MONITORING URBAN GROWTH AROUND THE METROPOLITAN AREA OF BARCELONA WITH SPOT SATELLITE IMAGERY.

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Summary

The SPOT5 satellite was launched in mid-2002 and offers the possibility of providing images for geographical areas measuring (60 km x by 60km) at a resolution of 2.5 metres. For urban planning applications in large metropolitan area, this degree of detail marks a significant advance over the specifications of previous images in the SPOT series.

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. 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 and travel to work flows.

This paper approaches the measurement of metropolitan urban growth from a strictly morphological perspective, drawing upon SPOT satellite imagery dating from 1995 and 2002. At the same time the paper assesses the value of the increased accuracy for urban planning activities from an operational perspective, resulting from the higher resolution of the SPOT5 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. [1] 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 [2].

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 [3]. 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 [4] 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". [4, p. 276]

This paper describes the results stemming from a joint research project carried out by the Universitat Politècnica de Catalunya and the MMAMB as part of the Spot 5 Application and Validation Programme (SAVP) during 2003-2004. The joint UPC/MMAMB research project sought to assess the extent to which 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'.

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 (5). 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 [6].

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 [5]. 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” [6, 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 [7]. 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. Four images were used for the research referred to in this paper:

- Spot 5 (2002) THR, black and white, 2.5 m resolution, Processing level 1A
- Spot 5 (2002) THR CNA C1-3, natural colours, 2.5 m resolution, Processing level 1A
- Spot 5 (2002) 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.

The researchers elaborated a supervised classification methodology, drawing upon the four images (with 2.5 m and 20 m resolutions) in order to maximise the number of distinguishable land cover classes for the study area. This methodology employed **maximum and minimum 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.

The images were classified without being broken down into smaller units. Rather once the initial classification had taken place, errors were searched for and where these occurred, the sections containing them were removed from the overall image, reclassified as single units and then reinserted in the master image in a mosaic form.

The methodology made use of **ER Mapper** and **ENVI** software applications.

This classification process led to the identification of some eight land cover classes:

- forestry
- agriculture
- irrigated fields
- dry land
- residential
- industrial (A and B)
- streets and roads
- shallow and deep waters

which was considerably more than was at first envisaged through the three bands (RGB) of the 2002 true colour Spot image.

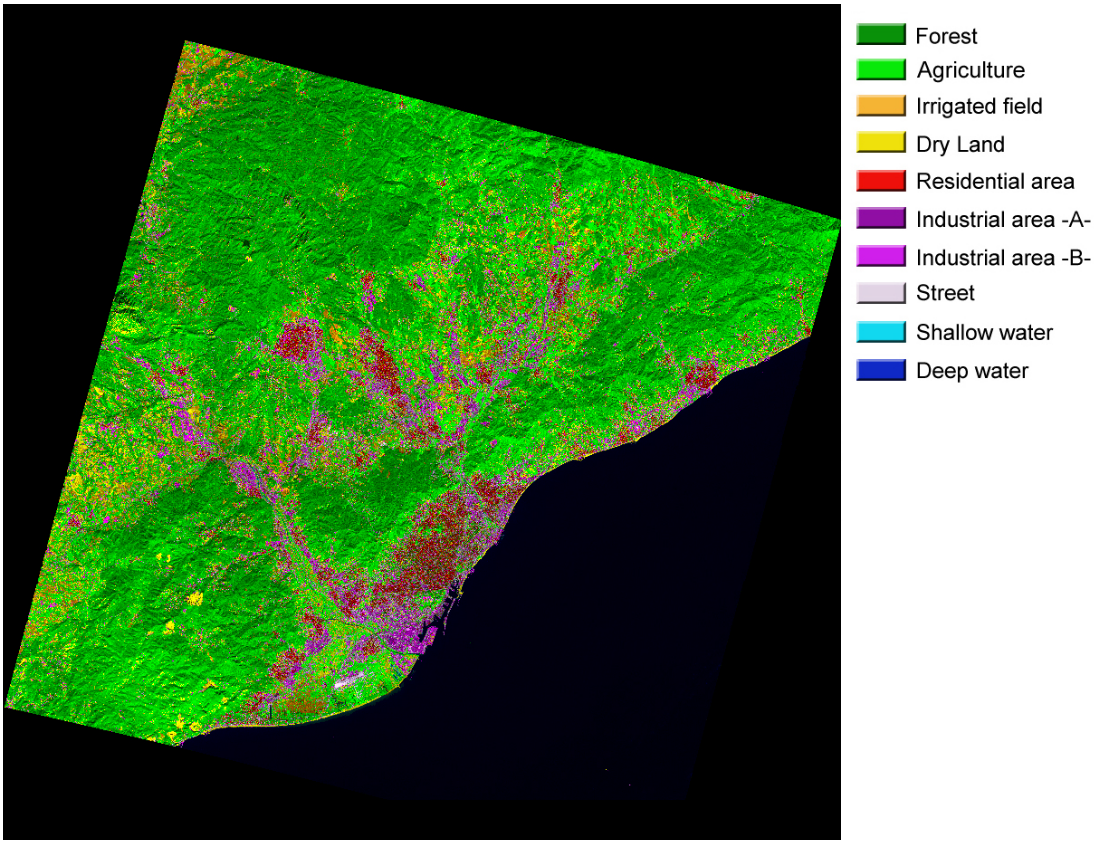

Figure 1: Supervised classification resulting from the 2002 Spot 5 (2.5 metre resolution) image of the study area (© SPOT Image Copyright 2002, CNES)

3. Results

3.1 Quantification of urban sprawl

In order to quantify the magnitude of the change in urban development experienced over the 1995-2002 study period, and measure what could legitimately be termed 'urban sprawl', it was decided to focus attention on the land which had been 'artificialised' for urban land uses, i.e. undergone some form of urbanisation. This meant focusing on the following land cover classes:

- residential
- industrial (A and B)
- streets and roads

It should be emphasised that these first results relate to the entire area contained within the respective Spot scenes for 1995 and 2002 (i.e. the 3.600 km^2), and not to any territorial area with fixed limits for administrative purposes. That is to say neither the 495 km^2 of the Metropolitan Area of Barcelona, as used by the MMAMB, nor the 3,236 km^2 of the Metropolitan Region of Barcelona.

LAND COVER	1995	2002
Urbanised	219.33 km^2 (8.15%)	397.09 km^2 (15.24%)
Non-urbanised	2,472.81 km^2 (91.85%)	2,209.08 km^2 (84.76%)
TOTAL	2,692.14 km^2 (25.21%)	2,606,17 km^2 (27.60%)

Table 2: Changes in urbanised and non-urbanised shares of the overall study area of the Spot scenes between 1995 and 2002.

While both images covered a surface area of 3.600 km^2, the total land areas obtained through the supervised classifications, excluding the shallow and deep water categories amounted to 2,692km^2 in 1995 and 2,606 km^2 for 2002. In 1995, the artificial or urbanised land cover accounted for 8.15% (219 km^2) of the entire study area. In 2002, the artificial or urbanised categories represented 15.24% (397 km^2) of the overall study area. This increase in the artificialised or urbanised component was matched by a concomitant decrease in the non-urbanised land cover, from 91.85% in 1995 to 84.76% in 2002.

As can be seen from Table 3, over the study period there was an apparent change in the overall proportion of residential land cover from 3.75% in 1995 to 5.27% in 2002. Industrial land cover accounted for a smaller proportion, increasing from 2.61% in 1995 to 4.18% in 2002. Finally streets and roads indicated a significant increase over the study period, from 1.78% of the overall study area in 1995 to 5.79% in 2002. While a significant degree of new road building has indeed taken place over the study period in the environs of Barcelona, it is considered that this degree of change is exaggerated. The figures may indeed reflect upgrading to existing roads, but in any event need to be treated with a certain degree of care.

LAND COVER CATEGORY	1995	2002
Residential	101 km^2 (3.75%)	137 km^2 (5.27%)
Industrial (A and B)	70.30 km^2 (2.61%)	108.87 km^2 (4.18%)
Streets and roads	48 km^2 (1.78%)	151 km^2 (5.79%)

Table 3: Changes denoted in the individual urban land cover classes between 1995 and 2002 for the overall Spot scenes.

Turning attention upon the dynamics within the 495 km^2 of the Metropolitan Area of Barcelona, i.e. the territorial area coming under the jurisdiction of the Mancomunitat de Municipis de l'Àrea Metropolitana de Barcelona (MMAMB), some difficulties were encountered in correctly superimposing the boundaries of the MAB over the respective images. Furthermore the assessment of the areas pertaining to the land cover classes in 1995 and 2002 was made from the two images in raster format, by assessing the sum of the pixels belonging to the different categories, rather than vector format which would have enabled the derivation of areas from polygons. This was because of the sheer weight of the 2002 image and difficulties in converting the entire image to vector format. As a consequence, the conversion of the actual boundaries to raster format led to their 'widening', thereby introducing an element of uncertainty as to the exact land areas, pertaining to the different land cover categories, within the overall area of the 31 municipalities of the Metropolitan Area of Barcelona. Having said that, the total land area obtained by way of the supervised classification for the 1995 image was 481.50 km^2, compared with 528,60 km^2 from the 2002 image. Therefore it is considered that these figures provide a reasonable fit to the MAB study area and in turn a reasonable approximation to the change experienced over the study period, taking into account the constraints imposed by a remote sensing exercise of this nature.

By definition the territory coming under the jurisdiction of the MMAMB is of a far greater urban nature, embracing the principal municipalities adjoining the City of Barcelona, than the remainder of the wider study area. This is clearly reflected in Table 4, where according to the supervised classification, the urbanised land cover category accounted for almost 25% of the MAB in 1995 and over 32% in 2002. However looking in more detail at the individual components of the urbanised category one sees greater change experienced in the industrial, and streets and roads categories than in the residential category.

LAND COVER CATEGORY	1995	2002
Urbanised	117.2 km^2 (24.74%)	167.598 km^2 (32.12%)
Residential	*53.466 km^2 (11,10%)*	*56.492 km^2 (10.69%)*
Industrial	*38.573 km^2 (8.01 %*	*46.904 km^2 (8.87%*
Streets and roads	*25.161km^2 (5.23%)*	*64.192 km^2 (12.14%*
Non-urbanised	356.504 km^2 (75.26%)	354.19 km^2 (67.88%)
Total	473.704 km^2 (100 %)	521.79 km^2 (100 %)

Table 4: Changes denoted in the urban land cover classes between 1995 and 2002 for the 495km^2 of the Metropolitan Area of Barcelona, coming under the jurisdiction of the *Mancomunitat de Municipis de l'Àrea Metropolitana de Barcelona*

With regard to interpreting these specific results for the residential category, what should be mentioned is that in the wider metropolitan area of Barcelona, beyond the immediate built up limits of the city, a substantial amount of the urban area is in the form of "garden city" type development. This forms a marked contrast with the compact form of urban development found within the built-up area of Barcelona. If one were analysing this more diffuse nature of urban development on a site by site basis, such private gardens would be interpreted as artificialised land, linked to the principal adjoining residential use. However through remote sensing, such gardens would automatically be classified as non-urbanised categories. For this reason and taking into consideration the enhanced precision facilitated by the 2.5 m resolution images of the Spot 5 series, it is considered that the 2002 image of the study area will have under-estimated the degree of more disperse and diffuse residential development beyond the immediate limits of the built-up areas of the Metropolitan Area of Barcelona.

4. Discussion and Conclusions

4.1 Monitoring urban sprawl

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, 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

The principal objective of the study was to assess the increased accuracy afforded by the new generation of satellite images from SPOT5, for the monitoring of key urban development issues both within the confines and beyond the edge of the Metropolitan Area of Barcelona (MAB).

The results of the study provided a broad indication of the magnitude of change in urban land cover classes experienced in the metropolitan area of Barcelona over the study period. This increase of some 180 km^2 in urban land cover uses denotes a corresponding decrease in the other land cover classes, indicating the magnitude of the outward encroachment of urban development into the surrounding countryside.

The enhanced visual clarity of the SPOT 5 images, with a resolution of 2.5 metres, is unquestionable, offering a wide range of immediate applications to contribute to a deeper understanding of the dynamics of urban growth and territorial management. (See Figure 2)

Consequently there would appear to be clear advantages for planning and monitoring needs, from the enhanced results emanating from the supervised classification processes undertaken in this study. The greater degree of precision afforded by the pixels, will guarantee considerably less error than will occur with classifications from images of a lower resolution. For public authorities such as the MMAMB with responsibilities in monitoring land use activity over time, whether it be at the municipal or regional scale, the increased reliability in the determination of different land uses is clearly of crucial importance.

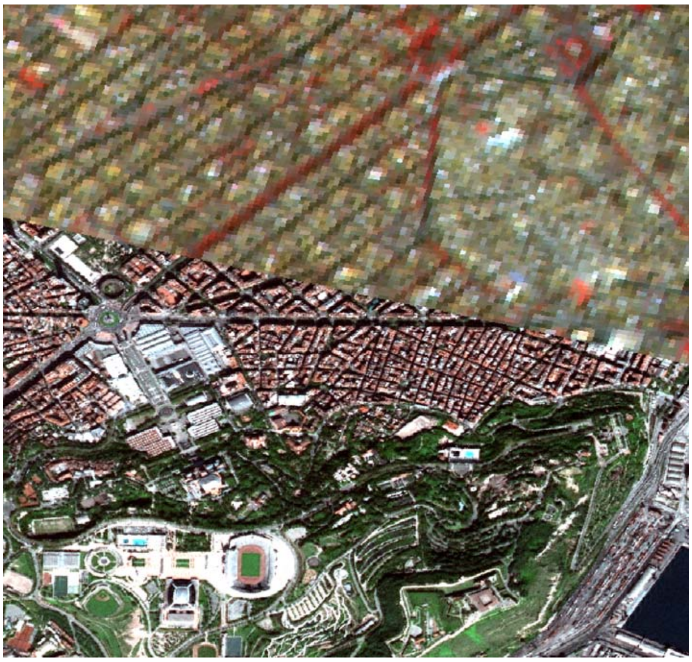

Figure 2: Contrast between 1995 SPOT 3 and 2002 SPOT 5 images for Barcelona, highlighting the enhanced visual clarity and quality of the SPOT 5 image
(© SPOT Image Copyright 1995 and 2002, CNES)

References:

[1]. METREX, 1999. The Metropolitan Magna Carta of Spatial Planning and Development Intent (The Porto Declaration)
[2]. Office of Management and Budget, 1990. Revised standards for defining metropolitan areas in the 1990s. Federal Register, 30 March 1990.
[3]. CPSV, 2001. The territorial and functional characterisation of the Spanish metropolitan areas, Final Report, November 2001, UPC, Barcelona.
[4]. Wilson, E. H. et. al., 2003. Development of a geospatial model to quantify, describe and map urban growth. *Remote sensing of environment*, 86, pp. 275-285.
[5]. European Environment Agency, 2002. Towards an urban atlas: assessment of spatial data on 25 European cities and urban areas, EEA, Copenhagen.
[6]. NASA, 2001. Satellite maps provide better urban sprawl insight. NASA News Release, 2 June 2001.
[7]. Lavalle, C. et. al., 2002. Monitoring and forecasting the dynamics of European urban areas – the territorial approach as key for urban development strategies. Paper presented to the EURA Conference on urban and Spatial European policies: Levels of Territorial Government, Turin, 18-20 April 2002.

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