IMAGE ANALYSIS USED TO MEASURE THE SPATIAL COMPLEXITY OF LAND COVER ACROSS COASTAL ZONE

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Introduction

Local governments, national coastline management and protection services, and international organisations such as the Blue Plan are always attentive to changes in the land cover in coastal areas. Studies in this field are based to a large extent on satellite images and the geographical databases derived from them, which are processed using geographical information systems (GIS). However, research tends to be focused on certain topics, such as urbanisation and the development of artificial surfaces, at the expense of a global analysis of the types of land cover and how they change. Moreover, GIS-based analyses are little more than an inventory of the objects contained in all or part of the image. Spatial analysis is still limited, as it takes neither the configuration of types of land use nor the resulting complexity of the regional mosaic into consideration.

In this article, we propose another, more global and morphological approach to land cover in the coastal areas. Land cover, as it is perceived through the prism of geographical databases, is like a puzzle whose characteristics are specific for each region, and which changes shape as a function of the changing land cover. We are more interested in the shape of the pieces of the puzzle, the irregularities in their contours, and how the pieces are arranged than in how many there are, or how big they are. We also want to monitor the effects of the attractiveness of coastal areas on the layout, and find out, in particular, if competition for space among the different activities there tends to simplify the puzzle configuration or, on the contrary, to complexify it. The spatial complexity is relevant to the way land use classes are interlaced and it is defined as a high degree of land use categories interweaving.

The study is concerned with the portion of Mediterranean coastline that includes the Côte d'Azur (French Riviera), western Liguria, and central Liguria. The images we analysed are from the LACOAST database, which corresponds to the biophysical inventory of territory covered by the CORINE land-cover project. The inventory was put together by national CORINE land-cover teams, based on satellite images taken in 1975 along a 10-km-wide strip of coastline in each European country concerned. The 1975 images are compared to those taken in 1992 for the Italian coastline, and to those taken in 1994 for the French coastline.

In a first stage, we discuss the interest and the limits of Gis-tools in detecting spatial configurations. Those tools belong to counting statistics family and they do not take into account the way geographical objects are interlaced to each other across the space. Next, spatial and morphological tools related to image analysis are presented and a method for measuring the spatial complexity of coastal land cover is proposed. Finally, we analyse and compare the spatial differentiations existing between Côte d'Azur and Liguria.

1. The advantages and limits of using GIS for spatial analysis

Using methods available with GIS, we can obtain basic information about the size and surface of polygons that delimit zones with the same type of land cover as defined by the CORINE land-cover project, and which are present over the whole image or inside a buffer. In this case, we grouped the 44 CORINE classes into 13 larger ones that are representative of the type of land cover in each study zone. In our paper we will use the term *components* to describe the different polygons.The inventories taken serve to establish the distribution in number and size for these components.

Performing an analysis of variance of these distributions provides information about their degree of heterogeneity. Calculating a coefficient of variation from a series made up of the surface of components that belong to each land cover category provides information about the diversity of land cover types. For example, the results of the coefficient of variation of the components belonging to the 13 categories indicate that the land cover in western Liguria is less diversified than the land cover in the centre of Liguria (western Liguria, coefficient of variation : 1,08 ; central Liguria, coefficient of variation : 2,01).

The spatial analysis is more informative. In the parts of the Mediterranean where there is a wide differentiation between the coastal areas and those further inland, gathering data inside increasingly larger buffers that are parallel to the coastline gives information about the way land cover changes as a function of distance from the coast. When transferred to a chart, the data make it possible to detect clustering or fragmentation of the components at certain distances from the coastline.

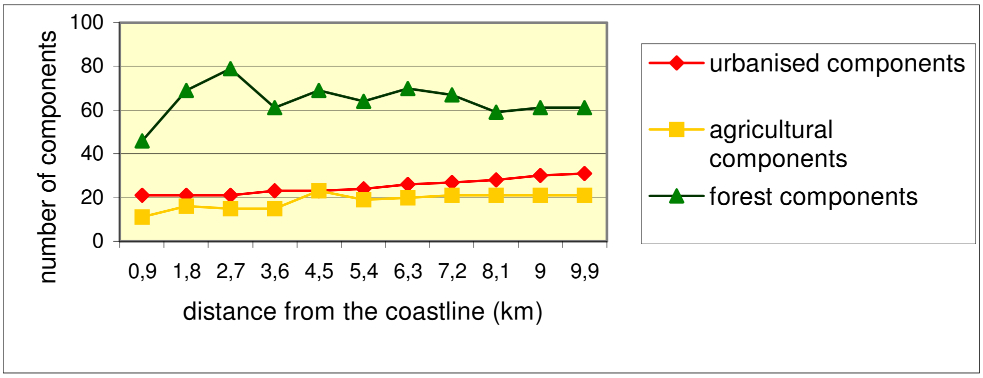

Fig. 1 : Distribution of land use components at certain distances from the coast (central Liguria)

However useful such processing techniques may be, they do not provide information about component layout, how components overlap, or the resulting pattern of contact.

2. Spatial analysis through image analysis and mathematical morphology

2.1 Converting LACOAST images to grey-tone images

The 13 land-cover categories are translated into grey-tone levels.The choice of values for the levels depends on the objective to be obtained. The graduations used in the present study (shown in the table below) take into account the degree to which humans have changed the space, on a scale from the most urbanised areas (lowest grey-tone level) to the areas of least human influence (highest levels).

Categories of land use	LACOAST Class	Grey Level
1.Zone with continuous urban fabric	111	19
2. Industrial and commercial zone with traffic network	121,122,123,124	38
3. Mines, dumps, and construction sites	131,132 ,133	57
4. Zone with discontinuous urban fabric	112	76
5. Artificial (non-agricultural) vegetated areas	141,142	95
6. Permanent crops	221,222,223	114
7. Heterogeneous agricultural area	241,242	133
8. Arable land and pastures	211,212,213,231	152
9. Agroforestry area	243,244	171
10. Shrub and/or herbaceous vegetation association	321,322,323,332,333,334	190
11. Transitional woodland shrub	324	209
12. Forest	311,312,313	228
13. Inland and coastal wetlands	411,511,512,513,522	247

Figure 1 shows an image extract of the central Liguria, converted into grey-tone levels. The selected grid is hexagonal rather than square, so that each pixel is equidistant from neighbouring pixels in all directions.

Since the classes and grey-tone levels are identical on the 1975 and 1992 images, any differences can only be due to changes occurring in the layout of types of land cover. Such changes are hardly visible to the naked eye, however. The average grey-tone level of each image went from 182 in 1975 to 180 in 1992, indicating an upward trend for artificial surfaces and areas subject to human influence. But did the internal differentiation necessarily change ? The answer is provided by two additional image processing procedures based on an analysis of the contrast between pixels in the image.

2.2 Detecting spatial differentiation based on a gradient image

- **The morphological gradient**

Morphological gradient analysis measures the grey-level variation between a single pixel and the six surrounding pixels in the hexagonal grid.The morphological gradient reveals the contours of the image components. The contours correspond to the transitional pixels where there is a change in grey tone. The greater the contrast between the adjacent areas, the higher the gradient value will be. All the contrast values found in the image are translated into grey-tone levels, in an image that is called a gradient image.

- **Hierarchization of the mosaic gradient**

Detecting internal differentiation is a two-step process.
First, the original image is transformed into an image that is called mosaic image, where component contours are more highly contrasted (Voiron-Canicio, 1995) ; then the gradient for the mosaic image is established. The gradient image is segmented using the morphological transformation known as the watershed which gives all the crest lines or dividing lines existing on the gradient image (Voiron-Canicio, 1992). The result produces an image that is segmented into a large number of cells. The more localised differentiation there is, the more the image will be subdivided, although the differences are not all of the same magnitude. Indeed, you have to add the micro-contrasts associated with indentations in the contours of overlapping components to the contrasts due to transitional grey-tone values for the types of land cover. To put it more colourfully, the internal contrasts are like walls for which the height varies as a function of the gradient value (Fig. 2).

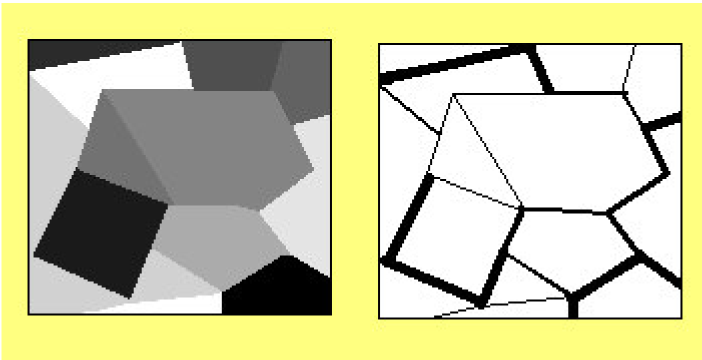

Fig. 2 : Grey-tone contrasts and the corresponding gradient values

The second stage removes the walls from the smallest to the highest. The morphological procedure involves establishing a hierarchical organisation for the mosaic image gradient and consists of eliminating the lowest level of contrast in the image, step by step. Through iterations, dividing lines corresponding to the the internal differentiations are gradually eliminated. (Voiron - Canicio, 1996).

Spatio-temporal analysis of internal differentiations can be done in one of three ways :

- The number of cells produced by internal contrasts can be compared to the number of components in the original image.

1975		1992	
Number of components	Number of differentiated cells	Number of components	Number of differentiated cells
518	586	508	534

In the land use image of central Liguria (Fig. 1), the number of cells is considerably higher than the number of image components, which indicates a great number of internal differences that are associated with a spatial configuration of land cover that includes overlapping land types. The decrease in number of components from 1975 to 1992 is a sign of spatial uniformization, a change that was accompanied by a sharper decrease in internal differentiation.

- The total perimeter for all differentiated cells can be calculated for each hierarchical level and each date. There was a considerable decrease in 1992, and which was much more noticeable in the first hierarchical level.

Hierarchical level	Total perimeter in 1975 (pixels)	Total perimeter in 1992 (pixels)
Level 1	40016	36821
Level 2	10682	9402
Level 3	7992	7280

- Measuring the fractality of land cover

The fractality of the spatial components can be calculated from the grey-tone images by using an overlap dimension (Voiron-Canicio, 1995). This three dimensional fractality measure is obtained by transforming the object under study into a unit with contours that become less and less irregular through successive and increasingly larger expansions and erosions, by means of the formula :

v [X ⊕ ëH) – v (X È ëH)

X = grey-tone image
X ⊕ ëH = dilation of X with an hexagonal structuring element of increasing size ë
X È ëH = erosion of X with an hexagonal structuring element of increasing size ë
v = the volume (sum of grey-tone values)

The following ratios show the evolution of heterogeneity for the types of land cover within the central Liguria :

v(1) 1992 / v(1) 1975 = 0.913
v(2) 1992 / v(2) 1975 = 0.925
v(3) 1992 / v(3) 1975 = 0.930
v(4) 1992 / v(4) 1975 = 0.934
v(5) 1992 / v(5) 1975 = 0.937

Spatial differentiation decreased considerably from 1975 to 1992, especially for the first levels v(1), v(2), that is, between the nearest pixels. The changing land cover produced a smoothing of internal differences.

3. Applications

3.1 A comparison of western Liguria and central Liguria

The land cover developed more or less the same in both regions. Artificial surfaces, including urban areas, gained ground. Forests also developed to the detriment of agroforestry areas and transitional woodland shrub (a class that includes unused agricultural land). Agricultural areas tended to increase, although in varying proportions as a function of region and distance from the coast.

There were indeed notable differences in the distribution of types of land cover between the areas that are close to the coast and those located more inland; for this reason, we split each of the two regions under study into two zones : a 5-km-wide zone along the coastline, and another one just inland, between five and ten kilometres away from the coast. Table 1 shows the percentage of the total for each main type of land cover in each zone, and the variation observed with respect to 1975.

	Central Liguria		Western Liguria	
	coastal zone		coastal zone	
Land use categories	1992 (%)	Variation	(1992 (%)	variation
Artificial areas (cat. 1 to 5)	17,4	+1,8	10,32	+0,86
Agricultural areas (cat. 6 to 8)	10,7	+0,4	43,02	+2,34
Agroforestry areas (cat. 9 to 11)	26,6	-3,3	33,20	-3,30
Forest areas (cat. 12)	45,2	+1,2	12,80	+0,2
	inland zone		inland zone	
Land use categories	1992 (%)	variation	1992 (%)	variation
Artificial areas (cat. 1 to 5)	2,17	+0,17	1,10	+0,2
Agricultural areas (cat. 6 to 8)	1,64	+0,10	27,15	-0,25
Agroforestry areas (cat. 9 to 11)	21,4	-3,70	32,56	-0,84
Forest areas (cat. 12)	74,7	+3,70	38,90	+0,90

Tab.1 : Distribution of land cover types in percentage

The greatest change occurred in the coastal zones of each region. In central Liguria, artificial surfaces increased along the coast of Genova (already highly urban), while in western Liguria, their spread was contained. Even more surprising, agricultural areas also increased, especially along the western Ligurian coastline. Forested areas increased slightly, as well. In the hinterland, the percentage of artificial surfaces slightly increased. The major development concerned the spread of forested areas, in particular in the Genova region.

The Mathematical morphology procedures, such as the gradient hierarchical organisation, and the three dimensional fractality measure, indicate noteworthy changes in the spatial arrangement of types of land cover. Internal contrasts tended to decrease as a whole, in detail, but there were observable differences between zones. For example, the smoothing of local contrasts is less pronounced along the coast of western Liguria than in the Genova region (Fig.3), and the perimeter of the highest contrasts increased from 1975 to 1992. Now, while the greatest differentiation in the central Liguria is concentrated along the coastal strip, in western Liguria, it spreads out all along the coast and penetrates inland through the valleys.
The spatial arrangement for types of land cover became more complex in western Liguria, but more simplified in central Liguria.

3.2 Comparison of the Côte d'Azur and western Liguria

The Côte d'Azur presents different land-cover characteristics than neighbouring western Liguria. In the French region, artificial surfaces cover roughly half of the coastal strip and 24% of the immediate hinterland, compared to 10% and 1% in Western Liguria. Inversely, agricultural land account for only 13% of the coastal strip, compared to 43% in the Italian coastal area.

However, despite the advanced stage of urbanisation along the Côte d'Azur, artificial surfaces increased considerably, from 48% of the total in 1975 to more than 53% in 1992. During the same period, artificial surfaces along the Italian coast increased from only 9.5% to 10.3%. Along the French part of the Riviera, artificial surfaces spread mostly at the expense of agricultural land, and to a lesser extent, of forested areas ; this is not at all the case in the Italian part, where agricultural land and forests increased, in particular in the coastal area. The same trends, although slighter, also occurred in the immediate hinterland.

This evolution shows up in the spatial organisation by a decrease in internal differentiation. Urbanisation tends to result in a coalescence of close patches that are already built up, and the gaps in between tend to disappear. The number of components decreases, but their surface increases, so the overlapping of the different land cover components becomes less complicated.The puzzle changes shape.

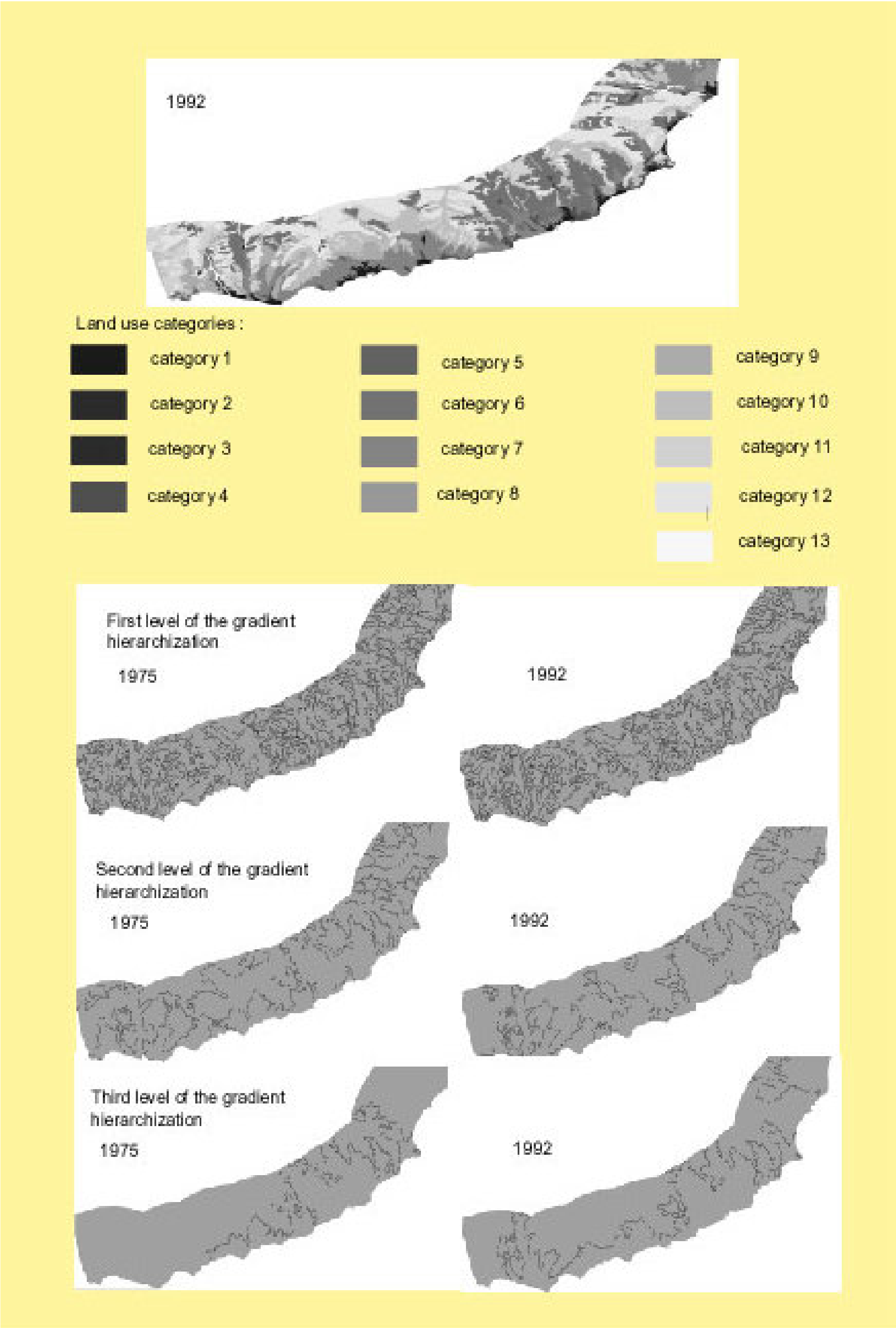

Fig.3 : LACOAST grey tone image of western Liguria and internal differentiations

Conclusion

Standard statistical methods made it possible to determine a broad outline for the evolution of land cover along this part of Mediterranean coastline, thereby revealing different characteristics for the French and Italian regions. The French region is distinguished by a steady advance of urbanisation at the expense of agriculture while, on the Italian side, artificial surfaces are growing moderately without encroaching upon agricultural land. The share of agricultural surfaces is even tending to increase, especially in western Liguria.

The way land use types are interlaced cannot be determined using such methods, because standard statistics are more concerned with the number than with the arrangement and shape of the geographical objects under study. Image analysis and mathematical morphology procedures revealed the internal differentiation resulting from the arrangement of the puzzle pieces, as well as its evolution over the given period of time. These methods show that the changes in land cover tend, on average, to smooth out the smallest irregularities of the puzzle's contour. However, while the least significant contrasts tend to become softened, the areas of high contrast between types of land cover, on the contrary, spread to cover more surface along the coastal strip.

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