MONITORING URBAN SPRAWL AROUND BARCELONA'S METROPOLITAN AREA WITH THE AID OF SATELLITE IMAGERY

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ABSTRACT:

The City of Barcelona has a population of just over 1.5 million inhabitants. The Metropolitan Region Barcelona (RMB) extends to some 3,236 km^2 and according to the 2001 Census has a population of almost 4.4 million inhabitants.
In recent years the population of the City of Barcelona has been in decline, in contrast to marked demographic increases in the wider metropolitan area. Indeed the RMB has witnessed a significant process of disperse urban development or urban sprawl, accompanied by increased land consumption. To date efforts to quantify such urban growth have depended upon the analysis of aerial photography and other more functional relations, utilising information based upon commuting travel flows for employment purposes.
This paper approaches the measurement of metropolitan urban growth from a strictly morphological perspective, drawing upon SPOT satellite imagery dating from 1995 and 2003, in order to quantify and analyse the process of 'periurbanisation' which has been experienced in Barcelona over this period. At the same time the paper also assesses the increased accuracy for urban planning activities from an operational perspective, afforded by the new generation of satellite images from SPOT5, through the higher resolution of the images, for the monitoring of key urban development issues, both within the confines and beyond the edges of Barcelona's metropolitan area.

1. INTRODUCTION

1.1 Metropolitan urban agglomerations

According to the METREX Network, throughout Europe, the metropolitan regions are all facing similar problems of economic change, social cohesion, urban sprawl, traffic congestion, city centre vitality and viability, and environmental damage and pollution. At the same time these areas and regions offer opportunities for renewal and regeneration, high quality urban life, and economic competitiveness. (METREX, 1999) While it is clearly recognised that these problems and opportunities arise at a general level within Europe, in spatial terms it is more difficult to ascertain with exactitude the spatial extent to which such problems and opportunities are found.

Traditionally the physical delimitation of urban areas and agglomerations has been characterised by two clearly differentiated approaches. On the one hand a delimitation based upon physical or morphological criteria, where the continuous built-up area, or the density of contiguous ambits, comprises the basic mechanisms for the delimitation. On the other hand studies based upon functional or economic criteria , where the emphasis is placed upon the existing relations and flows throughout the urbanised territory where the relation between place of residence and place of work is fundamental.

Having said that, the lack of homogeneous criteria for the definition and delimitation of 'metropolitan urban regions' does nothing to add to the ease of studying individual cases or making comparisons at the European level. In the case of European Commission funded research project under the INTERREG IIC initiative, aimed at reaching an understanding of the territorial and functional characteristics of the metropolitan system of South Western Europe, a common methodology was agreed between the three partner countries of Spain, Portugal and France, in order to allow a cross-border comparison of the respective metropolitan urban regions under consideration (Barcelona, Bilbao, Madrid, Málaga, Seville, Saragossa and Valencia in Spain; Lisbon and Oporto in Portugal; and Bordeaux, Montpellier and Toulouse in France). These metropolitan urban regions were defined taking a functional approach, consisting of adding to the central city of each area the adjoining municipalities where the level of commuting between place of residence/place of work was superior to a certain threshold, following the methodology based upon that used by the Bureau of Census in the United States, for the states of New England, for the definition of statistical metropolitan areas (Office of Management and Budget, 1990).

In the case of Barcelona, this methodology led to the delimitation of a metropolitan urban region of some 4,592 km^2 with a population of more than 4,5 million persons (CPSV, 2001). This contrasts strongly with two more administrative definitions used locally: the Metropolitan Region of Barcelona (RMB) and the Metropolitan Area of Barcelona (MAB).

The RMB, recognised for some aspects of regional planning, refers to an area of 3,236 km^2 incorporating some seven counties and a total of 164 municipalities. The MAB, under the jurisdiction of the *Mancomunitat de Municipis* (MMAMB) is a voluntary association of some 31 municipalities, comprising

cities and smaller towns and villages within the immediate environs of Barcelona extending over an area of 495 km^2. Although extending over approximately one tenth of the area of the metropolitan urban region, as defined under the INTERREG-IIC research project, the MAB contained some 62.5% of the metropolitan urban region's population, giving some indication of the compact form of urban development at the core of this wider metropolitan area.

	Area (km^2)	Population (2001)	Population density (inhabitants per km^2)
Barcelona City Council	98	1,503,884	15,322
Metropolitan Area of Barcelona (MMAMB)	495	2,833,349	5,724
Metropolitan Region of Barcelona (RMB)	3,236	4,390,390	1,357
Functional metropolitan area of Barcelona (CPSV)	4,592	4,537,468	988

Table 1: Basic characteristics of the different administrative and spatial areas of Barcelona's metropolitan urban region.

1.2 Urban sprawl

In recent years Barcelona's metropolitan area has witnessed significant growth in peripheral urban development, or urban sprawl, with progressively increased land consumption, matched by a decrease in population at the core. Regardless of the nuances between the different administrative and planning areas, it is clear that Barcelona and its surrounding area represent a metropolitan urban region of an international scale, experiencing those same problems and opportunities identified by the METREX network and referred to earlier, including that of "urban sprawl".

As Wilson et. al (2003) rightly indicate, no such universally accepted definition of urban sprawl exists and indeed the phenomenon it seeks to describe, i.e. the land-consumptive pattern of urban development, can be interpreted both positively and negatively. The authors develop an urban "growth", rather than "sprawl" model, to quantify the amount of land converted to urban uses, leaving it open to subjective interpretation whether or not it constitutes "sprawl". They wisely suggest that "the challenge is to quantify and categorise urban growth in a way that is useful and meaningful to land use decision-makers at the municipal, regional and state levels". (p. 276)

The invitation extended to the Universitat Politècnica de Catalunya and the MMAMB from the CNES and SPOT Image to participate in the Spot 5 Application and Validation Programme (SAVP) in 2003 provided the ideal opportunity to engage in research taking a physical or morphological approach to examine a number of key urban development issues both within the confines and beyond the edge of Barcelona's metropolitan area. The joint UPC/MMAMB research proposal therefore sought to assess the extent to which the satellite data could aid in the quantification and analysis of this pattern of apparent outward encroachment of urban development into the surrounding countryside of the metropolitan area or 'peri-urbanisation'.

Although recognising that Barcelona's functional metropolitan urban region is considerably more expansive, for the purposes of this study, the metropolitan area was taken as that defined by the 31 local authorities belonging to the MMAMB. The founding of the MMAMB in 1988 was based upon the premise of optimising resources and sharing them for questions of solidarity, for the delivery of a wide variety of services between and amongst the local authority members of the association. Amongst the services managed by the MMAMB, one finds the conservation and promotion of a large natural space, the Collserola Park; the creation, maintenance and conservation of a network of some 27 metropolitan parks, covering a total of 244 hectares; the adapting, maintenance and provision of basic facilities along the beaches of the Mediterranean coastline; the construction of affordable housing; and a wide range of planning projects aimed towards structuring and increasing the territorial quality of the metropolitan city of Barcelona. In view of these urban planning services and responsibilities, the MMAMB represents an ideal end user for the results emanating from a study of this nature. Since 1986, the Universitat Politècnica de Catalunya, through its Centre de Política de Sòl i Valoracions, has been engaged in a wide range of specialised teaching and research activities in the fields of land use and environmental planning, territorial management, urban property valuations, geographical information systems, the virtual modelling of architecture and the city, and environmental sustainability.

This paper describes some of the initial results emerging from the UPC/MMAMB participation in the Spot 5 Application and Validation Programme, scheduled to terminate in July/August 2004.

2. METHODOLOGY

2.1 Background

It is irrefutable that Earth observation is a modern science, which studies the Earth's changing environment, through "remote sensing" tools such as satellite imagery and aerial photography (EEA, 2002). A report published by NASA in 2001 highlighted the fact that the advances in satellite-based land surface mapping are contributing to the creation of considerably more detailed urban maps, offering planners a much deeper understanding of the dynamics of urban growth, as well as associated matters relating to territorial management (NASA, 2001).

Within the European context, the most recent comparable study of this nature is that of the MURBANDY/MOLAND project (Monitoring Urban Dynamics / Monitoring Land Use Changes) which has used "remote sensing", the results of which have been published by the European Environment Agency (EEA, 2002). This project drew together a network of European partners and sought to measure and assess urban dynamics, through the creation of a land use data base, for a range of European cities and urban regions, including Bilbao. These data bases combine environmental, social and economic information, in order to reach a better understanding of the characteristics and dynamics of urban growth and the changes related to land use, such as transport and energy infrastructure, and the changes in agriculture and natural areas. The results show the spatial

evolution of a group of urban areas, with the objective of proposing a methodology for strategic monitoring of the environmental impact of urban development.

It is relevant to highlight the fact that the Report of this project suggests that "urban growth and sprawl is a pertinent topic for analysis and assessment today. The environmental impacts of urban sprawl and the extent of urban problems have been growing in complexity and relevance, generating strong imbalances between the city and its hinterland. The need to address this complexity in assessing and monitoring urban planning and management processes and practices is strongly felt" (EEA, 2002, p.7).

The MOLAND methodology, a more advanced version than MURBANDY, has created the data bases for four periods, for the 1950s, the 1960s, the 1980s and the 1990s, through the interpretation of satellite images, principally IRS images, but in some cases IKONOS and SPOT images (Lavalle et. alt., 2002). It is important to note that the nomenclature adopted for the "remote sensing" was a more extensive version of the CORINE legend. One of the fundamental differences between Murbandy/Moland and Corine, apart from the greater precision with the level of detail, is that with Murbandy/Moland it is possible to make the distinction between different land uses. By contrast, Corine is more limited related to the distinction between different land classifications. This methodology has enabled the evaluation of "urban sprawl" for the 25 case studies, understood as the percentage increase in the urbanised surface area during the period under review.

2.2 Data

Participation in the Spot 5 Application and Validation Programme provided the researchers with access to a range of SPOT satellite images. In view of the wish on the part of the UPC/MMAMB to carry out a dynamic study, satellite images were provided dating from 1995 permitting their comparison with more recent 2003 images.

Four images were used for the research referred to in this paper:

- Spot 5 (2003) THR, black and white, 2.5 m resolution, Processing level 1A
- Spot 5 (2003) THR CNA C1-3, natural colours, 2.5 m resolution, Processing level 1A
- Spot 5 (2003) THX FC C1-3, false colours, 2.5 m resolution, Processing level 1A
- Spot 3 (1995) Infrared, 20m resolution, Processing level 1A

The 60km x 60km SPOT Scene extends to a land area of some 2,700 km^2, taking into consideration the significant component of the sea.

2.3 Method

The three 2,5 metre resolution images were orthorectified simultaneously, with the aid of a 2.5 metre Orthophoto, in TIFF format, for the entire study area. This saved time and also contributed to the subsequent classification process. Owing to the magnitude of the image, it was divided into four roughly equal parts, thereby making the rectifying process more manageable, as illustrated by the 2003 True Colour image below.

The supervised classification methodology drew upon the same three images (true colours, false colours, and black and white, all with a 2.5 metre resolution) in order to maximise the number of distinguishable land cover classes for the study area. At the time of writing (April 2004) this methodology has been applied to the south-eastern quadrant of the study area, as illustrated in Figure 1, which contains the vast majority of the compact urban development found within Barcelona's metropolitan area. This methodology has made use of maximum likelihood, binary encoding and parallel piped methods, prior to scattergram processes and the merging of all the data, drawing upon a subtraction process to arrive at the final classified image. It made use of ER Mapper and ENVI software applications.

Figure 1: SPOT scene for Barcelona

The same broad supervised classification method (parallel piped and maximum likelihood) was applied to the entire area contained within the SPOT scene, comparing the 1995 and 2003 images, for a more reduced range of land cover classes than those isolated under the previous exercise.

3. RESULTS

3.1 Indications of urban sprawl

It is too early to offer conclusive results of this study, on the basis of the work yet to be carried out. Nevertheless the work to date has highlighted a number of points worthy of mention.

As can be seen from Table 2, over the eight year period between 1995 and 2003 in the wider metropolitan territory and beyond, there has been an increase of just under 50% in the broad category of "occupied land". At the same time, there has been a commensurate decrease in "green areas" and "soil", the two remaining categories of this albeit broad classification, indicative of a wholesale outward encroachment of development into the countryside. These results arise following the application of the same supervised classification methodology over the entire area of the 1995 and 2003 SPOT Images, as illustrated by Figures 2 and 3.

Even allowing for error and the clear need for refinement, this analysis offers evidence which clearly corroborates the hypothesis of increased land consumption on the periphery of Barcelona's metropolitan area.

Land cover class	1995	2003
Occupied	30,827,294 points	44,554,426 points
All green areas	53,749,872 points	43,710,583 points
Soil	10,097,770 points	234,581 points

Table 2: Broad land cover for the area of study - 1995 and 2003

Figure 2: 2003 SPOT Image following supervised maximum likelihood classification (occupied area; green area; and soil)

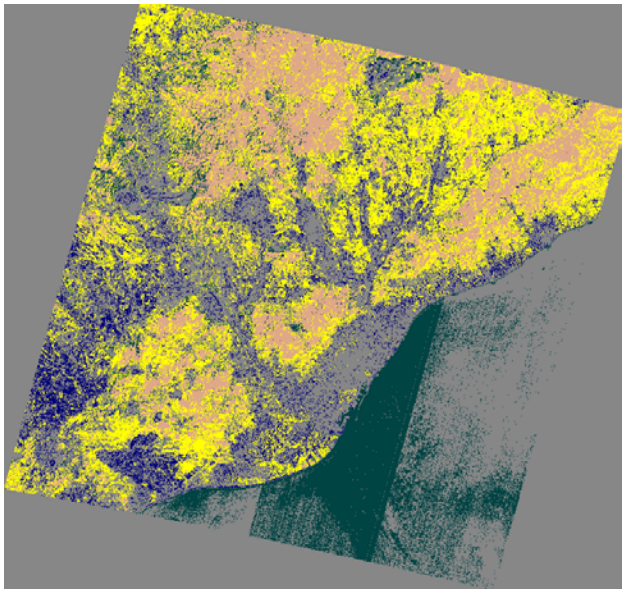

Figure 3: 1995 SPOT Image following supervised maximum likelihood classification (occupied area; green area; and soil)

In purely visual terms, the evolution or change in urban development over the 1995-2003 period, again in the broad sense, can easily be discerned from the super-imposition of the 1995 and 2003 images. Figures 4 and 5 clearly illustrate the existing development in 1995 in blue tones, with new and or redevelopment being represented by the red tones. Figure 4 shows a detail of Mataró, an important sub-centre of Barcelona's wider metropolitan area, lying on the coast to the north of Barcelona. The figure clearly identifies, amongst other things, industrial redevelopment in the south-west, and new commercial and industrial development lying to the north of the new outer ring-road.

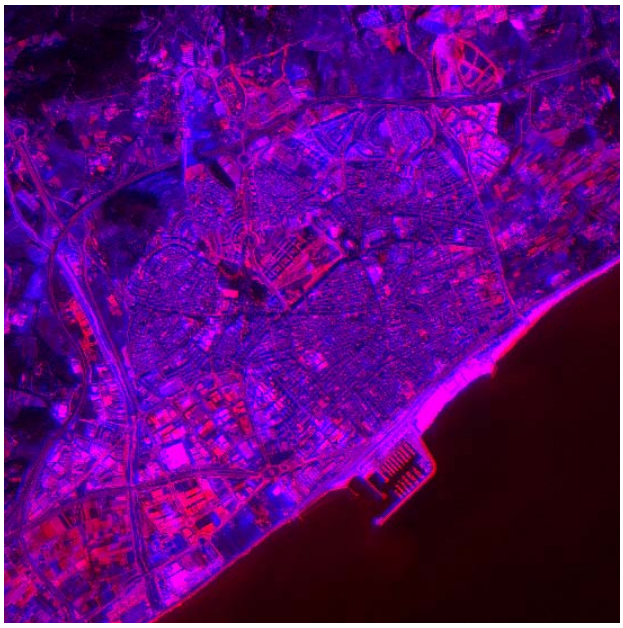

Figure 4: Mataró - comparison between 2003 (red) and 1995 (blue)

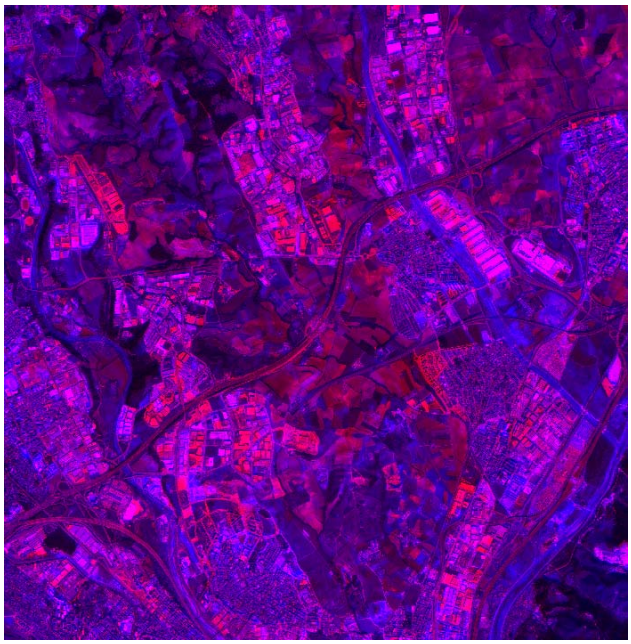

Figure 5: Vallès Occidental - comparison between 2003 (red) and 1995 (blue)

In the same vein, Figure 5 clearly identifies important infrastructure investment and/or improvements. In the area of Vallès Occidental (Ripollet, Santa perpètua de Mogoda, La Llagosta and Mollet del Vallès), the existing communication

system is easily seen by the blue tones, whereas the new transversal east-west road stands out, contributing to the enhanced connectivity within the wider metropolitan area.

As mentioned previously, the classification exercise for determining the land cover classes for the 2003 images has, at the time of writing, only been completed for one part of the SPOT Scene, covering just 172 km^2 of the MAB. The full results will be presented the ISPRS Conference in Istanbul in July 2004, however it is worth mentioning that some nine land cover classes have been isolated resulting from the supervised classification methodology used and described under Section 2.3 of this paper: shadow; 3 industrial classes; residential; soil; green; shallow water; and occupied area.

Figure 6 illustrates a detail of the final map resulting from the aforementioned supervised classification process, focusing on the industrial areas of the *Zona Franca*, in Barcelona, lying to the north of the Llobregat River and the adjoining Logistic activities zone (*ZAL*), within the municipality of El Prat de Llobregat, lying to the south.

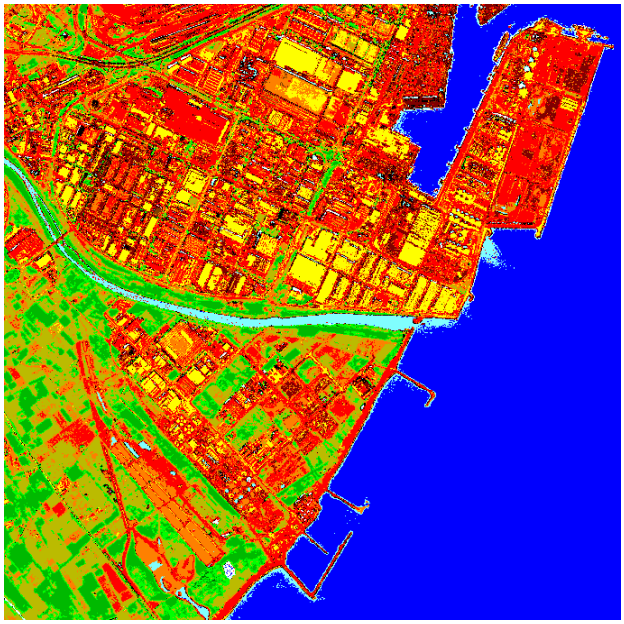

Figure 6: Example of the resulting supervised classification

4. DISCUSSION AND CONCLUSIONS

4.1 Monitoring urban sprawl

Official figures relating to the growth in population of the Metropolitan Area of Barcelona for the five-year period 1996-2001 indicate an overall increase in population of some 0.295%. This demographic change has by no means been uniform, as is highlighted by Table 3. While the population of the City of Barcelona has decreased by some 0.326%, the remainder of the Metropolitan Area under the jurisdiction of the MMAMB saw an overall increase in population of just over 1%.

This level of growth is more modest than that suggested by Table 2, but is probably nearer the truth for a number of reasons. On the one hand the spatial extent of the MAB is just one part of the much wider territory subjected to the satellite image interpretation (remote sensing) comparison between 1995 and 2003. On the other hand this comparison identified just three very broad classes of land cover: occupied areas (implying some form of human intervention), green areas and soil. Furthermore the two images used for this comparative exercise are in raster data format. For greater accuracy they would need to be in vector data format enabling the delimitation of polygons and the determination of exact areas. Once this conversion procedure has been carried out upon the SPOT Images used in this project, the research team will then be in a position to quantify with precision the level of urban growth and development experienced between 1995 and 2003 within the limits of the MAB, and make the judgement as to what extent this growth can be constituted as urban sprawl.

	1996	2001	% change
Barcelona	1,508,805	1,503,884	-0.326
Rest of MAB	1,328,735	1,342,041	+1.001
Total MAB	2,837,540	2,845,925	+0.295

Table 3: Change in population for the Metropolitan Area of Barcelona 1995-2003

As yet, the research project referred to here is not sufficiently advanced to offer conclusive results concerning the quantification and qualification of urban sprawl or urban growth within and on the edge of Barcelona's metropolitan area. However the emerging results clearly corroborate the hypothesis of increased land consumption beyond the central core of the MAB.

In this sense the morphological approximation to the delimitation of urban and/or metropolitan systems through the interpretation and analysis of satellite images, particularly incorporating a dynamic approach by comparing two points in time, would appear to offer a clear advantage over more functional approaches. By simply superimposing the earlier and later of two images, as carried out in Section 3.1 and illustrated by Figures 4 and 5, the professionals working in the realm of urban and regional planning are provided with a wealth of information. This enables them to determine at a glance the areas where development pressures have been most strongly experienced.

4.2 Conclusions

Part of the reasoning behind the invitation extended to the UPC/MMAMB from the CNES and SPOT Image to participate in the SAVP exercise was to gain feedback on the potential applications of Spot 5 data for the purposes of urban planning. With this in mind, although the final results of the project are still to be reached, it seems appropriate to offer some comments concerning the enhanced characteristics of the Spot 5 Images, resulting from the increased resolution.

The difference between the 2003 and the 1995 images, in terms of increased visual clarity and quality, is patently obvious from Figure 7. This illustrates the built-up fabric of Barcelona, incorporating the city's historic core to the north-east adjoining the former Port Area, today with a leisure boat marina and other recreational/leisure uses, and the grid-ironed 19th Century extension to the city to the north-west. The clarity of the urban fabric in the southern portion of the figure contrasts sharply with the more blurred nature of the northern section.

Figure 7 clearly provides very real and local evidence of the potential for a deeper understanding of the dynamics of urban

growth and territorial management in general, as suggested by the NASA report referred to in section 2.1 (NASA, 2001).

Figure 7: Contrast between the Spot 3 1995 and Spot 5 2003 images for Barcelona
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Having said that, from a planning and monitoring perspective, the clear advantage of the increased resolution afforded through the 2003 image lies in enhanced possibilities of results emanating from the classification process. The greater degree of precision afforded by the pixels, will guarantee considerably less error than will occur with the classification resulting from the images with the lower resolution. It is here precisely this aspect that is of greatest interest to the MMAMB, as the formal end user of the results of this dynamic study of the Metropolitan Area of Barcelona.

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