CARTOGRAPHY AND SPATIAL ANALYSIS OF URBAN SPRAWL

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ABSTRACT
This article is aimad at exploring urban sprawl as a new leading behavior pattern of cities. Undoubtedly, the traditional city is changing to a landscape dominated by new urban development of low density, road networks and shopping centers. Geographic information technologies have to face the cartographic and quantitative analysis of this new urban spatial structure This article presents a methodology to identify patterns of urban sprawl in the Concepción Metropolitan Area (CMA, Chile), based on four dimensions: *Density*, *Continuity*, *Centrality and Proximity*. Dispersion is defined by low values of density and continuity and high values of centrality and proximity. Its main characteristics are determined by statistical analysis, which define a spatial classification of dimensions in different urban developments and the factor or factors that affect more this hypothetical behavior.
KEYWORDS: urban sprawl, dimensions, Concepción Metropolitan Area.

RESUMEN
Este artículo intenta analizar el crecimiento urbano disperso como nuevo e imperante patrón de comportamiento de las ciudades. Sin duda, la ciudad tradicional se está transformando en un paisaje dominado por nuevos desarrollos urbanos de baja densidad, con extensas infraestructuras de transporte y grandes centros comerciales. Ante esta nueva estructura espacial, las tecnologías de información geográfica deben estar a la altura, especialmente mediante su aportación cartográfica y el análisis cuantitativo. Este artículo presenta una metodología para identificar los patrones de crecimiento disperso en el Área Metropolitana de Concepción (Chile). Los patrones de uso del suelo se basan en cuatro dimensiones: *Densidad, Continuidad, Centralidad y Proximidad*. La dispersión estará definida por los bajos valores de densidad y continuidad, y altos valores en centralidad y proximidad. Sus principales características se determinan por análisis estadísticos, mediante los cuales se define una clasificación espacial de las dimensiones en diferentes desarrollos urbanos y el o los factores que más inciden en este hipotético comportamiento.

PALABRAS CLAVES: crecimiento disperso, dimensiones, Área Metropolitana de Concepción

1. INTRODUCTION

It is clear that cities are growing faster than its planning, and some of their spatial patterns can be interpreted as urban sprawl. Urban sprawl is a consequence of socioeconomic development under certain circumstances (Ji et al., 2006). It is often associated to low residential density, leapfrog, scattered suburban linear patterns, and dependence on private transport (Besussi & Chin, 2004; Batty, 2005; Ji et al, 2006). But the two most cited definitions on urban sprawl are: (1) ‘‘a pattern of land use in an urbanized area that exhibits low levels of some combination of eight distinct dimensions: density, continuity, concentration, clustering, centrality, nuclearity, mixed uses and proximity’’ (Galster et al., 2001, p. 685); (2) ‘‘the term is used variously to mean the gluttonous use of land, uninterrupted monotonous development, leapfrog discontinuous development and inefficient use of land’’ (Peiser, 2001, p. 278). Both definitions are relatively close to the American version of sprawl, a much more complex phenomenon compared with the European case, which is more constrained and focused on the chaotic nature and random patterns of land use (European Environment Agency, 2006).As for Latin American cities, they are often compared with North American cities or described using their theories, since both of them are mainly distinguished by peripheral growth. But growth of Latin American cities, unlike growth of North American cities, should be defined as a process characterized by the expansion of borders of the city through the massive formation of peripheral settlements, which are, in most cases, large spontaneous low income residential areas (Barros, 2004). A good example is Santiago Metropolitan Area (Chile), undoubtedly defined by indiscriminate growth in its periphery and regulated by free market laws (Ducci, 1998). So, we can conclude that there is not a general definition of urban sprawl we can apply to American, Latin American and European cities (Muñiz & García - López, 2008).

It turns out interesting to compare the definitions of urban sprawl given by Galster et al. (2001) and by Muñiz & García López (2008), considering that Galster’s definition was formulated in the year 2001 and the latter is from this decade. Doing so, we can appreciate its evolution over the years. For Galster et al. (2001), urban sprawl is an example of how a city that is developing shows certain aesthetic patterns, due to high dependence on private transport in settlements of low density, whereas in Muñiz & García López (2008), it is described as a process of suburbanization, which has adverse consequences like excessive land consumption , the formation of polycentric structures and the dispersion of urban services.This last definition refers more to the functional

aspects of urban structure in comparison with Galster et al. (2001) definition, that refers mainly to the urban morphology. Concerning this, Bessusi & Chin (2004) consider that the sprawling city adopts an urban pattern different to that of the compact city, characterized by high density, centralized development and spatial mixture of functions.

Because of this, it is important to generate our own methodologies to characterize urban sprawl in Latin American cities and to get a comprehensive understanding of it. Technically, the cited definitions have been evaluated with different indicators that use socioeconomic variables, such as density, population growth and employment (Galster et al., 2001; García- López & Muñiz, 2007; Muñiz & García - López, 2008). We also used landscape metrics calculated from land-cover maps (Ji et al., 2006) which, in tun, were generated through remote sensing and geographical information system techniques (Irwin & Bockstael, 2007; Jat et al., 2008; Martinuzzi et al., 2007; Ji et al., 2006).

Our specific aim is to achieve a comprehensive understanding of main patterns of urban sprawl in Concepcion Metropolitan Area (CMA), using spatial indexes that represent four urban sprawl dimensions with their respective cartography representations.

2. STUDY AREA

The Concepción Metropolitan Area (CMA) is located in south central Chile, between 36 ° 35 'and 37 ° 00' south latitude, and 72 ° 45 ' and 73 ° 15' west longitude, occupying the coastal territory of the Bio Bio Region. Its limits are set up in the Metropolitan Urban Planning of Concepción, where it is defined as a functional and hierarchical territory formed by 11 communes apparently closely integrated. These communes are: Concepción, Chiguayante, Haulpén , Hualqui Talcahuano, Penco, San Pedro, Tomé, Coronel, Lota and Santa Juana (Figure 1).

The total area covers 2.830,40 km^2 , representing a 7.63% of the total regional area. According to the last Population and Housing Census (2002), it has 902,712 inhabitants, which corresponds to a 48.49% of the total population of the region. The CMA has a very high percentage of urban population (97%), being equivalent to 57.31% of the regional urban population, with a density of 318.9 inhabitants /km^2

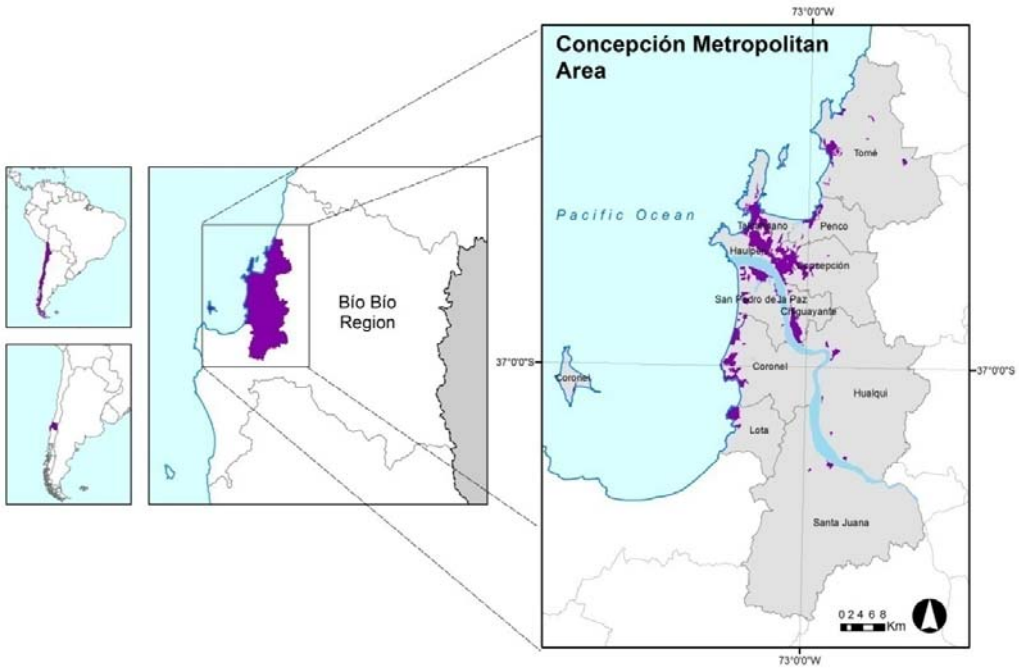


Figure 1. Study Area: Concepción Metropolitan Area
Source. Boundaries, National Census of National Statistics Institute (2002).
Built-up areas in Rojas, Opazo & Jaque (2009).

3. METHODOLOGY

Methods are based on quantitave spatial measures applied on every dimension of urban sprawl (density, continuity, centrality and proximity). Geospatial database and geographic information systems are used in each one of them. The analysis are performed on Census Districts and basically define that urban sprawl will be present where low values of density and continuity and high values of centrality and proximity are found. Afterwards, we explore in a spatial context a classification of density and continuity. Finally, we determine which are the main correlates of sprawl.

3.1. GEOSPATIAL DATABASE: The data used for this work have been collected from primary data sources. Population and housing statistics, and census on district zone (scale 1:50.000) were taken from National Census (2002). Metropolitan map and projected roads (scale 1:50.000) from Urban Planning (2003). Central business districts (CBD) and Subcenters points (SUB) were obtained with digitalized and calculated centroids of census district zone. Built-up areas were obtained using remote sensing techniques. Landsat orthorectificated images were taken by the Enhanced Thematic Mapper (ETM +) sensor with a resolution of 30 m. (from January 18th 2000; path 001/row 086 – from December 22nd 2001), The mosaic was classificated according to

the Principal Component Analysis (PCA). Subsequently, an unsupervised ISODATA classification was carried out, using the three bands resulting of PCA. Thus, the built-up areas were obtained (Rojas et al., 2009). This technique has been used in the extraction of built-up areas with good results (Martinuzzi et al., 2007; Yu & Nam Ng, 2007). After that, the built-up areas were verified using the land use map (1:50.000) created by the National Forestry Corporation (CONAF), in 1998, the field verification campaign (November 2007) and the visual interpretation of the satellite image (RGB – 7-4-1). With these proceedings, the image was reclassified into two classes: urban and non-urban. Post-processing of classification were performed using ArcGIS (ESRI, Inc).
All geodataset was processed into a vectorial model and the spatial reference system used in the study was UTM - WGS84, zone 18S (Figure 2).

Figure 2. Geographic Dataset
Source. Boundaries and District Population, National Census of National Statistics Institute (2002).
Built-up areas in Rojas, Opazo & Jaque (2009). Roads of Urban Planning (2003).

3.2 DIMENSION INDEXES: Correspond to the abovementioned urban sprawl dimensions and were calculated for each census district zone. These spatial units are defined by National Statistics Institute.

a) **Density:** It is the most popular index of urban growth and sprawl, and in this case it refers to the relationship between inhabitant and built-up area (BA) per census district *(j)*.This index is given by:

$$D = \frac{Pj}{\sum_{i=1}^{n} BAj} \quad (1)$$

Where *Pj* is the population of the district, that is the commune spatial unit in which the census organized the population and housing data, and *BA* is the built-up area in hectares in the same spatial unit.

b) **Continuity:** This dimension shows the degree to which residential housing is developed in fragmented surfaces, and it is given by the formula:

$$CN = \frac{Hj \Big/ \sum_{i=1}^{n} BAi}{N} \quad (2)$$

Where *Hj* is the number of housing in the census district, *BA* is the built-up area in hectares in the same spatial unit and *N* is the number of urban polygons on the district.

c) **Centrality:** It is the degree of closeness to the Central Business District (CBD) of subcenters. A CBD is the more dynamic and populated point of a city, it is the commercial, office, retail, and cultural center of the city and usually the meeting point for transportation. In the Concepción Metropolitan Area we find two CBDs. They are Concepción (CBD1) and Talcahuano (CBD2). The Sub-Centers are each built-up area per district. Centrality is given by Euclidean distance between Sub-centers (SUB1, SUB2,…..,SUBn) and CBD1 and CBD2, therefore euclidean distance for Centrality is:

$$ED = \sqrt{\sum_{i=1}^{n} (SUBi - CDBi)^2}$$

$$CNT = \gamma_{SUB}^{mindist}{}_{CBD} \quad (3)$$

Finally, this index (CNT) represents the minimum distance or the closest to CBD. *Point Distan*ce (an ArcGIS proximity tool) was used.

d) **Proximity:** It is the degree of closeness to metropolitan roads of a built-up area. To obtain this dimension, it is used the same method as in centrality (*Euclidean distance*), and it is given by the equation:

$$P = \sqrt{\sum_{i=1}^{n} (SUBi - MRi)^2} \quad (4)$$

3.3 STATISCAL ANALYSIS: It was performed with SPPS Statistic 17.0 software.We perfomed K-means clusters analysis, with a fixed number of clusters, to identify relatively homogeneous groups of census districts based on the four sprawl dimensions. Afterwards, the main dimension of urban sprawl were determined by principal component analysis (PCA). This method reduced the original set of variables, i.e. the dimensions of urban sprawl, into a smaller set of uncorrelated components that summarized the majority of the information of the original variables. Although this technique is more useful with a large number of variables, for our interpretation it is useful to understand the dimension that explains better urban sprawl.

4. RESULTS

Table 1 shows descriptive statistics for the four dimensions in a land space where built-up areas represent 10% of the total district area. The more urbanized areas are in the central zone and located in the smallest districts of the metropolitan area.

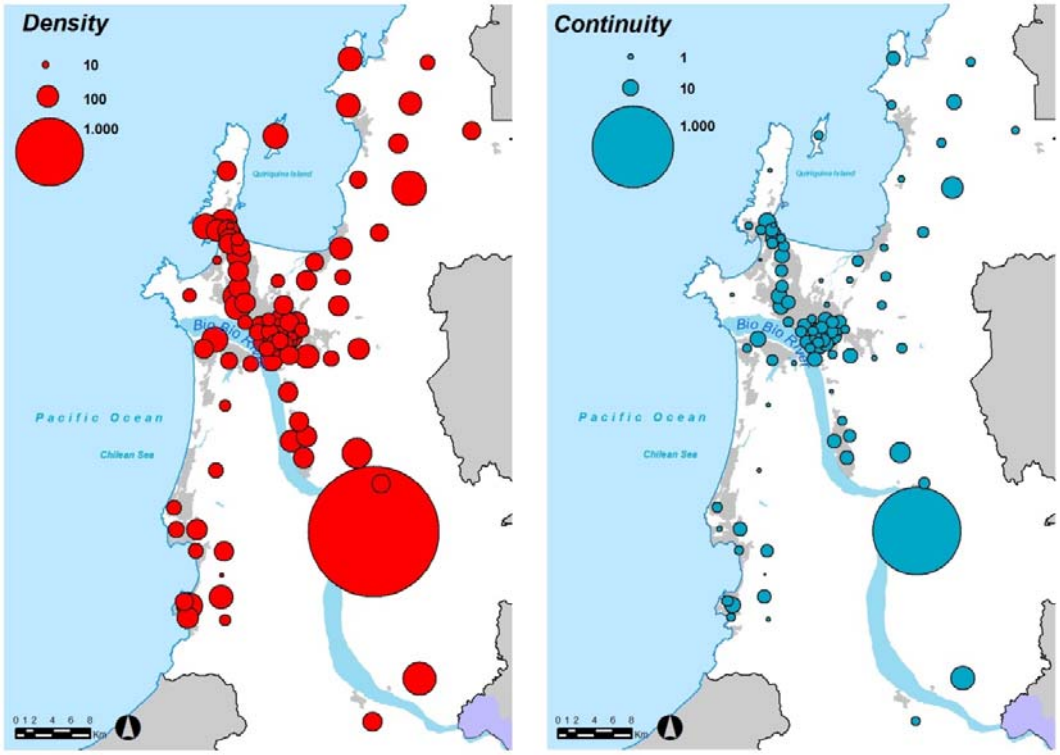
	N	Minimum	Maximum	Mean	Std. Deviation
Density	93	5,0	3733,9	128,9	380,1
Continuity	93	0,9	1184,3	33,9	121,4
Centrality	93	0,0	47,2	10,1	10,9
Proximity	93	20	49,4	25,5	5,7
Valid N	93				

Table 1. Descriptive Statistics

Density (inhabitants per hectare) shows a mean with a high difference between minimum and maximum values, which indicates high dispersion in the values. On the

other hand, Centrality and Proximity show more regular values with less variability in their data and very similar maximum distance values.

CMA is developed with a medium density model, considering as suitable 40 dwellings per hectare (Hall, 2007), something like 160 inhabitants per hectare. Regarding both resulting maps, the difference between the more urbanized or concentrated urban space and the less urbanized open areas can clearly be seen (Figure 3).



a. b.

Figure 3. Spatial results of Density and Continuity
Source. Built-up areas in Rojas, Opazo, Jaque (2009).

For this reason, the interpretation of urban patterns can be much better done if a cluster analysis is made with two dimensions (density and continuity). K-means (a cluster analysis) is a statistic technique that allows identifying relatively homogeneous groups of cases based on selected characteristics, using an algorhythm that can handle large number of cases; however the algorhythm requires the number of clusters to be specified. According to values of final cluster centers of *Density* and *Continuity*, they can be grouped in three classes. They represent different urban types of built-up areas, these are *Low*, *Medium* and *High* (Table 2).

	1 (Low)	2 (Medium)	3 (High)
Density	70,4	139,2	3733,9
Continuity	15,9	35,4	1184,3

Table 2. Final Cluster Centers

The group of census district classified as *High* represents hypothetically more compact cities, obviously for having the highest values in density and continuity. This is specially so in districts close to CBDs. These districts are located in the city squares, representing the core of the metropolitan area. This means that traditional centers are favoured with high density and less fragmented development. Nevertheless they are surrounded by medium developments that have extended along the banks of the Bío-Bío River and the coastal border. Anyway, compact development does not mean sustainable urban growth. To analyze sustainability, it would be necessary to add other variables like housing energy consumption and dependence on private transport, for example (Figure 4).

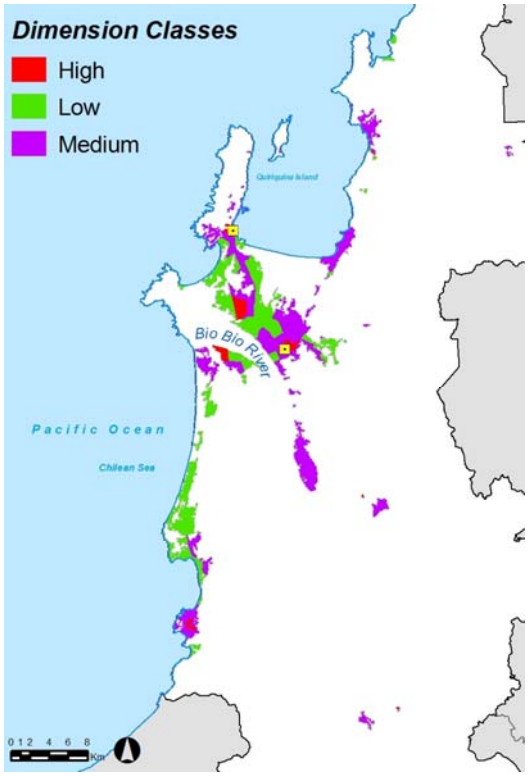
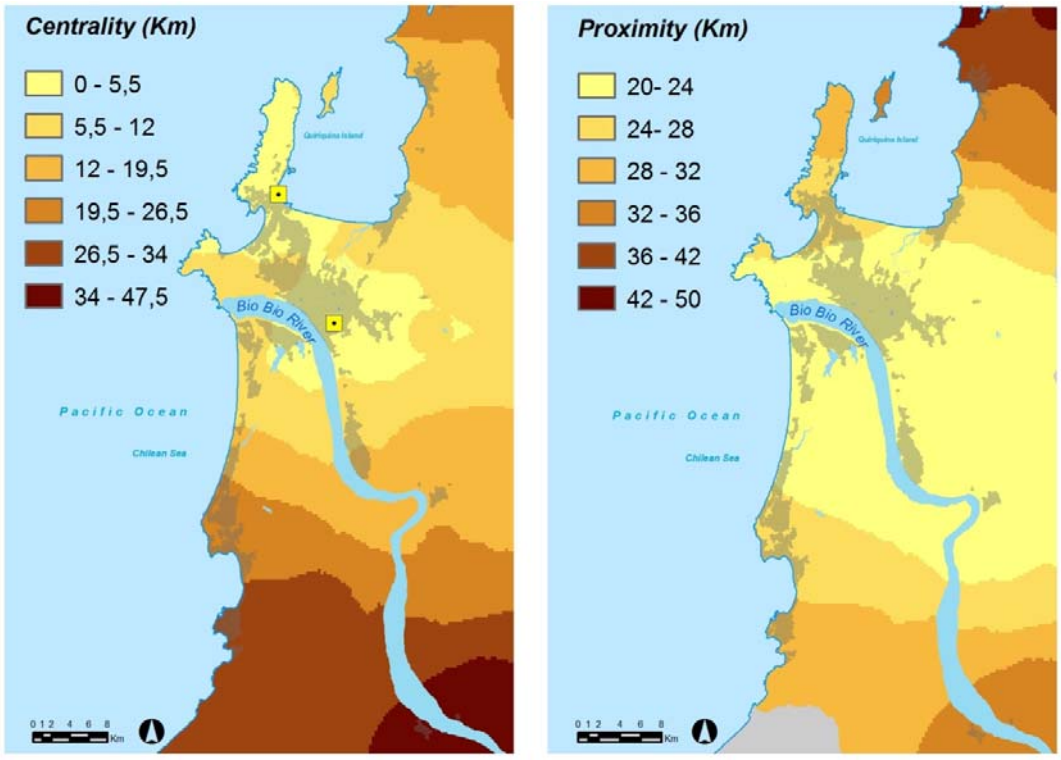


Figure 4. Urban dimension classes

Low developments are located in tentacular growth in Coronel, in residential new areas in San Pedro and the extending urban area between Concepción and Talcahuano. In the periphery there is also a new shopping area.

With regards to Centrality and Proximity (distance in kilometers), the more urbanized areas or central conurbation can be spatially explained by the distance to both CBDs and transport infrastructures. The average distance to any of the two CBDs is about 10 km, and about 25 km to metropolitan roads.This matches with a tentacular growth. Spatially the built-up area is more frequently found in the central area than in anywhere in the region and at the same time forms a buffer area representing the least distances in centrality and proximity (Figure 5a y 5b).



a. b.

Figure 5. Spatial results on Centrality and Proximity

After analyzing the variables, a principal component analysis (PCA) was performed, to determine which is the main dimension factor that better explains urban sprawl. The analysis of the components is p