters such as density and marginalisation.

One of the present findings is that, considering all the vegetated areas, the provision of UGS Mazatlan (>50 m^2/inh.) is similar to the US median national ratio (50.2 m^2 per capita), as well as those estimated for Recife (46.0 m^2/inh.) in Brazil, and Mexicali (45.5 m^2/inh.) in the north of Mexico (Peña-Salmón et al. 2014; Wolch, Byrne, and Newell 2014; Magarotto et al. 2017). This estimated is high compared with some densely populated European and Latin-American cities, such as Berlin and Leipzig in Germany and Santiago in Chile, which aim for 4–10 m^2 per capita (Kabisch and Haase 2014; Moris et al. 2014), and even with the 40 m^2 of green urban areas per capita recommended by different experts to meet the ecological balance of human existence (Wang 2009).

Moreover, the value estimated in this study, is at an intermediate level compared with some American and European cities, and even with other Mexican localities, ranging from 1.7 to > 300 m^2 per capita (Fuller and Gaston 2009; Flores-Xolocotzi and González-Guillén 2010). However, the average values are not enough to know how the UGS are distributed in relation with different social strata or ethnic groups, as mentioned by Kabisch and Haase (2014) for different case studies in European and US cities. In this sense, in local future studies, it is imperative to obtain data related with the inequities in access to urban green spaces, within cultural and demographic local contexts.

The UGS area per inhabitant is the most widely used indicator to assess green spaces respect to the total population (De la Barrera, Reyes Paecke, and Banzhaf 2016), but this indicator does not inform on how green areas are distributed and neither about the possible ecosystem services provided (Yao et al. 2014). In addition, some reports do not indicate the procedure to evaluate this index at local scope. Here, it was possible to have an approximation to this, obtaining information on the vegetation quality, directly related with ecosystem services delivering, besides the UGS allocation regarding socio-economic parameters.

Present results confirm the trend observed by Ruiz-Luna and Berlanga-Robles (2003) about growth of Mazatlan city, with rates around 1.1% per year in extent during the last 20 years, transforming vegetation cover to impervious surfaces, currently reaching a proportion of 30% of the assessed MUZ. The UGS are unevenly spread in the study area, producing deficits in specific zones, particularly the most densely populated, which correspond to the Low and Medium marginalisation strata, that together amount 61% of the total population, with densities ranging between 73 and 88 inh./ha.

Additionally, most of the vegetated areas (75–83%) in the AGEB from those marginalisation levels, correspond to highly fragmented (UT) or open vegetation (OS) areas, qualified as low vegetation condition, compared with the GS vegetation class. Therefore, benefits and services provided there could be different or limited in some ways to local dwellers, as those delivered by the GS particularly in the Very low marginalisation AGEB, which also have the lowest population density.

Although positive correlation between household incomes and GS has been demonstrated in other cities (Landry and Chakraborty 2009; Pham et al. 2012; De la Barrera, Reyes Paecke, and Banzhaf 2016), but in our case study, there were not found significant correlations among marginalisation status and the extent of any of the vegetation types or the UGS as a whole. Our study results also reveal inequities in terms of the availability of GS, pointing out the urban areas where these disparities exist. In addition, the analysis showed that a large extension of GS areas are potentially endangered, as with few exceptions, they belong to private owners, and currently are subject to rapid transformations, mostly to residential areas for medium and high-income level residents. This kind of development only assign 10–15% of the total surface for public areas, including some green areas, most of the times using exotic vegetation, which reduces the local biodiversity and eventually conducts to the local flora extinction (Kong et al. 2010).

Consequently, it is expected a dramatic reduction in the UGS distribution, that must be cushioned with a good green infrastructure planning, which includes increasing in the public access green areas, green corridors and strategies for conservation of green spaces, through the adoption of a green network approach (Goddard, Dougill, and Benton 2010; Kong et al. 2010). In addition to conservation plans, connectivity of green and blue urban areas, prioritising areas for threatened species, must be included in urban planning, minimising the species extinction and improving the human contact with nature (Gordon et al. 2009; Goddard, Dougill, and Benton 2010; Xiu, Ignatieva, and Konijnendijk van den Bosch 2016).

In our case study, despite the vegetation allotment by inhabitant, it is perceived a high fragmentation level, with small, isolated patches, particularly in the oldest areas of the city, where only in bumpy terrains, hillsides and inner wetland areas there are larger, sound vegetation patches. In most of the AGEB located in this zone, the UT and OS predominate, with a continuous alteration of the tree composition, always favouring ornamental plantation, most of the time with exotic species, despite the local conditions of the area.

Considering that coastal locations, such as Mazatlan, have some of the highest growth rates at national and global scope, the quality of life must be preserved and even enhanced. Thus, it is necessary to increase the green areas with public access, throughout strategies not only focused on the provision of new green spaces, but also on their interconnection to create a green network, very important to maintain a sustainable urban landscape, providing long term maintenance to guarantee the ecosystem services provision (Kong et al. 2010; Elmqvist et al. 2015). Consequently, benefits derived from this improvement must not aim only for a minimum area allocation per capita, but also looking for a better distribution and accessibility, improving the social relationships and balancing the environmental justice for different age, gender and social groups (Kazmierczak 2013; Wolch, Byrne, and Newell 2014), making in addition more resilient communities (Nowak et al. 2013; Baró et al. 2014). Part of the above statements are foreseen by law, however, it is imperative to make them mandatory.

Finally, although our results were produced with a level accuracy just acceptable, we are confident that some limitations in this study, mainly related with quantity, quality and accessibility to UGS, can be addressed in the future. First, every pixel was considered as a single UGS in the analysis. Although this information is also valuable, it is important to set a minimum mapping unit to include in the analysis. According to De la Barrera, Reyes Paecke, and Banzhaf (2016), size and shape of UGS matters: "the larger the size, the greater the magnitude and diversity of ecosystems services provided". Second, the NDVI was the single parameter considered in the quality assessment, but UGS quality is also determined by other factors such as landscape integrity, the impact of interesting or innovative designs, and residents' preferences (Yao et al. 2014). Additionally, the diversity and characteristics of the urban tree stratum were estimated based on a relatively small survey sample, but studies on minimum sample size in urban areas must be encouraged to improve results.

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