

# The Contribution of Mathematical Morphology in Spatial Analysis of Aggregated Data: Home-Building Evolution in the French Riviera during the Twentieth Century

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## Abstract

The process of littoralization, characterised by the concentration of people and activities on the coast, is a strong trend in the Mediterranean regions. If the causes of these evolutions are well-known, few analyses emphasise the spatial aspects of these processes. Yet, behind the general trend, some territorial effects are spatially differentiated and the coastal overload fuels new evolutions on littoralization. As disaggregated data on urbanization are not always available to do a retrospective analysis, this paper proposes to show how an image analysis method, named Mathematical Morphology, can contribute to determining spatial differentiations with the use of aggregated data. This study concerns the French Riviera in the second half of the twentieth century, which is considered as a striking example of intensive littoralization. Through the analysis of home-building contrasts at a municipal level, Mathematical Morphology can detect spatial regionalization and its evolution.

*Keywords:* Mathematical Morphology, Aggregated data, Home-building, Urbanization

## 1 Introduction

Littoralization is a strong trend in the Mediterranean regions. This process has begun on northern Mediterranean coasts in the late nineteenth century with the disintegration of traditional rural society and its economy. The result is an over-concentration of coastal people and activities in opposition to the mainland area. Littoralization leads to an intense urbanization of coastal areas, where the shore is lined with a “concrete wall” made up of tourist facilities, holiday houses, and infrastructures which invade the maritime domain [3].

The littoralization issue is fundamentally linked with the relationships between the coast and the hinterland. On the one hand, the intensification of the coastal occupation results from the migration of populations from the inner lands to the seashore. On the other hand, the areas concerned by the intensification of human occupation tend to expand more and more, and inland territories become attractive again for some functions [13]. Indeed, a redeployment of settlement is observed from the coast towards the inner lands in some Mediterranean regions. In France, from 1990 to 2000, the highest level of coastal urbanization reached between five hundred and two thousand meters from the coast [6]. Many factors contribute to this suburbanization movement, such as facilitated mobility, the price of available lands in the outer suburbs or the choice of individual housing [8].

The development of the Mediterranean coastal regions is described in several studies [2, 8]. But fewer analyses emphasise the spatial aspects of these processes. Inland regions are not homogeneous anymore. The areas situated just behind the coast are becoming very attractive and are experiencing significant functional changes [14]. The

development of coast and hinterland relationships implies a territorial restructuring. The analysis of these new developments requires a broader recognition of the coast, including inland spaces. The spatial dimension of the littoralization processes deserves a greater attention, in order to understand local differentiations and dynamics.

This paper shows the contribution of an image analysis method, Mathematical Morphology (MM), to study the spatial aspects of littoralization processes on the French Riviera. Mainly relying on the Set Theory, MM can analyze both the spatial organization and the intensity of geographical phenomena. In addition, as spatially explicit data about urbanization are not always available to do a retrospective analysis, this paper shows why spatializing aggregated data sets is interesting, and how Mathematical Morphology, used as a spatial analysis method, is useful to analyze them.

After a brief statement about the difficulty of getting disaggregated data, we will present the interest of spatializing aggregated data. We will show the possibility of applying MM to these spatialized aggregated data. The purpose of MM application is to determine the evolution of main home-building regional structures, as a marker of coastal development.

## 2 Data for Spatial Analysis of Urban Dynamics

### 2.1 Limitations in Spatially Explicit Data Availability

Geographical analysis of urban sprawl can be based on several types of data: old pictures (aerial photography and satellite images), land use data and ancient maps. The interest of these data in mapping and analysing urban changes is well known. However, such data are not available or easily obtainable to carry on a retrospective survey of littoralization dynamics on the north-Mediterranean coasts. So, the identification of spatial organizations linked to these dynamics is restricted. Indeed, such an analysis requires old data at several time steps, with an exhaustive and homogeneous coverage of the study area.

Ancient maps are directly faced with this problem. Regarding aerial photography, the French National Geographic Institute (IGN) has conducted the first mission of systematic coverage of the French territory between 1939 and 1952. Regular missions have been held every five years since 1945 making it possible to go pretty far in the past. However, a single aerial photograph covers an area between 5 and 25 square kilometres. The French Riviera, including its hinterland, has two departments (Var and Alpes-Maritimes) with a total area of over 10,000 square kilometres. Thereby, the work of digitalization, georeferencing and assembly in a mosaic would be time consuming. Earth observation programs with satellite images encompass much larger areas (up to tens of thousands of square kilometres for the latest Landsat satellites) but they don't reach the mid-twentieth century. Actually, they appeared after aerial photography (the first Landsat satellite was launched in 1972 and the first Spot satellite in 1986). As a consequence, land-use data only cover the last decades.

These aerial and satellite pictures require some image analysis treatment in order to obtain the relevant information on urbanized sites. If the automatic method (spatial information extraction) is faster than the manual one (photo interpretation), both are very long to implement [1]. Moreover, extraction is less precise and requires manual editing. The poor quality of the older photographs may limit the use of an automatic method. Finally, with resolution improvement, changes may be overvalued for the latest periods. These limitations in data availability lead us to focus on the possibility to use aggregated data sets, often more available, and to spatialize them.

## 2.2 The Interest of Spatializing Available Aggregated Data

With the term "aggregated data", we mean non-spatially explicit data, such as values at an administrative level. These data may cover longer past periods, resulting for instance from censuses. They can also have the advantage of being spatially homogeneous and temporally consistent. As we are faced with the problem of disaggregated data availability, we think that these data could be useful, even for spatial analysis.

As the functioning of the territory is based on a residential economy [4], home-building is a relevant variable to analyze the littoralization processes on the French Riviera. The French national institute of statistics and economic studies (INSEE) provides data about the number of dwellings built before 2004, classified by construction completion periods (before

1949, 1949-1974, 1975-1981, 1982-1989, 1990-1998 and 1999-2003), at a municipal level. Our study area is composed of the two departments of the French Riviera: the Alpes-Maritimes and the Var. The analyses do not integrate the Principality of Monaco, where urbanization follows a very particular pattern.

The first step in the spatialization of these data is to map them. Instead of mapping the average annual number of constructed dwellings, we choose to map a relative value (the rate of change between two dates). It allows for a better perception of inland dynamics, where the values of new dwellings are low compared to the coast. The maps on Figure 1 depict, for each period, the average annual home-building growth rates in each municipality.

The first map (1949 - 1974) shows that the more dynamic area is situated between Toulon and Nice, all along the coast, with municipalities like Villeneuve-Loubet, Mandelieu-la-Napoule, Fréjus and Cavalaire-sur-Mer. During the next period (1975-1981), some groups of municipalities emerge near the shore on the back of Nice, Antibes, Cannes, Saint-Raphaël, Ramatuelle, Hyères. We observe a redeployment towards the inner lands, especially in the Western part of the French Riviera. The eastern part is characterized by high growth rates on the coast and in the Southern Alps municipalities (corresponding to the development of winter sport resorts, such as Isola 2000 created in 1971) and by an intermediary zone presenting lower growth rates.

This development towards inner lands carries on between 1982 and 1989, while major cities such as Nice, Cannes, Toulon and Saint-Raphaël experience a growth slowdown. This slowdown spreads to the entire study area from 1990 to 1999, but the inner Western part of the Var department, keeps the highest growth rates in the last period (1999 - 2003).

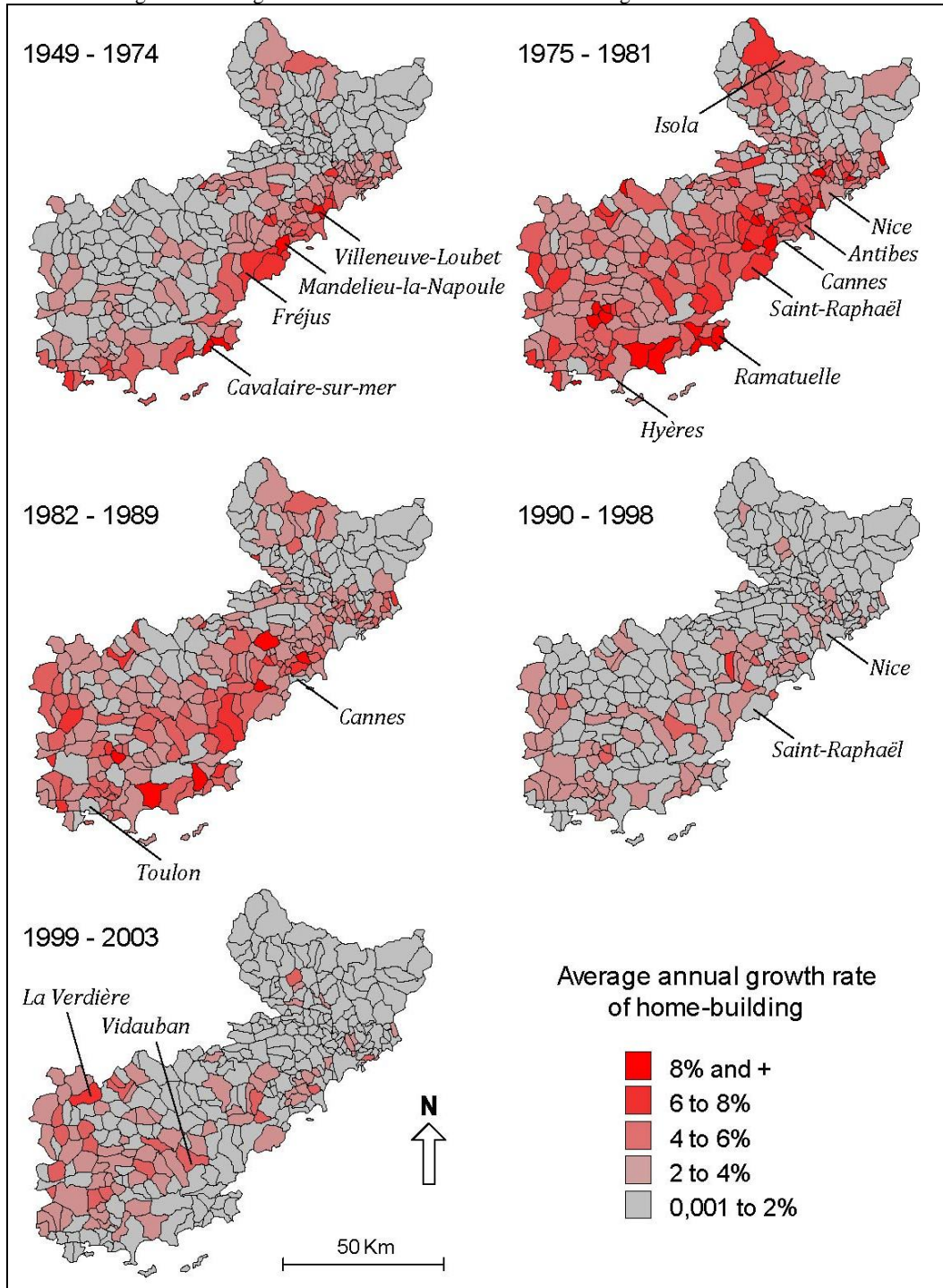
The map analysis shows where the strongest dynamics take place for the different periods. If the interest of mapping data sets is obvious, it is nonetheless difficult to see the evolutions in terms of spatial regionalization. The use of spatial analysis methods gives us the opportunity to improve the analysis of littoralization dynamics. In a second step, we use Mathematical Morphology to determine spatial regionalizations from aggregated data.

## 3 The Contribution of Mathematical Morphology in the Detection of Spatial Regionalizations from Aggregated Data

### 3.1 Method: Mathematical Morphology (MM)

The use of spatial analysis goes beyond mapping: it detects structures and patterns of space organization with rigorous and reproducible methods. It identifies some spatial arrangements that are not always obvious to the cartographer's eyes, but whose meaning can be highlighted by the researcher's knowledge. It leads us to apply Mathematical Morphology and to consider its use on non-spatially explicit data -even if these ones do not seem adapted to spatial analysis at first sight.

Figure 1: Average Annual Growth Rates of Home-Building on the French Riviera



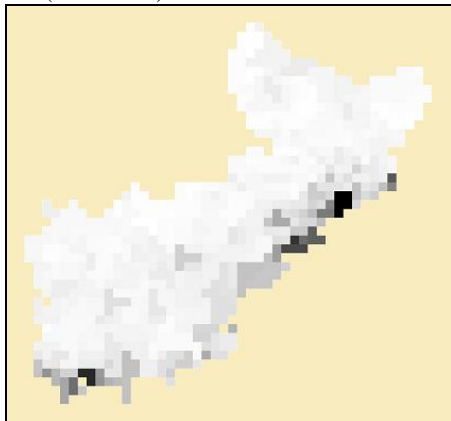
This method was created in the mid-1960's in France at the Ecole des Mines de Paris in Fontainebleau by G. Matheron [7] and J. Serra [9, 10] and keeps being developed. MM is both a theory and a toolbox. The objects of digitalized images are only a set of points on a grid. The purpose of MM is to organize the information contained in each pixel, designing their arrangement and providing quantitative and qualitative

descriptions of geometrical structures of images and three-dimensional objects. Unlike most of image processing methods which use linear mathematical operations, MM is essentially based on min-max operators. Distance plays a central role in morphological operations. Most of them are based on expanding and shrinking the set of pixels [5]. MM is relevant to describe spatial structures and to reveal

organization laws, so it is well adapted to spatial analysis and modelling [11]. It differs from other methods as the pixel value is here less important than its relationships with its neighbourhood. Therefore this method is suited to all spread issues.

By applying these methods on the data previously described, our aim is to analyze trends and spatial dimensions of littoralization through home-building values. The initial images correspond to the values of home-building for each municipality, translated into 256 grey levels. On a frame representing the study area, each pixel is described by a grey level value calculated from the home-building value of the municipality. If a municipality is composed by several pixels, the grey level value is evenly distributed on all pixels (by dividing the value with the number of pixels). Obviously, if spatially explicit data were available, we could attribute the exact value to each pixel and the analysis would be more accurate. Despite this smoothing effect, we try to identify emerging regionalizations. Each period is represented by a greyscale image (Figure 2). We deal with BMP image format with a hexagonal grid resolution of 48 x 46 pixels. A pixel stands for around 3 kilometres.

Figure 2: Greyscale Image of Home-Building on the French Riviera (1975-1981)



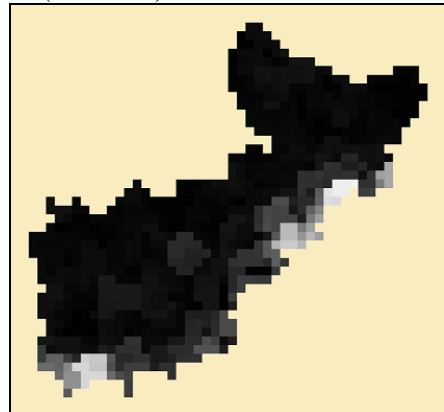
### 3.2 The Use of the Morphological Gradient in Order to Detect Spatial Differentiations of Home-Building Values

This analysis consists of detecting the hierarchy of intra-regional contrasts and their changes through a mathematical morphology processing. Two processes are realized in order to detect internal differentiation.

First, we convert the original image into a *mosaic image*, where component contours are more highly contrasted [11], and then we calculate the gradient of the mosaic image. The morphological gradient analysis measures the grey-level variation between a single pixel and the six surrounding pixels in the hexagonal grid. The morphological gradient of a numerical image called *gradient de Beucher* is the subtraction between the Sup of a function  $f$  and the Inf of this function. The Sup function is the maximum value of the function  $f$  in a circle of a given radius centered in a pixel, the Inf function is

the minimum of  $f$ . On the gradient images, the contrasts are depicted by grey levels which become lighter as the gradient increases (Figure 3). Gradient values are comprised between 0 and 255. The greater the contrast between the adjacent pixels is, the higher the gradient value will be.

Figure 3: Gradient Image of Home-Building on the French Riviera (1975-1981)



Then, the gradient image is segmented using a morphological transformation called *watershed* which provides all the crest lines or dividing lines existing on the gradient image [11]. The crest lines delimit the watersheds which constitute relatively homogeneous subsets. The height of the dividing lines depends on the gradient values. These lines may be compared to walls of different heights.

The second process consists in removing these walls from the smallest to the highest. This morphological process makes it possible to organize the mosaic image gradient into a hierarchy. Then, the dividing lines corresponding to the internal differentiations are gradually eliminated [12]. This method enables to find the main regional structures in terms of contrasts. Figure 4 represents successive hierarchy levels at the different periods. The analysis will focus on the final result for each period.

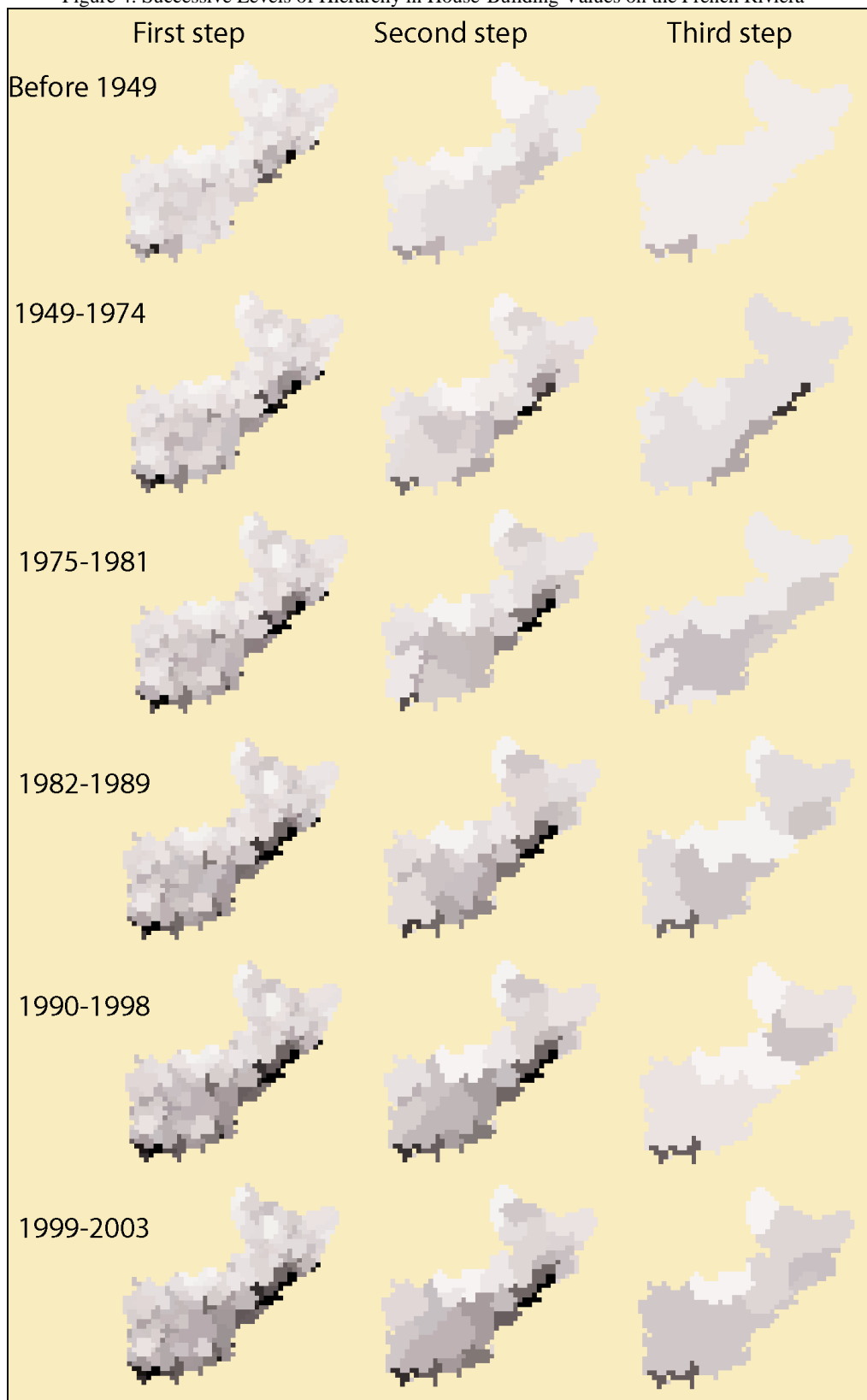
The result of the hierarchical organisation for pre-1949 home-building shows few inner differentiations. The main structure distinguishes Toulon's maritime industrial land from the rest of the region.

The 1960's mass tourism rise provoked the individuation of a narrow strip clearly lying from Nice to Bormes-les-Mimosas. We can notice that Toulon's region does not belong to this tourism-linked coastal strip.

During the 1975-1981 period, coastal and inland contrasts increase. The touristic coastal strip significantly widens towards the inner lands, especially in the Var. Inner structures evolve during the two following periods, and if the main contrasts were previously parallel to the coast, they shift progressively to a perpendicular organization. We observe now four areas, but Toulon's region is still distinct.

During the last period (1999-2003), contrasts are organized around the two urban regions of Nice and Toulon, and sprawl towards the inner lands. The Fréjus-Le Muy-Dranguignan zone separates these two areas.

Figure 4: Successive Levels of Hierarchy in House-Building Values on the French Riviera



This analysis enhances the characterization of the steps of littoralization: first the individuation of some parts of the coast, then the formation of a continuous coastal strip and its progressive spread towards the inner lands. More complex differentiation processes appear then with the individuation of sub-regional systems connecting different parts of the coast with their hinterlands, and finally a homogenization of hinterlands.

#### 4 Concluding Remarks

Defining the scopes and the boundaries of distinct regions is certainly one of the toughest challenges of geography. Mathematical Morphology (MM) algorithms enable us to take spatial units' contiguity into account. *Watershed* line, *mosaic image* and its derivatives are some of the most powerful algorithms of MM: they can automatically locate spatial structures, based on different criteria. In a diachronic analysis, they help to see spatial reshaping.

Littoralization analysis is done with home-building values on the French Riviera during the twentieth century, with MM methods. Structures and evolutions are revealed with accuracy and robustness, whereas they are not obvious with a simple map reading. The results show that changes do not only depend any longer on the distance from the sea. Of course, geographers still have to link these changes to the relevant processes and to interpret them.

Working on aggregated data and greyscale images involves nevertheless paying attention to two potential data biases. First, if the studied phenomenon is not homogeneously distributed in space, the researcher can be led astray by the differences in the municipalities' size. Indeed, the aggregated values are divided by the number of pixels included in each municipality, which can lead to a kind of smoothing. However, sharper data is not always available and the results show the interest of spatializing and analyzing aggregated data. The information is not only in the values within the pixels but also in their spatial arrangement, which influences diffusion processes and differentiation phenomena. Crossing different data sources could be a solution in order to spatialize more precisely non-spatially explicit data.

Secondly, it is possible to wonder about the reliability of the borderline areas' results. If exterior neighbouring zones had been taken into account, the regionalization could have changed in these particular areas. This problem is not specific to MM. In our particular study, we can postulate that the results are reliable because the spatial borders of the study area match shoreline or crest lines, and some of them became the France/Italy boundary. In the Western part, it would be useful to include neighbouring municipalities of the Var department, in order to check the sensitivity of the results.

The interest of this knowledge lies in a geographic forecasting of littoralization processes, not only on the French Riviera, but also on other North-Mediterranean coasts, presenting less advanced stages of coastal development.

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