The Modifiable Areas Unit Problem

Claude Grasland, Malika Madelin, Hélène Mathian, Lena Sanders, Nicolas Lambert, Maher Ben Rebah, Martin Charlton, Jianquan Cheng, Stewart Fotheringham, Einar Holm, et al.

EUROPEAN SPATIAL PLANNING OBSERVATION NETWORK

ESPON 3.4.3

THE MODIFIABLE AREAS UNIT PROBLEM

Final Report

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List of contributors

UMR Géographie-cités (FR)
Maher Ben Rebah
Claude Grasland*
Hélène Mathian
Léna Sanders

UMS RIATE (FR)
Nicolas Lambert
Malika Madelin*

NCGIA (IE)
Martin Charlton
Jianquan Cheng
Stewart Fotheringham

University of UMEA (SE)
Einar Holm
Kirsten Holme
Magnus Stromberg

IGEAT (BE)
Moritz Lennert
Pablo Medina Lockard
Christian Vandermotten

IMAG (FR)
Jean-Marc Vincent

CESA (FR)
Philippe Mathis
Kemal Serrhini

BBR (DE)
Wolf-Dieter Rase

*** Scientific coordinators**

Table of contents

Figures

Tables

Frames

Scientific summary

Introduction

This project, as its title suggests, focuses on the sensitivity of the results of cartographic representations and spatial analyses to the spatial zoning which is used in a study. This could introduce a bias when one analyses the spatial variations of social phenomena, which may have consequences as well from a scientific point of view (when the aim is to understand the underlying mechanisms), as from a planning one. The purpose of the project is then strongly methodological, but the associated issues are considerable from a scientific and a political point of view.

We have proceeded through two main steps: the first one consists in being clear with what "the modifiable area unit problem" (MAUP) really is and what kind of consequences it can lead to, when emphasising the spatial dimension of a social phenomena. The second one consists in presenting and discussing different ways of taking into account and solving the eventual misleading consequences that such a phenomenon may produce.

We have combined two approaches: -1 doing **a state of the art** in order to list quite exhaustively all problems and solutions elaborated by researcher in the field; 2- using **case studies** emanating from the different partners to support the reflexion on some specific ideas and hypothesis. This approach seemed fruitful as the MAUP has given rise to a large literature, as well classical as the question arised early among geographers and statisticians, as very contemporary as the development of GIS, the multiplication of databases combined with the reinforcement of confidentiality constraints, have given rise to a renewed interest.

1. What lay behind the MAUP?

The MAUP states that the results of cartography, statistical analysis, and any spatial modelling are dependent on the definition of the studied units. It means that a change of zoning will lead to a change in the results, as well visual as statistical. In fact the spatial level which is chosen for describing a phenomenon plays the role of a filter. That choice is then comparable to that of the settings that are necessary for any instrument of measure in an experiment in physics. In that spirit, it bears simultaneously constraints and possibilities.

Following points have been in focus:

- the differences and complementarities between statistical and spatial distributions of a phenomenon (often confused) are underlined and illustrated; this is essential in order to make the distinction between social cohesion (reduction of inequalities between individuals or households) and territorial cohesion (reduction of inequalities between territories).

- the spatial organisation as well as the evolution of a phenomenon appear different with different zonings and the different ways to deal with that are gone through. At one extreme one tries to find out an optimal partition of space, either by finding the best geographical objects adapted to the nature and variability of the studied phenomenon, either by searching an optimum with statistical methods. At the other extreme one focuses explicitly on the shown differences and consider them as revealing knowledge on the spatial structure of the phenomenon under study. The Swedish case study was used to show how interesting it is to have a multiscale representation, and how maps complement each other, from level to level.

- the relations between phenomena appear different depending on the scale of observation and also on the spatial extent of the studied region. It implies that the generalization of a result to other scales or to other spatial zonings most often doesn't make sense. But, it means also that, when contradictory results appear, the study of the mechanisms underlying these differences between the results will give a better understanding of spatial differentiation.

- the effect of MAUP when dealing with spatial discontinuity is analysed. In some cases an administrative boundary acts as a functional limit, it is the case for what is related to policy action for example (planning, social policy, etc). But when administrative units are used as the basic spatial entities for representing socio-demographic phenomena, an apparent discontinuity could be artificial. Investigation can be successfully be explored by using and comparing studies at different levels. Another feature is that of the border corresponding to a discontinuity in the spatial units system of delimitation. One case study explores systematically the effect of a boundary on the relation between phenomena with a multivariate statistical analysis on socio-economic variables for Ireland and Northern Ireland. From a theoretical point of view, the question is to what extent do the observed differences in statistical analyses on either side of a national border result from incompatible spatial units or from the fact that the socio-economic processes which are operating on each side of the border are different. The results highlight the effects of the MAUP and the need for a consistently defined set of spatial units for statistical analysis throughout Europe.

2. Some scientific conclusions coming from empirical tests using different methods

We could summarize principal causes of MAUP in a socio-economical perspective by the fact that:

- Population are not uniformly distributed over space. Thus there is a compromise to do between population weight (statistical distribution) and area weight (cartographical representation).

- Territorial delimitations *as any discretisation*, play as a filter on spatial organisation of statistical distributions that are at first continuous over space.

- The processes lying behind a given spatial organisation are eminently complex and most of them involve different spatial scales.

The main scientific conclusion of the report is that there exists no mechanical solution to the MAUP but lots of new considerations and methodology going from the observations to the representation through analyses that may guarantee a robustness of the different representations.

In this perspective, the second and third parts of the report propose an overview and discussions of methodologies that may response to these different difficulties that any statistical study on geographical units is confronted to. The idea is to give tracks of reflexion at each step of the process of producing knowledge from territorial analysis – data elaboration ; - data treatment ; - cartographic representation. The three steps are detailed hereafter:

1) The good identification of the different levels of observation, analysis and cartography:

The fact is that the more the level of observation is disaggregated, the easiest it is to test and construct the zoning that is the best adapted to the phenomenon for analyse and cartographical representations. That is not necessarily the lowest one which often creates great spatial heterogeneity. This depends both on the phenomena and its spatial distribution. Thus it is possible to construct entities that are semantically homogeneous either from the population point of view, or the area, or the functioning… This point is particularly discussed in the case study developed on Sweden, comparing spatial patterns obtained with same indicators represented on grid maps (homogeneity of area) and comparable territorial zoning (homogeneity of population).

To work on a grid is a good alternative. But, as shown by the Swedish case study the information given by analysis at a grid level or at an administrative entity level are complementary. One choice is not globally better than another one.

The specific case of the individual level is also examined : the access to individual data is the ideal situation, but not because the individual level is in all cases the most appropriate one to observe or model a phenomenon. It is mainly because it gives the choice to observe information at all possible levels and for all forms of spatial partitions. That way it authorises multilevel exploration, in the way it is showed for the Swedish case study.

2) The use of new statistical methods integrating spatial dimensions: in order to progress in the validation of the statistical treatments made on modifiable area units, new statistical methods are proposed that (1) integrate the local dimension and (2) allow the heterogeneity of a measure of relation among space.

An example is given of such methodology with the Geographically Weighted Regression (GWR) illustrated first on a transboarder region between Northern Ireland and the Republic of Ireland, and then applied on Europe.

3) The use of new methods of transformational cartography:

Two families of new cartographical methods are explored:

o Cartograms that allow a transformation of space taking into account the target variable, that is most of the time population while keeping territorial approach, that is territorial delimitation. This is illustrated by a case study on Germany where such representations are discussed

o Smoothing maps that allow to take into account the multiscalar dimension of the space and to integrate spatial functioning. A smoothing method is particularly recommended: the neighbourhood potential method. This method allows integrating different functions of space adapted to the phenomena, and is "quite" zoning independent if the range of smooth is coherent with the range of spatial units. That is not the case with classical geometrical or statistical interpolation. This is illustrated by examples on Europe.

New potentialities of the interactive cartography are presented in a last part of the report.

But whenever it is not possible either to reconstruct better zonings or to use some new transformational cartography, it is whatever recommended to use cartographical representations combining as well indicators of size and of intensity or structure.

Conclusion

The aim of this report has been to explore systematically two directions in front of a MAUP: - discuss in what sense such different results depending on the used zoning is a problem to be solved; but also - discuss in what sense it could produce knowledge about the studied phenomena.

The conclusion from a scientific point of view is a recommendation to be very aware of : - the multiple hypothesis that lay under each zoning system; - the weakness of using a SINGLE cartography.

The recommendation is thus to learn from the modifiable areal units using methods of analyse and representation integrating the multiscalar dimension. The idea is then to see the MAUP as a tool to explore the multi-scalar structure of a phenomenon.

The report underlines the new potentialities of the interactive cartography to explore the multiple dimensions of space.

Executive Summary

For planning purpose as well as for research topic, it is necessary to get an insight in the spatial variations of social and natural phenomena. It means to be able to have a representation of spatial inequalities, to identify specific zones, to identify discontinuities in space, and to understand the underlying principle of the spatial organization of a phenomenon as well as its correlation or independence relatively to other phenomena. Classical tools such as cartography, statistical analysis, and spatial modelling are used for that purpose. The fact is that the results of these analyses are dependent on the definition of the studied units. This problem is nowadays well known and referred to as the Modifiable Areal Unit Problem or MAUP and is the subject of this ESPON research.

This is not a classical ESPON Project but a Scientific Support Project which means that very precise outputs are expected in order to improve past and future production of research developed in the ESPON Program (especially considering the future ESPON II). The MAUP problem has not been ignored in previous work of ESPON. This question has been identified in several projects working in the field of Spatial Analysis and Cartography. For example, in the framework of the SPESP, where C. Grasland had proposed a working paper called "Objective 13 bis" which suggests that the allocation of funds to regions could be strongly modified by the choice of various territorial breakdowns. The MAUP question is scientific AND political and both aspects should be jointly considered.

What is the MAUP?

The Modifiable Areal Unit Problem or MAUP design the sensitivity of the results to the definition of the spatial units that are studied. It is known over its two manifestations: the ***scale*** or level at which the spatial entities are observed; the kind of spatial ***aggregation*** which has been adopted.

In other words, the results vary according to the spatial zoning which is used in the study. For example, it can then happen that one analysis shows that wealth is negatively correlated with population density when another one will show the opposite. It can also happen that the mapping of a same indicator reveals a polycentric pattern with one spatial zoning, and a monocentric with another one. Such contradictory results could, quite naturally, be very disturbing for the decision maker.

Statistical distribution and spatial organisation

There is often confusion between the descriptions of *statistical* and *spatial* distribution of a phenomenon. This is often due to the definition of the elementary units, and of the level of analysis. Notice that this scale problem is crucial from political point of view as it is the basis of the distinction between social cohesion (reduction of inequalities between individuals or households) and territorial cohesion (reduction of inequalities between territories).

To illustrate our purpose, Figure 1 shows the multiple possible correspondences, between profiles of statistical distributions of a same phenomenon at two different levels. These correspondences are also multiple between statistical distribution and spatial organisation of a phenomenon at a given scale: it is thus very important to precise the level of observation when studying localised information.

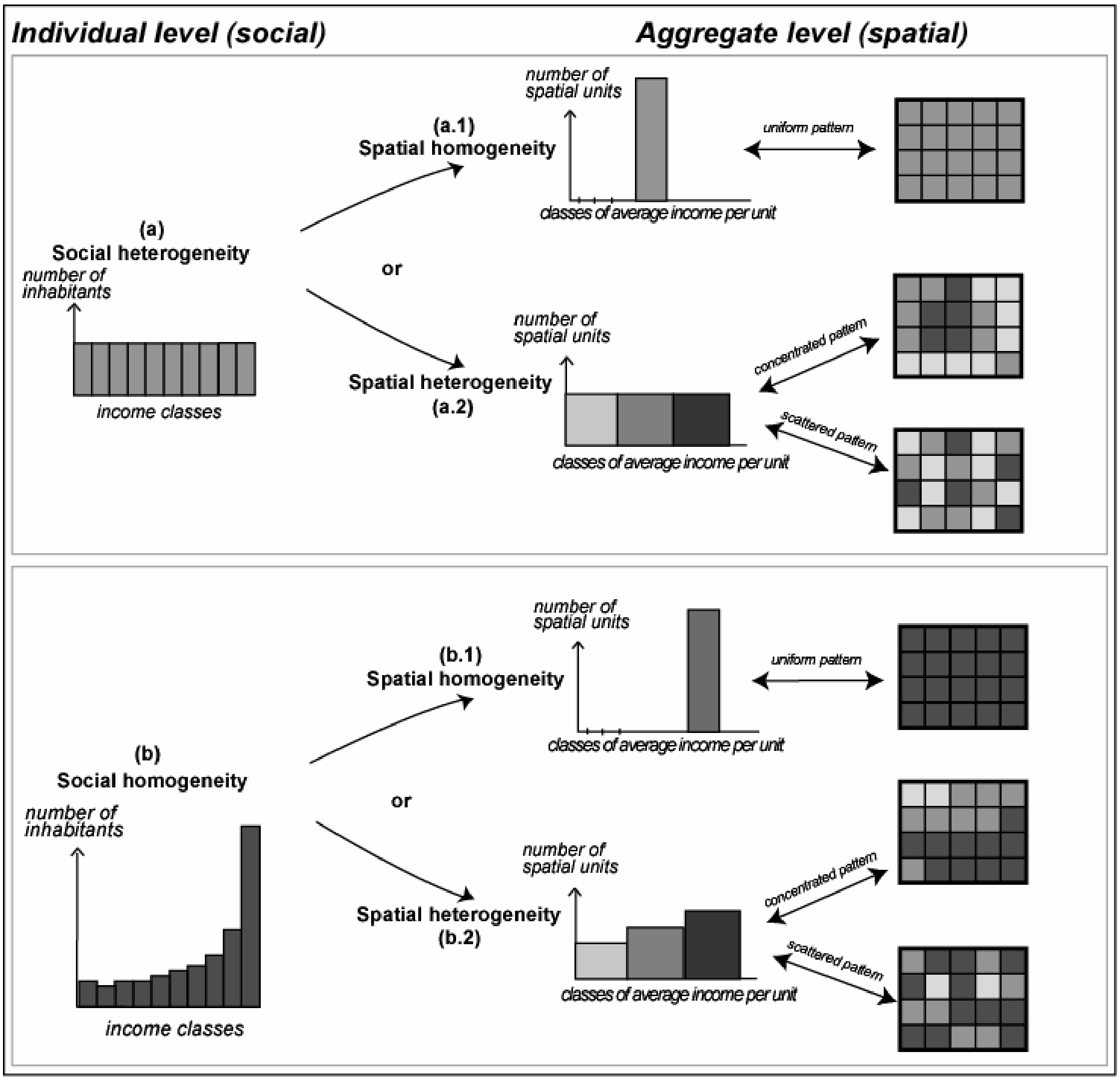

Figure 1 Statistical distribution, spatial organisation

What is of interest for the question of the MAUP is also that to one statistical distribution can correspond to different spatial patterns depending on the underlying spatial processes of localisation. For example, the social heterogeneity that is observed at the individual level may be associated either to spatial homogeneity (case a.1) or to spatial heterogeneity (case a.2).

More generally than aggregation from individuals to spatial entities (like this example), all types of spatial aggregation operate a transformation that one should be aware about. Let's illustrate how MAUP is involved in cartography and statistical analyses.

With different zoning, spatial variations don't look the same

The perception of the global organisation is fully dependent on the zoning and the scale. For example, in the Swedish case study (presented in the report), a systematic multiscale series of analysis have been made as well on administrative zoning as on regular square grids. Figure 2 presents an empirical example mixing the "zoning effect" and the "scale effect": with four *resolution*s, two types of zoning (administrative ones and regular grids). It shows obviously how scales smooth the phenomena. It shows also how interesting it is to have this multiscale representation, and how maps complement nicely each other, from level to level.

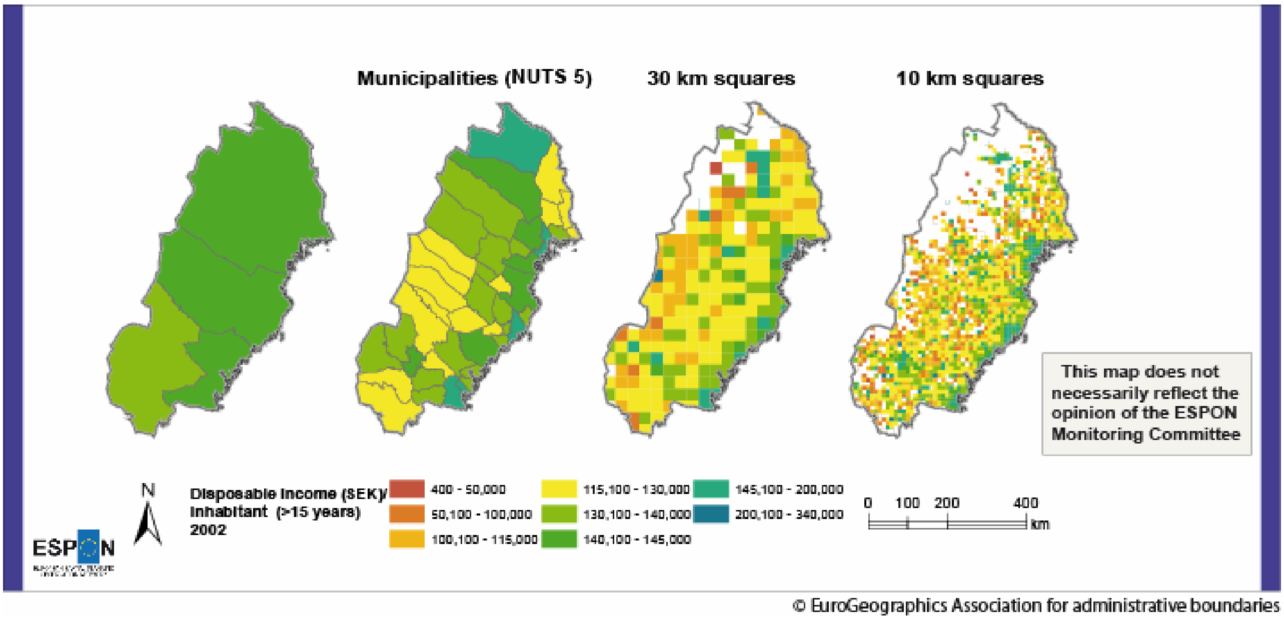

Figure 2 Influence of the zoning on the perception of the phenomena (empirical example)

Moreover a related question is that of the *position* of spatial discontinuities or barriers in the distribution of phenomena. In some cases an administrative boundary acts as a functional limit, it is the case for what is related to policy action for example (planning, social policy, taxations etc). But when administrative units are used as the basic spatial entities for representing socio-demographic phenomena, an apparent discontinuity could be artificial.

The relations between phenomena seem different depending on the scale of observation and with the spatial extent of the study region

Beside the cartographical point of view, the MAUP is also involved in statistical analyses, i.e. relationships analyses. Indeed, these analyses show the intensity, significance and sign of the relationships between variables. Such analyses help to explore the links between different phenomena and in the case where the statistical units are spatial entities, the links between different spatial patterns. But, the user should be aware that the value of a result (a coefficient of correlation for example) could vary according to the spatial units at the level of which the variables have been observed. It implies that the generalization of a result to other scales or to other spatial zonings most often doesn't make sense. But, it means also that, when contradictory results appear, the study of the mechanisms underlying these differences between the results will give a better understanding of spatial differentiation.

In what sense is the MAUP a problem?

We have just seen that cartographic representation and statistical analyses of phenomena are giving different results according to the elementary spatial entities chosen for the study. But is it a problem? The denomination MAUP suggests it, and in some situations it obviously is. But it is not systematically the case.

- why it is a false problem?

The differences in the results of statistical analyses according to the scale are, in that sense, creating knowledge about the observed phenomena. The identification of the scales at which segregation for example does or does not exist, learns a lot about the organization of the concerned society.

- why it is a real problem?

The most important problem is about international and historical comparisons: do the elementary spatial units which are used for the analysis have the same meaning in two different countries? At two different time periods? It is not easy to determine if a difference in the results is due to a difference in the processes which are underlying the observed phenomena, or simply to a difference in the meaning of the spatial entities that are used for the observation.

As a conclusion, we want to underline that, even if MAUP is an old issue, even if there doesn't exist a miraculous solution permitting to infer a result obtained for a given spatial zoning to another one, the MAUP issue is still a promising domain of consideration, with a high potential of knowledge creation. On the other hand, when it is well integrated in the methodological and conceptual framework of an application, it appears that the "P" of MAUP, rather than referring to a problem, would be better associated to "potential", "possibility" and "progress".

ESPON and the MAUP

The question of the potential influence of changing territorial divisions on applied research in the field of spatial planning has been regularly discussed in the framework of the ESPON program and even before.

Examples of the MAUP in ESPON

In the report, we illustrated the MAUP question through the analysis of selected examples of analysis of ESPON indicators. They have revealed that in many cases, different conclusion could have be obtained by ESPON TPG is they have used different territorial division than the actual NUTS 2 and NUTS 3 units. We used the most classical or emblematic variables (GDP/inh. PPS, Unemployment rate, ...) to provide examples which was organised in an order of growing complexity, from simple univariate analysis to spatial analysis tools. In this Executive Summary, we selected two examples which present how ESPON is concerned by the MAUP from both statistical and cartographical point of view.

- Influence of NUTS division on cartographic perception of results

Cartography is a major tool for political decision in the ESPON program. But the choice of territorial divisions and statistical divisions has an important influence on the perception of results. As an example we propose to compare three maps presenting the distribution of regions with low level of GDP/inh. PPS in 1999 at NUTS 1, NUTS 2 and NUTS 3 levels and with three different statistical thresholds for the identification of low level (index 90, 75 and 50 with 100 equal to the mean of UE25).

The example of Germany (Figure 3) is certainly one of the most spectacular examples of modification of the perception. At NUTS 1 (not showed here), all Länder from eastern Germany except Berlin have relative low values and all other Länder from western part have relative high values producing the vision of a complete West-East opposition. This feeling of opposition begins to change at NUTS 2 with the apparition of local differentiations in western part as well as in eastern part. At NUTS 3 level, a completely different picture appears with a mosaic of colors indicated by very different levels both in eastern part (where some urban Kreis are above EU mean) and western part (where many rural Kreis are in blue). The comparison of the maps reveals therefore very different patterns of regions with low level of GDP/inh.

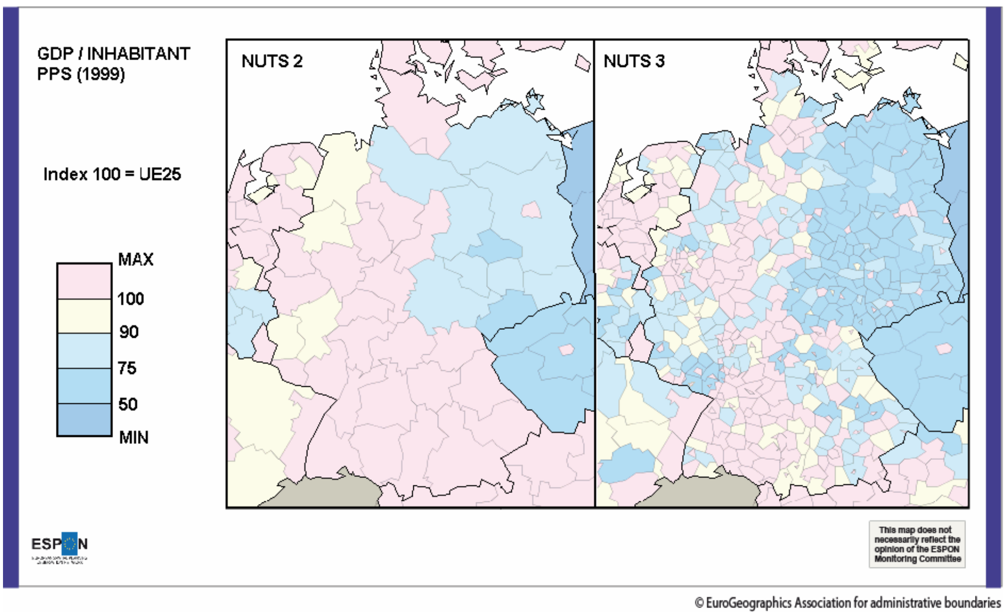

Figure 3 Changing cartographic perception of areas with low GDP / inh. pps (1999)

in GermanyCartographic changes in visual pattern are not always as dramatic as in this case, but it is perfectly clear that policymakers which try to analyse spatial patterns of regional development will receive completely different information according to the level of spatial aggregation.

- Influence of NUTS division on relationship results and GWR

We tried to account for the population variation by other criteria and to see the stability of this relationship. For example, at NUTS 0 level, the GDPpps/Inh. variable explains mainly the change in the population variation: the higher the GDPpps/Inh. of a given country, the higher the increase of its population between 1995 and 2000. On the other hand, this high relationship is not observed at the other levels. This result shows that the relationships we can extract from a dataset depend both on the scale and the space on which the analyses are performed.

Nevertherless, in these global analyses performed on the whole ESPON space, we invoke a strong hypothesis: we assume a spatial stationarity of the relationship which means that we neglect the local variations in the relation between Y and X. One method to go beyond the spatial stationarity hypothesis is to use the geographically weighted regression (GWR) to appraise local variation in the parameter estimates of the independent variables (Fotheringham *et al.*, 1999). One can appreciate the spatial variations in the models by mapping the different local regression parameters over the considered space. For example, Figure 4 illustrates the local regression model between the evolution of the population and the GDP/Inh.

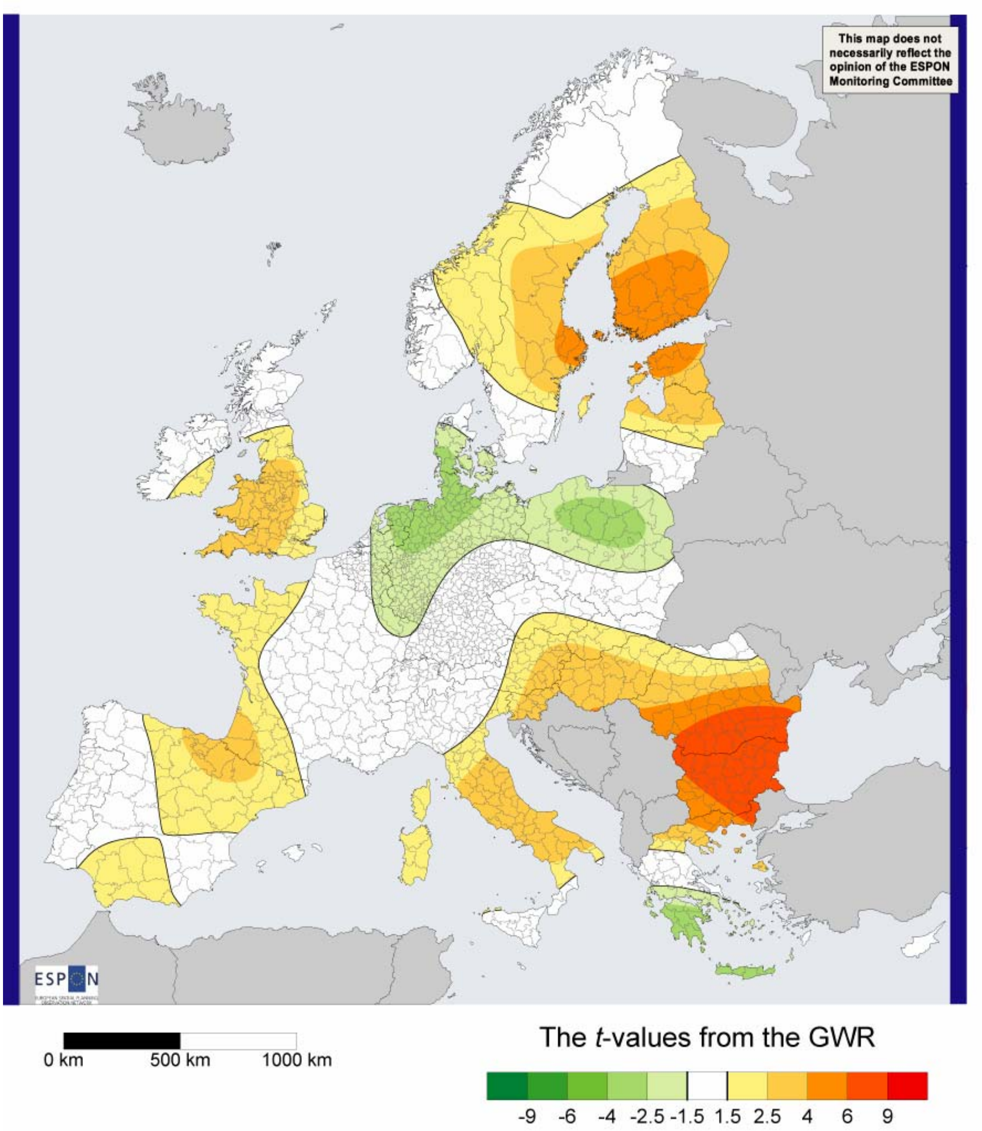

Figure 4 Local regression model between the evolution of population (1995-2000) and the GDP/Inh. (2000)

Survey on maps perception and analysis of maps vision

Maps has been recognised since the beginning of ESPON as a major concern and strong effort has always been made in order to improve their quality and harmonisation by ESPON Coordination Unit and by TPG in charge of integration of results (ESPON 3.1 and ESPON 3.2). The different guidance papers produced by ESPON has defined very precise rules for realisation of maps according to specific templates. Moreover, the external diffusion of ESPON and its promotion has been always strongly related to the promotion of maps (like the one published in the 3rd Cohesion Report).

This focus on cartographic results is probably normal, as ESPON is an applied research program on *spatial* planning and *territorial* cohesion. But we can ask if this focus has not been sometimes exaggerated as major results has also been produced in forms of statistical tables, graphics, definition and of course texts about concepts and policy recommendations. We do believe that some discussion should be engaged by ESPON community on this point as we have sometime the feeling that the promotion and diffusion of reports is more correlated with the importance of cartographic production than with the real quality of outputs.

Whatever the future of this debate, we decided in the framework of project MAUP to proceed to a in depth investigation on the practice of maps by ESPON community. With the support of ESPON Coordination units, we decided firstly to launch a survey on the practice of maps which was realised during the Salzburg meeting in Spring 2006. And we tried also to complete this survey by some experiments on the perception of maps by observers using a sophisticated method of measure of path followed by the eye of observer. The questions that we asked ourselves with this double analysis are:

- *What is the practice of maps by ESPON members?*

The fact that both scientists and policy makers are using very frequently maps does not mean that they have the same practice and the same expectations. Scientists are producing frequently directly the maps that they need in a research perspective. Policy makers are less able to control the production of the maps they need for their activity of decision and research. A coordination procedure is therefore necessary in ESPON in order to insure that the maps produced by scientists in a research perspective can be also useful for policy makers in an operational perspective…

- *Which maps are preferred? why? and overall how many maps can be used for the description of the same phenomena?*

What appears very clearly with the results of the survey is the fact that ESPON community do no more believe that it is possible to define a "best map" for the representation of a phenomena. It is something relatively new if one compares the actual situation with the period of the SPESP (1998) where the representative of the Commission had clearly declared that interactive mapping with multiple choices was excluded because it was a bad solution from political point of view. The development of new cartographic tools making possible the easy and quick realisation of various maps of the same phenomena is one possible explanation of this evolution of mentalities. But the technical aspect is not the major fact and we can rather observe a conceptual evolution of ESPON which has fully integrated a multi-level approach, both at scientific and at political levels.

- *What is really perceived by the eye of observer looking at maps?*

What is at stake is to evaluate if the message delivered by maps is really perceived in a correct way by the reader and, more generally, if different people looking at the same maps are really depicting the same message, the same information. The resource of the project ESPON 3.4.3 was clearly not sufficient to launch an in depth analysis on this subject, but we have decided to introduce at less some hints on what could be such an in depth evaluation of the perception of maps based on an objective methodology elaborated by K. Serrhini (University of Compiègne) and P. Mathis (CESA). The basic idea of this approach is to examine the path follow by the eye of the observer when he discover and explore a new map. The eye of the observer is indeed attracted by some specific elements of the maps like the legend, the title, the sources and is more generally attracted by certain spatial configurations which are recognised as more interesting than others (maximum values, minimum values, discontinuities…). The comparison of the path followed by different people give us the opportunity to discover regularities or specificities in the ways that people are following when they look at maps. For example, the initiated volunteers of this experiment seem to have acquired characteristic visual strategies compared to the non initiated ones (i.e. with a systematic reading of the title and the caption).

Progress for ESPON II with revised ESPON maps

With the final part of the report, we develop a set of proposals which do not intend to solve the question of MAUP (as explained before, it is a false problem) but to suggest progress for ESPON II. We limit here our analysis to the question of cartography. We often used the same variable, the GDP/inh. (2000), in order to make easier the comparison between different solutions or alternative methods.

Proposal for a new European statistical division

As mentioned before, considering the heterogeneity of the units size and population, it is hard to use such a division as a basis for structural analyses. The simple mixture of NUTS 2 and NUTS 3 units is not sufficient to solve the question of optimal territorial divisions for ESPON II. In particular, this mixed solution is far from solving the basic question of a good assessment of the situation prevailing in metropolitan regions and functional urban areas of the largest cities (FUAs), in which, as the case may be, metropolitan realities are either arbitrarily divided out among centre and periphery inside common FUAs, or inversely, dissolved in too huge entities.

Our first proposal in this research is the elaboration of a new hierarchy of NUTS division elaborated by C. Vandermotten and P. Medina from IGEAT. We propose therefore more accurate methods of aggregation based either on equal population or functional areas. At the same time, we use pragmatic rules in order to propose a really operational solution: using only a process of NUTS 3 units aggregation; keeping national divisions as superior framework.

The present proposals aim at providing a more adequate framework for a regional description of Europe, in particular better highlighting metropolitan realities which actually structure a European space integrated and inserted into the globalised economy. However, we insist we do not intend here to do away with the provision of basic statistical data at the most disaggregated possible level – NUTS 3 at least–, still less in some countries where the NUTS 3 level appears insufficiently fine as in some regions of France (for instance the NUTS 4 sub-prefectures or the labour pools corresponding to the Dutch NUTS 3, the COROP). Lastly, the proposed creation of such statistical units does not aim to take the place of administrative areas which have their own legitimacy and in which States apply structural policies.

We developed also a set of proposals of alternative methods of cartography based on cartograms, gridding and smoothing methods which are relatively easy to apply and which present specific advantages for some fields of investigation.

Exploration of smoothing methods

The aim of a continuous representation of socio-economical data on a geographical space is to provide a set of abstraction of the studied phenomena. One could define maxima and minima, attraction or repulsion basins, etc. which explain global tendencies of the phenomena and produces information at a higher level than the level at which data were collected.

However, the choice of the smoothing method is not a technical detail but a crucial choice which can not be based on trivial consideration of availability or subjective feeling. This question is discuted in the report. Taking into account the particular nature of data available (generally areal data, based on NUTS2 and NUTS3 divisions with a certain level of uncertainty)[1], the methods of interpolation related to point measurement, which are the most classical and integrated in GIS (triangulation, nearest neighbour, kriging…), are not relevant and should not be used for the realisation of smoothed maps in ESPON. Indeed, with classical interpolation methods, the results remains dependant from initial NUTS divisions and are simply a more or less fuzzy version of what can be observed in classical choroplethes maps. They are therefore dangerous as they give a false impression of solving the problem when they are only introducing confusion and should be avoided in the ESPON program.

Thus we used the neighbourhood potential method, for which the spatial pattern is independent from the initial scale of aggregation of information. It was elaborated by C. Grasland (*1991*) and further developed by the Hypercarte research group (*Grasland, Mathian & Vincent, 2001)* and has been applied several times to ESPON data (*see. Dictionary of tools in Final Report of ESPON projects 3.1*). Figure 5 shows the result of this kind of interpolation method realised on the GDP/Inh. variable at NUTS 3 level (with a Gaussian smoothing and a span of 100 km).

1 In the majority of cases, ESPON data are collected on the base of areal division and are based on counting: counting of surfaces, of people, of production, etc. The index which are derived from this data are therefore combinations of raw-count variables which can not be measured directly but are necessarily related to a particular territorial division.

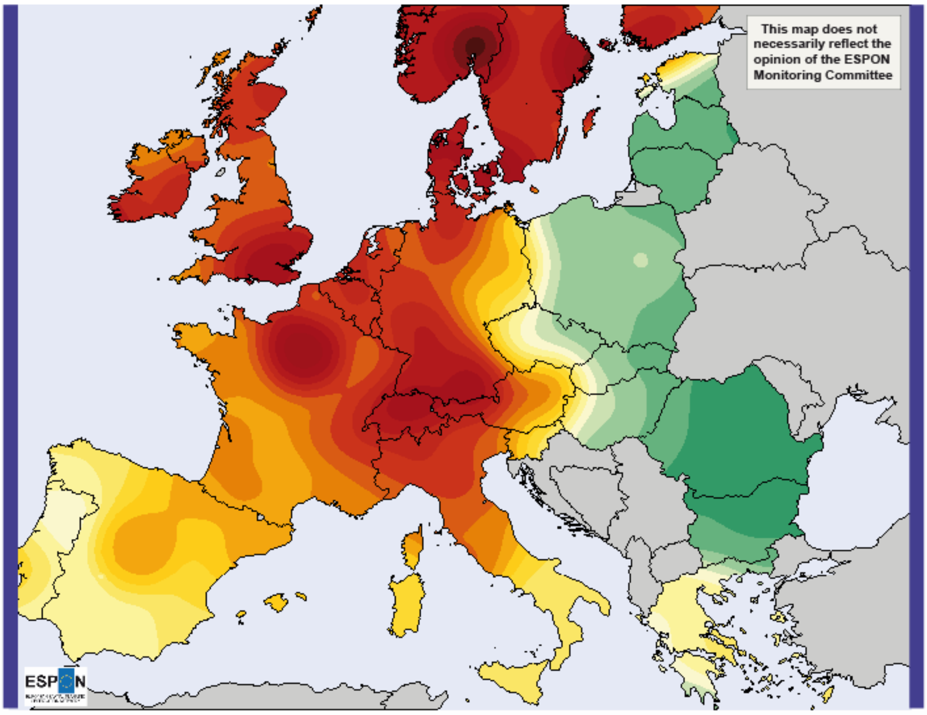

Figure 5 : Gaussian smoothing method realised on the GDP/Inh. variable at NUTS 3 level

Exploration of cartography of ratio and visualisation of denominator

As the majority of index and variables produced in ESPON are ratio (division of two count variables) or synthetic parameters of intensity which do not fulfil the property of additivity, the great majority of map is based on the choropleth method which is the filling of the area of territorial units with a colour or a pattern which describe the state of the population living in territorial unit. The problem with this type of representation is that the visual perception of the global map is proportional to the area of units and not to their economic or demographic size, as evidenced by the experiments made on visual perception by the CESA with the Oculographe (see Part2, §2.2).

Figure 6, map of GDP/inh. in 2000 at NUTS 2 level, proposes an alternative to overcome this representation problem, using a denominator (Population) which is introduced here as a size variable. As compared to a classical map presenting only GDP/inh., the figure give to the policy makers a much more accurate vision of economic unequalities in ESPON 29 because he/she can combine two complementary informations (GDP/inh. and population) and eventually three if we consider that he can deduce population density from the more or less important coverage of areal units by circles proportional to population. This map answer to the question "*Where are <u>people</u> located in region with high/low GDP per capita*" when the classical map answered only to the question "*Where are <u>surfaces</u> located in region with high/low GDP per capita*". It is not a minor difference!

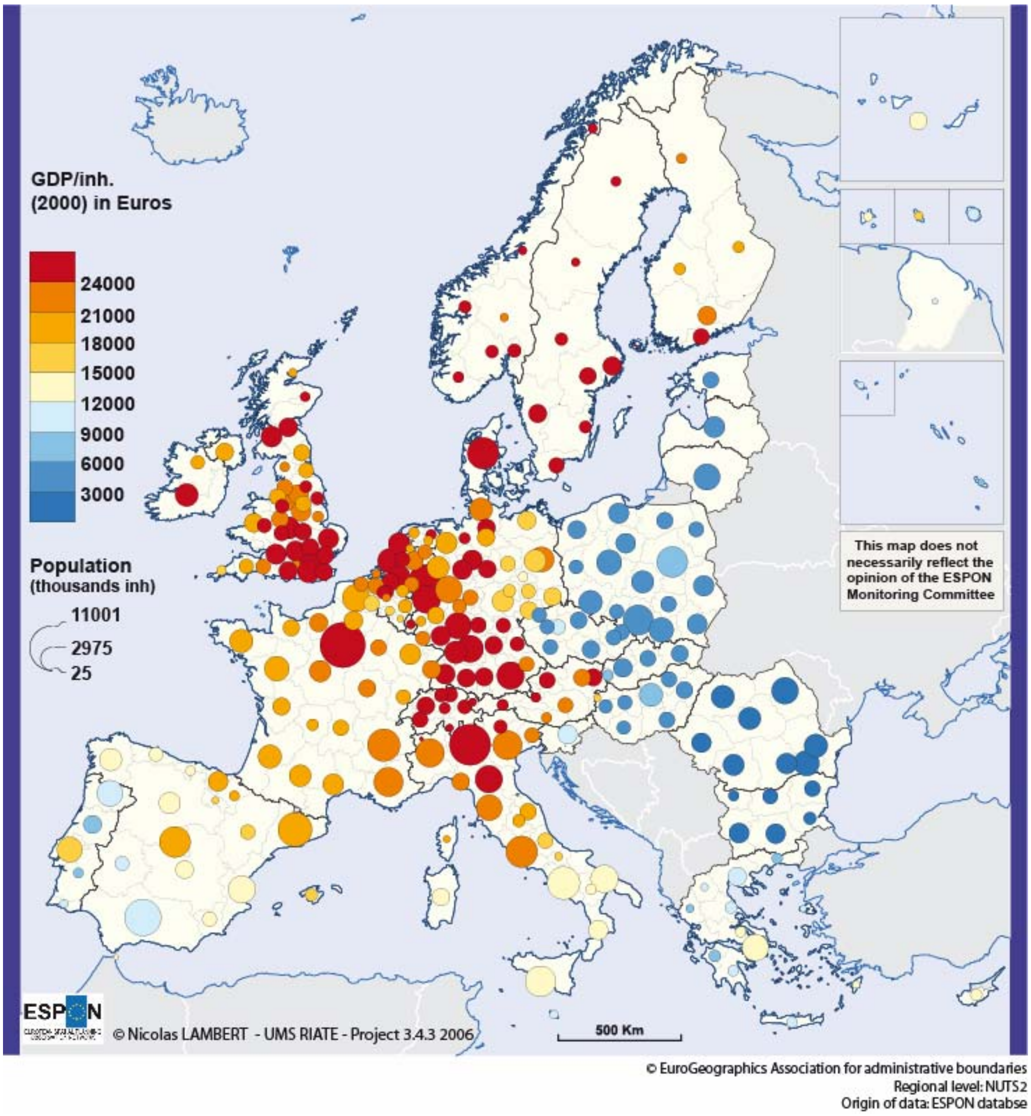

Figure 6 : GDP/inh combined with population at NUTS 2 level in 2000

Exploration of the cartograms

The previous method can be less relevant at the NUTS 3 level because of the high heterogeneity of size of spatial units and sometimes of the insufficient size which can yield too complex maps. Moreover, and it is true at NUTS 2 or NUTS 3 level, the introduction of circle proportional to the size of spatial units has an important default which is to make more difficult the analysis of spatial heterogeneity and territorial discontinuities along borders. The reader's eye is obliged to produce a greater effort when it has to define cluster of regions which are similar or when it has to delineate lines of maximum differences between homogeneous areas.

We propose therefore another alternative method of cartography: the cartograms (or polygon-related cartograms) which are a particularly interesting solution as they solve the spatial continuity of the phenomena (as classical maps) but make also possible the visualisation of size effects (as maps based on circle proportional to denominator). For example, the map of GDP/inh. in 2000 with area proportional to population at NUTS 2 level (Figure 7) provide a clear and comprehensive view of the distribution of GDP between inhabitants of ESPON

29. The reader can immediately identified the most important regions in demographic terms (size of the area) and the regions where the level of GDP/inh. is high or low (colour value of the area). The region of "*Inner London*" which was hardly visible on a classical map is now very easy to observe, as the other metropolitan regions of small superficy but high population (Hamburg, Brussels, Wien, Athens, …). On the contrary, the wide region with very few population like northern Scandinavia, Scotland or rural regions of Spain are dramatically shrinking.

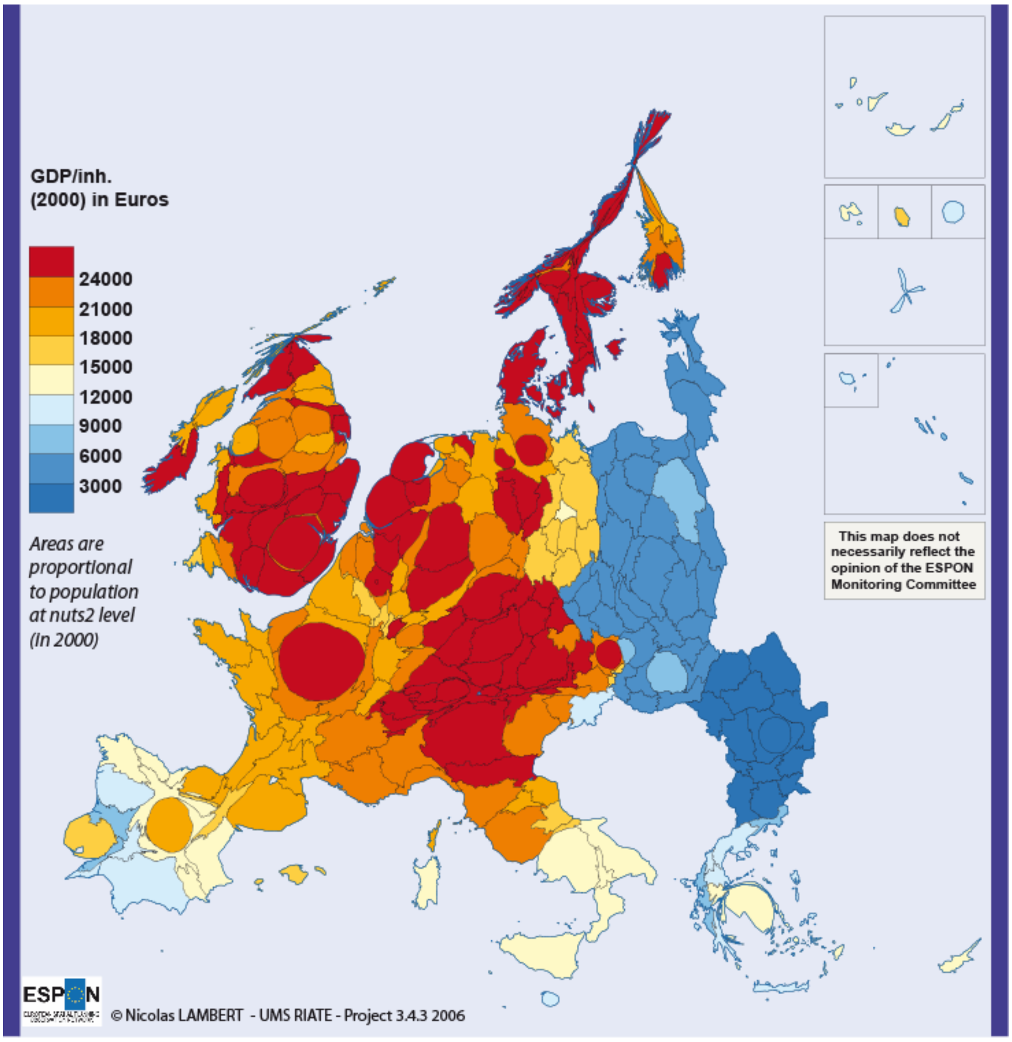

Figure 7 : GDP/inh 2000 with cartogram proportional to population (NUTS2)

The effect of MAUP is therefore strongly reduced on cartogram where surface is proportional to the denominator of the ratio of interest. In that sense, cartogram are the expression of scientific and political choices and it is not innocent to use one type of transformation or another one. Territorial cohesion, social cohesion or economic competitiveness implies different cartographic tools for their representation. For example, if Lisbonne strategy and competitiveness are the prior objective of EU, then the good cartographic representation should be a cartogram of region proportional to GDP and not not population or area. What would be visible on maps would be the biggest and most competitive regions.

Exploration of gridding methods

The case study on Sweden presented in the report (see Part1, §3.1) has revealed the very high potential interest of gridding method for spatial analysis of social facts in general, and for spatial planning in particular. Analysis realised in the framework of official delimitation gains in accuracy when they are completed by further analysis elaborated on grid of different scales which provide a trans-scalar view of the phenomena of interest.

Starting from the pragmatic assumption that, during a long time, it will remain difficult to obtain complete datasets at local level like in Sweden (with a geographical resolution of census of 100 m) covering the whole ESPON 29 territory, we have tried to elaborate grid maps starting from information available at NUTS 3 level.

Figure 8 shows the distribution of population and GDP in euro (2000) with a grid of 80x80 km2. Among the other maps with different cell sizes, this map is probably here the best possible compromise between conservation of spatial differences and elimination of biases introduced by the conversion from territorial units to grid cells. The abstraction which is produced by grid transformation is both an advantage (as it obliges the reader to focus on the general pattern and not on local regional situations) and an inconvenient (as it is impossible for local spatial planners to recognize their territory and as national borders as no more visible).

One of the most promising applications of gridding methods for ESPON is not only the transformation of NUTS 3 units but the integration of heterogeneous databases. We can distinguish two potential fields of application:

a. **for time harmonisation of changing territorial units (**for building an harmonised territorial framework and for the analysis of time variation, even if such operation should be carefully realised)

b. **for thematic harmonisation and combination of heterogeneous spatial sources** (NUTS 2 or NUTS 3 units information; the Corine Land Cover; the number of kilometres of railways, etc.)

(a) General view *(b) Zoom*

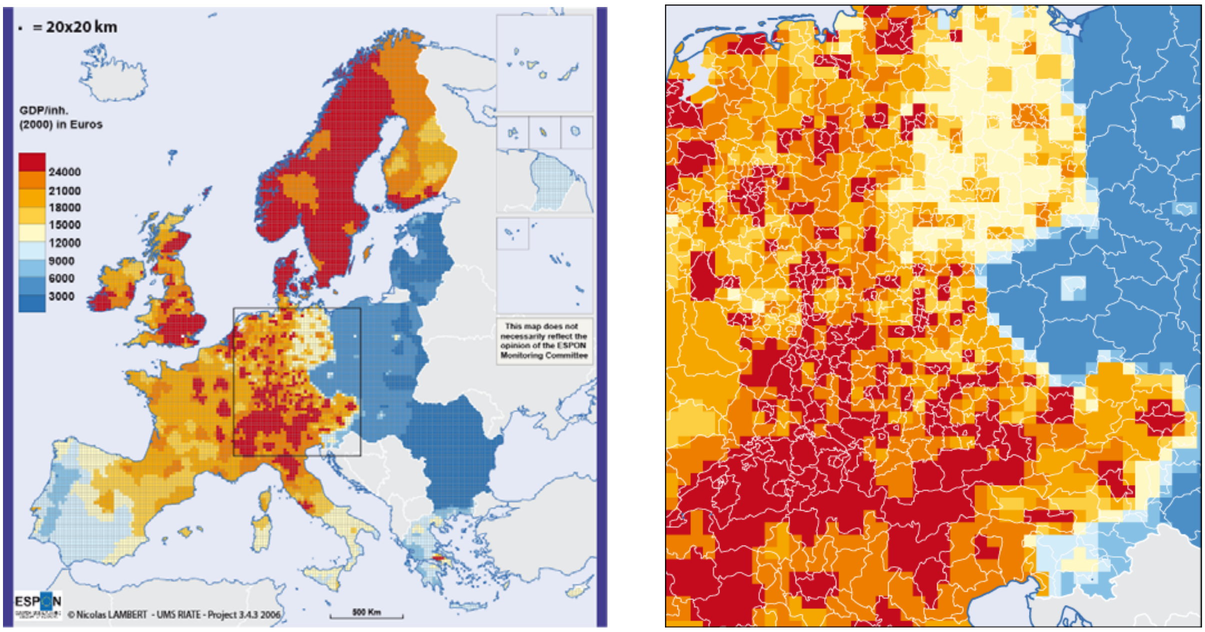

Figure 8 : Gridding transformation of GDP/inh. 2000 (square 80 km)

Interactive cartography

In cartographical terms, the MAUP is associated to questions of scale and level of aggregation which are not directly a problem but rather a difficulty related to the fact that it is not possible to combine several solutions on the same piece of paper when we use traditional method of cartography. Some progress can be realised by better use of the possibilities of traditional cartography like cartograms or combination of several variables on the same map. But this solutions are limited because they are generally complex: the user is not necessary able to interpret cartogram or he can have difficulties to analyse at the same time a variable of size and a variable of intensity. The alternative solution is therefore to avoid too complex maps and to propose a multiplication of simple and elementary maps. If we consider that MAUP is a factor of progress, we have therefore to explore more in details the technical solution which make possible the analysis of several maps of the same phenomena, which mean to explore innovative methods of cartography different from the classical static maps. MacEachren (1994) & Openshaw (1994) consider that the dynamic cartographic has an important potential for the development of knowledge and communication tools, which is not the case for classical static cartography.

From scientific point of view, the MAUP problem was primarily related to the fact that it is not possible to consider that one map of a phenomenon is better than the other. Having concluded that different maps are not contradictory but complementary, we have to imagine the technical solutions which make easier the analysis of multiple cartographic representations of the same phenomena. In this perspective animated maps appears as a particularly promising solution:

c. animation of typologies: instead of providing a "flat" and usual typology, nested typologies to examine the results at different levels of details;

d. scalar animation[2]: change of the level of spatial aggregation in order to visualize alternative representations of the same phenomenon, to choose for the user the most relevant level of aggregation in a panel of choices and to compare alternative results in real time;

e. and cartographic zooms.

From political point of view, animated maps presents at first glance some difficulties as, in a classical normative perspective of political decision, the "official" maps should be one and only one, printed on a paper like the international treaties. Interactive maps available on multimedia support which can be modified interactively by the political decision makers are something very tricking but may be very innovative from political point of view.

Recommendations for ESPON II

To conclude this Executive Summary, we focus on selected key message to be addressed to ESPON CU and ESPON MC for the elaboration of the future program ESPON II.

1. **Adoption of a new hierarchy of NUTS division to be used for research and strategic purpose**. We strongly suggest that ESPON II is not obliged to restrict the production of maps to official NUTS 2 and NUTS 3 territorial divisions actually existing as legal instrument in European Union. This official delimitations could be used when needed (for example if the European Commission request a study on Structural funds) but the majority of ESPON production should be based on the revised NUTS division based on functional criteria which is proposed in this report. ESPON like OECD (which has adopted a mixture of NUTS 2 and NUTS 3 units for its regional studies) will gain in credibility at international level with this major change. It is not possible to go on with maps at NUTS 3 level which produce confusion and errors of interpretation because of scale confusion.

2. **Development of interactive cartographic tools making possible the delivery alternative representation of the same phenomena in real time**. Considering that different cartographic representation delivers different political message which are complementary, we suggest to develop the access of policymakers and researcher to alternative representation through multimedia and web technologies. Maps will no more be stored on paper version or picture file but would be generated at the request of the user by interactive systems. The actual tools elaborated

[2] Scalar animation is available both in ESPON Hyperatlas and ESPON Web Gis. To examine the global pattern of a phenomenon for the whole Europe with large territorial units (Nuts 1 or Nuts 2) vs local differences in cross-border areas, with more detailed spatial resolution (Nuts 3 or Nuts 5).

by ESPON I (Web Gis, Hyperatlas) should be completed by new ones related to gridding method, picnophylactic interpolation, cartogram, Gaussian smoothing, etc.

3. **Development of research on cartographic perception and political decision process**. If we admit that cartographic is a major tool for decision makers in the field of spatial planning, we should analyse very cautiously and with adapted tools (survey, analysis of eye movement, …) what is the real message which is delivered by maps in order to verify the potential mistakes or bias. Moreover, we have to explore the consequence for political decision of what could be called an "*Open Cartographic Method*" where different decision makers try to reach a consensus based on a collection of maps of different types, different scales, … Like in Delphi method, we could compare the different interpretations of a set of maps by different experts which are isolated at the beginning and which, in following rounds, are informed of the interpretations of the other experts. At the end of the different rounds, we should obtain a set of maps which are the most relevant and one of several major messages delivered by these maps.
4. **Development of multiscalar statistical analysis methods for a better diagnosis of spatial trends and territorial impacts**. In statistical terms, we suggest to develop the use of tools like GWR or spatial autocorrelation methods which explore the relation between statistical parameters at different scales. As explained in part 2 of the report, they are many situations where two phenomena A and B does not display the same level or sign of correlation according to the scale of observation. For example, we can observe spatial segregation and territorial imbalances at local level which disappear at the regional one. We can also determine that structural funds are positively correlated with economic growth in certain part of the European territory and not in others. Multilevel statistical methods are crucial for the development of taylor-made strategies of spatial development which take into account the local contexts and not only the average trends of ESPON territory.
5. **Enlarging scales of analysis in both directions: toward more local and more global levels**. Spatial differences have been sometimes compared to waves of different frequencies (Tobler) and the question of MAUP can be understood as a confusion between different frequencies producing noise in the perception of the message (e.g. NUTS 3 is very "noisy"). Following this comparison, we can state that the actual research develop in ESPON is limited to a relatively narrow band of spatial frequencies (between regional and European levels) which means that many messages are not interpreted and used because they are related to highest (World) or lowest (local) frequencies. It is true that the actual band of frequency (regional-European) is the core of the mission of ESPON, but the interpretation of this band would be much accurate with

additional information on World dynamics and local dynamics. It means that, on the one hand, it is necessary to maintain research on the situation of Europe in the world (database at state levels) and, on the other hand, it is necessary to develop case studies at local level (database at LAU1 and LAU2 levels). *"Broadband spatial planning"* is certainly a major challenge for ESPON II.

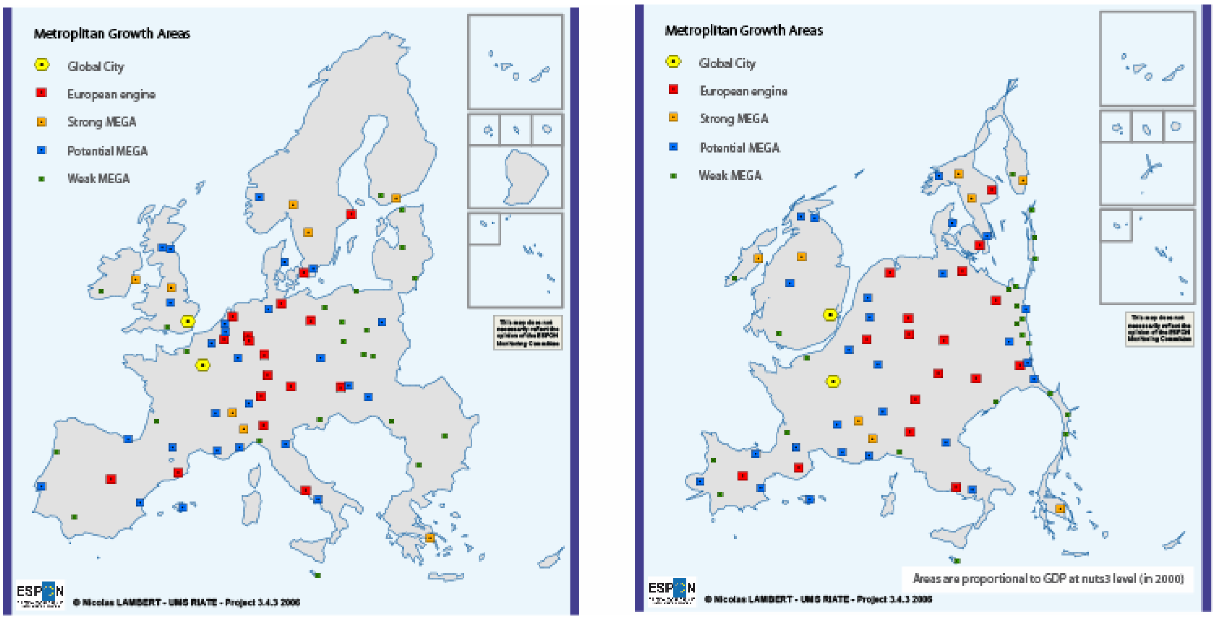

Figure 9 : Distribution of MEGAs in classical map and in a cartogram of wealth

Report on Networking

Internal Networking: The ESPON project 3.4.3. involved since a very important number of research teams of different countries with two leading partners from France (UMS RIATE & UMR Géographie-cités), 3 core partners from Belgium (IGEAT), Sweden (Umea University) and Ireland (NCGIA) and 3 expert teams from France (ID-IMAG , CESA) and Germany (BBR). It was without any doubt a crazy challenge to build such a wide network for the answer of a scientific support study where the global budget was very limited (50 k€) because it was obviously impossible for research teams to meet several time without paying the travel expense on their own resources…

The lead partner organised a single kick-off meeting took place in Paris at the beginning of the project where all core teams and expert teams was present and could elaborate a common understanding of the work to be done during the short delay of 6 months. After this kick off meeting, most exchange was realised by internet, thanks to the elaboration of a specific intranet website by UMS RIATE where all data, maps, bibliography and other material could be download and upload. But this "virtual exchange" could not always replace face to face contact and some bilateral extra-meeting took also place between the research teams. It was relatively easy for French teams (being in contact by other national projects) or for French and Belgium teams (which participated in other ESPON projects with more funds like 3.4.1 and 3.2 and had therefore the opportunity to meet from time to time). But more difficult in other cases. The lead partner (UMS RIATE) was for example obliged to reduce its own share in order to allocate a larger amount of funds to the Swedish partner (Umea university) which made possible for him to be present at the ESPON seminar in Manchester (november 2005) and to discuss results. The discussion with the expert of cartogram (W.D. Rase, BBR) would not have been possible without an external scientific support, out of ESPON, which made possible a travel in France. Such solution for extra meeting could not be found with the Irish partner and it was therefore more difficult to integrate fully its very interesting contribution on statistical effects of the MAUP and the innovative method of Geographically Weighted Regression.

The research teams which accepted to participate to project 3.4.3 has clearly done it because of the exceptional scientific interest of the subject… But most of them also conclude that it was the first but also the last time that they would agree to work in such condition, lacking of money and being subject to a high time pressure. If ESPON II decide to launch equivalent scientific studies in the future, it would be better to allocate more funds and time because we can have some doubts on the possibility to find one more time research teams ready to do the work that has been done in 3.4.3 for 50 k€ !

External Networking

Some links was established with project **3.4.1 "Europe in the World"** and also **project 3.2 "Scenarios"**, because it appears quickly obvious that some of the innovative methods of mapping discussed in Project 3.4.3. MAUP could be of interest for the visualisation of scenarios (cartogram) or the representation of world dynamics. But this links was obviously induced by the fact that the lead partner of project 3.4.3. was at the same time leader of project 3.4.1 and partner of project 3.2. In fact, much wider links could have been elaborated with all other projects running at the same time which was all de facto concerned by this question of modifiable area unit. But as explained before, time and resources was very scarce and it was for example impossible to participate at all LP meeting.

The greater effort of networking took place at the ESPON meeting of Salzbourg (spring 2006) where the project 3.4.3. – supported by ESPON CU - realised a **survey on the cartographic practice and preferences of the ESPON community**. Primary results was immediately delivered to the participant which was really appreciated and complete results of the survey provided very important inputs for the redaction of the final report. Without this survey, it would have been impossible to appreciate correctly the fact that policy makers are not very different from researchers in terms of potential adoption of new cartographic methods and are ready to adopt several representations of the same phenomena. The proposal to replace NUTS3 units either by mixture of NUTS2 and NUTS3 (like OECD) or by a more local but harmonised level (like LAU1 or LAU2) is and idea which was clearly revealed by the survey.

The **linkage with ESPON CU was excellent** during all the realisation of the project, both from administrative point of view (help for contracts, etc.) and from scientific point of view (comments of the intermediate report, preparation of a text for ESPON scientific synthesis, opportunity to present results at ESPON meeting, …). **The only negative point in networking was related to the publication of the ESPON Atlas**. The leader of Project 3.4.3. was asked to propose 2 pages in a final chapter of 6 pages but could never received communication of the first 4 pages… When 2 pages was finally proposed, they was refused by the responsible of the ESPON Atlas which considered that they was "politically uncorrect" (we had proposed to publish the "unofficial" NUTS2/NUTS3 units elaborated by IGEAT and to illustrate the danger of "gerrymandering" when states modify their territorial units in order to obtain more structural funds). The project 3.4.3. refused to replace this proposal by "*nice innovative maps*" as it was asked by responsible of ESPON Atlas !

Part 1: Scientific approach of the MAUP?

Introduction

For planning purpose as well as for research topic, it is necessary to get an insight in the spatial variations of social and natural phenomena. It means to be able to have a representation of spatial inequalities, to identify specific zones, to identify discontinuities in space, and to understand the underlying principle of the spatial organization of a phenomenon as well as its correlation or independence relatively to other phenomena. Classical tools such as cartography, statistical analysis, and spatial modelling are used for that purpose. The fact is that the results of these analyses are dependent on the definition of the studied units. This problem is nowadays well known and referred to as the Modifiable Areal Unit Problem or MAUP. Spatial aggregation, change of zoning has impacts that will be illustrate by empirical examples in the first section of this part. We will try there to show over a set of examples why this problem is most of the time in the core of some geographical studies involving measures as well as its different aspects and its the different impacts. In a second part a review of the literature is proposed in order to understand the resurgence of this problem since few years, and the different trends in the proposed issues.

1 What is the MAUP?

The Modifiable Areal Unit Problem or MAUP design the sensitivity of the results to the definition of the spatial units that are studied. It is known over its two manifestations:

1) the ***scale*** or level at which the spatial entities are observed; **figure 1a** represents for example three nested levels of administrative units in France;

2) the kind of spatial ***aggregation*** which has been adopted; **figure 1b** represents an example of four incompatible zonings associated to public action in matter of fight against poverty.

In other words, the results vary according to the spatial zoning which is used in the study. For example, it can then happen that one analysis shows that wealth is negatively correlated with population density when another one will show the opposite. It can also happen that the mapping of a same indicator reveals a polycentric pattern with one spatial zoning, and a monocentric with another one. Such contradictory results could, quite naturally, be very disturbing for the decision maker…

Scale and aggregation define the resolution of the description of the phenomena. Whether the zoning is regular (**figure 1c**) or not (**figure 1d**), the spatial level which is chosen plays as a filter for the observation of the phenomena. In fact, one could compare these choices with the settings that are necessary for any instrument of measure in an experiment in physics. In a similar spirit, the choice of a spatial zoning on the one hand implies constraints, and on the other hand offers a tool of knowledge building.

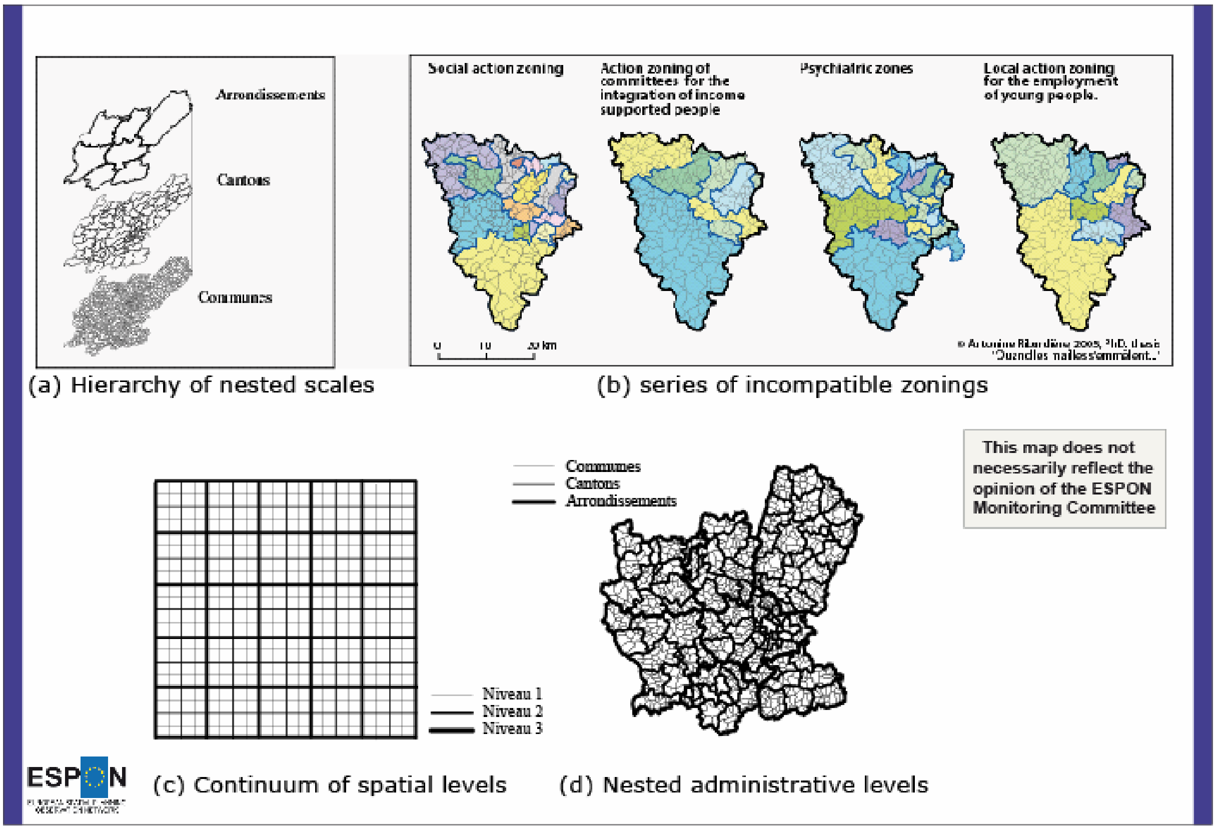

Figure 1 Zonings and relations between zonings

In the following sections we will explain and illustrate the different forms that this question can take. We first introduce the question from a theoretical and methodological point of view. Then we present the main cases of MAUP which occur in thematic research or in an operational perspective and we illustrate them with a series of examples. From a methodological point of view the two first examples concern the spatial organisation of a single variable (sections 1 and 2), the third one has a temporal perspective (section 3), and the two last ones concern situations where multivariate analysis is involved. At last we will discuss in what sense such contradictory results is a problem to be solved but also in what sense it could produce knowledge about the phenomena studied.

1.1 Preliminary methodological consideration: Statistical distribution and spatial organisation

There is often confusion between the descriptions of *statistical* and *spatial* distribution of a phenomenon. This is often due to the definition of the elementary units, and of the level of analysis. Notice that this scale problem is crucial from political point of view as it is the basis of the distinction between social cohesion (reduction of inequalities between individuals or households) and territorial cohesion (reduction of inequalities between territories).

Let's illustrate this with an example starting at the micro level (individuals) described by their income (**figure 2**). The first statistical graphics (**case a**) illustrates a uniform distribution. This describes a *heterogeneous* situation from a social point of view, as all income categories are co-existing. There are as many households earning with lowest incomes as those with highest incomes, as those with middle incomes. In order to represent the spatial dimension of the income distribution, individuals have to be aggregate into spatial units. In that purpose, a function of aggregation has to be chosen. Part of the ambiguity comes from this operation.

First, when it is from individuals to spatial entities, the aggregation transforms totally the observed phenomena. Even if it is less evident when the aggregation concerns the passage from one spatial level to an upper one, all types of aggregation operate a transformation that one should be aware about (see section 2).

Figure 2 shows the multiple possible correspondences, between profiles of statistical distributions of a same phenomena at two different levels. These correspondences are also multiple between statistical distribution and spatial organisation of a phenomenon at a given scale: it is thus very important to precise the level of observation when studying localised information.

In the example of the income, a mixed situation (high heterogeneity) is characterized by a uniform distribution of the income when observed at the individual level. At the aggregate level of the district for instance, one could observe the average income per inhabitant (it could be the median, the heterogeneity, the range between minimum and maximum…). The social heterogeneity that is observed at the individual level may be associated either to spatial homogeneity (case a.1) or to spatial heterogeneity (case a.2). Case b is the same illustration, starting from a more egalitarian global situation from a social point of view, i.e. households are more concentrate around highest classes (case b) may lead theoretically to the same diversity of profiles of the statistical distributions at an upper level, and to the same diversity of spatial patterns. What is of interest for the question of the MAUP is also that to one statistical distribution can correspond to different spatial patterns depending on the underlying spatial processes of localisation. For instance the case a.1 corresponds to a segregation process taking place at upper spatial levels. Reversely the case b.1 illustrates a situation where the segregation process is very local. In this last case, at any upper levels the aggregation will smooth the local heterogeneity and produce a homogeneous pattern.

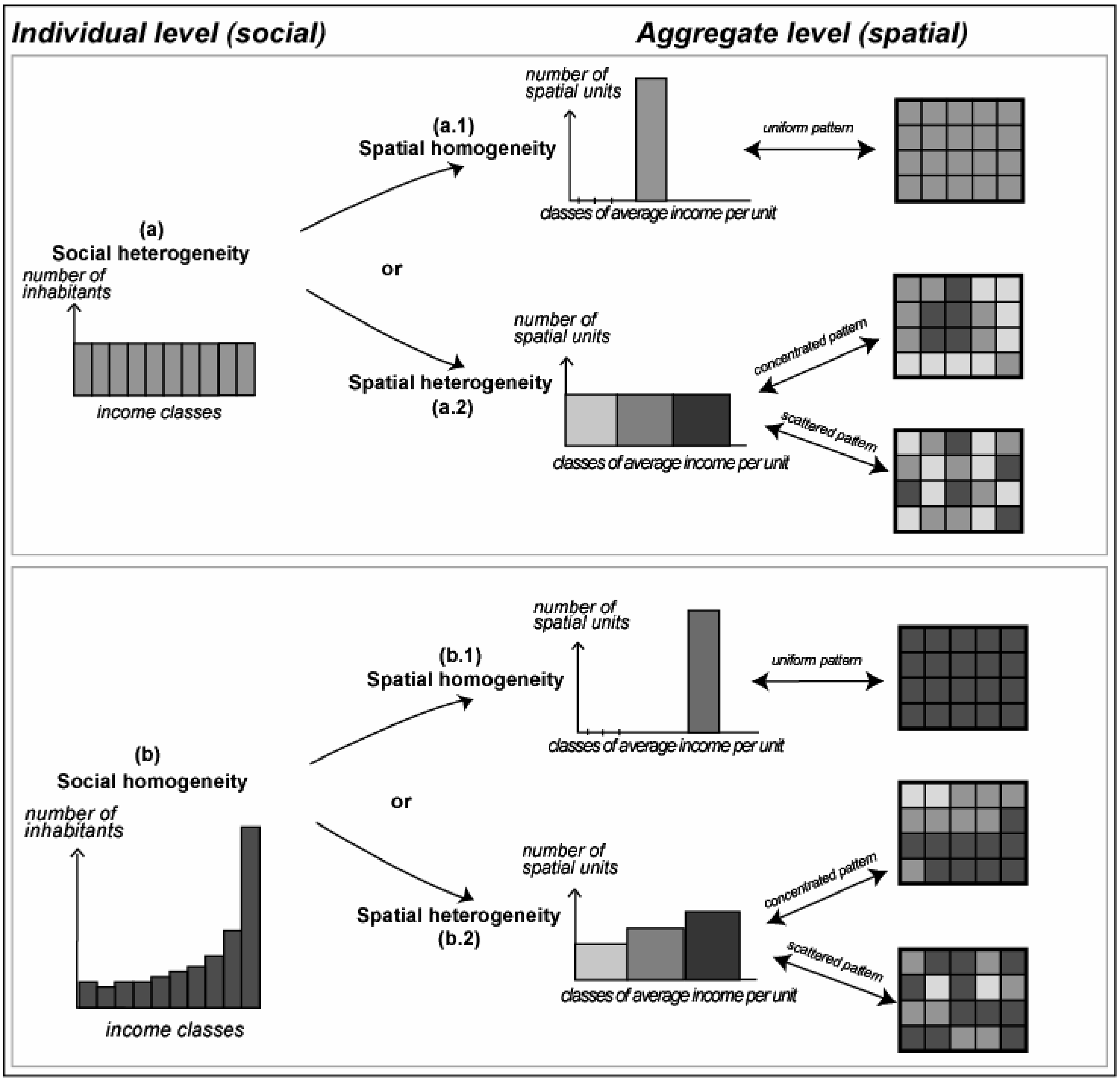

Figure 2 Statistical distribution, spatial organisation

These are really theoretical examples, and most of the time the combinatory is not as much extended. But this shows how the spatial dimension is complex even for the description of the organisation of one variable and how it is important to be explicit in order to understand the change in statistical relations.

1.2 With different zoning, spatial variations don't look the same

A statistical mapping is one possible representation of the phenomena among many. The perception of the global organisation is fully dependent on the zoning and the scale. **Figure 3** shows a theoretical construction of two different aggregations, with same resolution, starting from the same data. But a little move of the grid may lead to very different perception of the phenomenon.

Figure 4 shows a classical example of the "zoning effect" (change due to the zoning at a same scale) built up by Openshaw and Rao (1995): the two maps represent the spatial distribution of an indicator, the percentage of ethnic population in the county of Merseyside. The two maps represent the same phenomena, the relative importance of ethnic population in different places of the city, but they give two very different images of the associated spatial pattern:

- The map in **figure 4a** uses a zoning in 119 wards, which corresponds to conventional administrative zoning in Merseyside;
- The map in **figure 4b** uses the same number of spatial units but subdivided according to: the spatial entities are simply built from aggregation of the number of blocks necessary to reach a determined threshold of population. It means that all the spatial entities in that case have been built just to have the same population.

The two maps reveal different spatial organisation of the same phenomenon: a higher presence of ethnic population in the northern part in one case, in the south-eastern part of the municipality in the other one. This example shows clearly that the image of a phenomenon can't be interpreted and understood without having in mind the meaning of the spatial elementary units which are used for the representation.

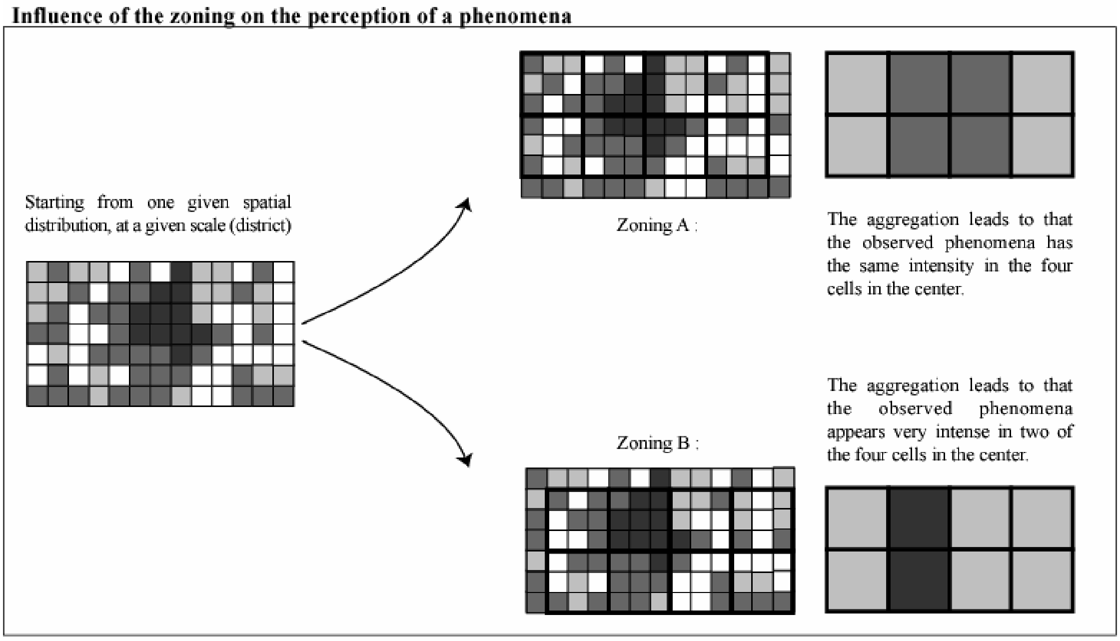

Figure 3 Influence of the zoning on the perception of the phenomena (theoretical example)

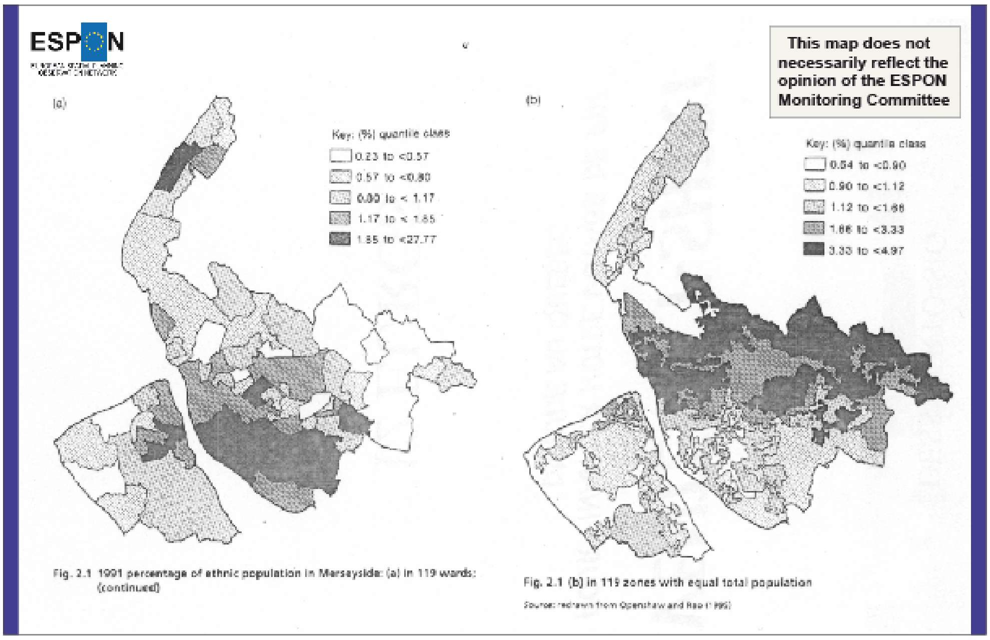

Figure 4 Influence of the zoning on the perception of the phenomena

(from Openshaw and Rao 1995)

In the Swedish case study (see §3.1), a systematic multiscale series of analysis have been made as well on administrative zoning as on regular square grids. **Figure 5** presents an empirical example mixing the "zoning effect" and the "scale effect". The studied region is northern Sweden, and the variable is the income per inhabitant. Four *resolution*s are compared as well as two types of zoning: two administrative ones (Counties – NUTS 3 and municipalities – NUTS 5), and two regular grids (30km squares and 10km squares). It shows obviously how scales smooth the phenomena. It shows also how interesting it is to have this multiscale representation, and how maps complement nicely each other, from level to level. Indeed, when the spatial organisation reveals juxtaposition of homogeneous regions at the upper levels, distinguishing the south, the centre and the north, the 30 kms grid map rather shows a lateral organisation with a gradient from coast to inner zones. This is very less typical in the administrative region, because of their shapes. Finally, the 10 kms grid map shows a more mosaic pattern.

This example is also a good illustration of the question of the meaning of a zoning. A zoning refers simultaneously to the delimitation of the zones and to the contents of the zones. The two first zonings of **Figure 5** are associated to a normative power, a decision-maker, when the two last ones are without any *a posteriori* meaning.

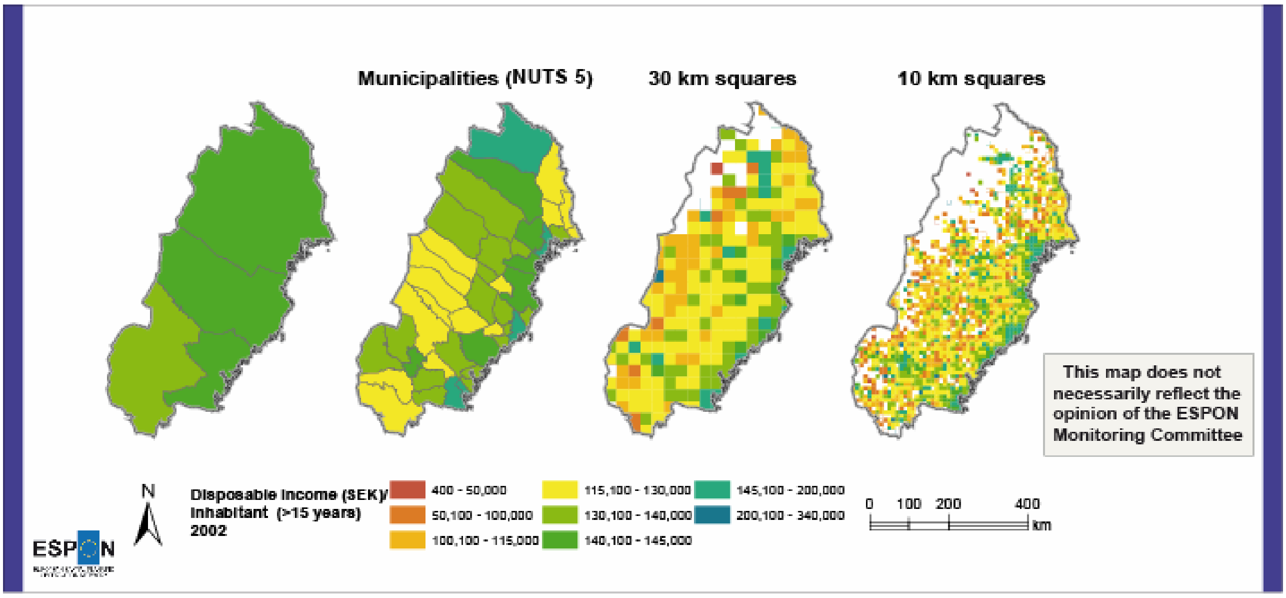

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Figure 5 Influence of the zoning on the perception of the phenomena (empirical example)

(see Case Study on Sweden, §3.1, M. Strömgren, K. Holme, E. Holm)

1.3 Correspondence between administrative limits and spatial discontinuities: a possibility, but seldom a rule

As underlined in previous section, the spatial configuration of phenomena looks different depending on the adopted zoning. A related question is that of the *position* of spatial discontinuities or barriers in the distribution of phenomena. In some cases an administrative boundary acts as a functional limit, it is the case for what is related to policy action for example (planning, social policy, taxations etc). But when administrative units are used as the basic spatial entities for representing socio-demographic phenomena, an apparent discontinuity could be artificial.

Let's use a study about social cohesion in the Parisian metropole in order to precise this fact. **Figure 6** represents the distribution of low income household at: a) the level of the commune[3], lowest administrative entity (NUTS 5); b) the level of the IRIS[4], an equal populated division used in order to collect and represent data in intraurban areas. Two comments:

- a strong discontinuity between richer and poorer zones in northern Paris is clearly visible on **figure 6a**. It shows a gap between the city-centre and the neighbouring suburbs. Indeed the discontinuity exists but, as shown on **figure 6b**, its "real" position is moved a bit towards the city-centre. And we can notice that when ESPON uses NUTS 2 division to measure social and economic cohesion, the line of discontinuity between Paris and its suburbs is removed which is different from London where Inner/Outer London produces the most important difference of GDP/inh. in absolute terms (see. ESPON 3.1, FR).
- in some cases in the north-eastern suburbs, the mixing of different IRIS inside a commune smooth out discontinuities at the commune level, when there are strong inside the commune. For example, an opposition between a "richer" centre and a poorer periphery appears in a series of communes.

[3] The communes exist since around 1800. It is a very fine zoning as there are 36 000 communes in France, the mean area being about 12 km^2. These units correspond to old parishes and still make sense from an administrative and political point of view.

[4] IRIS are districts, divisions of the communes of more than 5000 inhabitants, defined in order to gather no more than 2500 inhabitants and to be socially quite homogeneous.

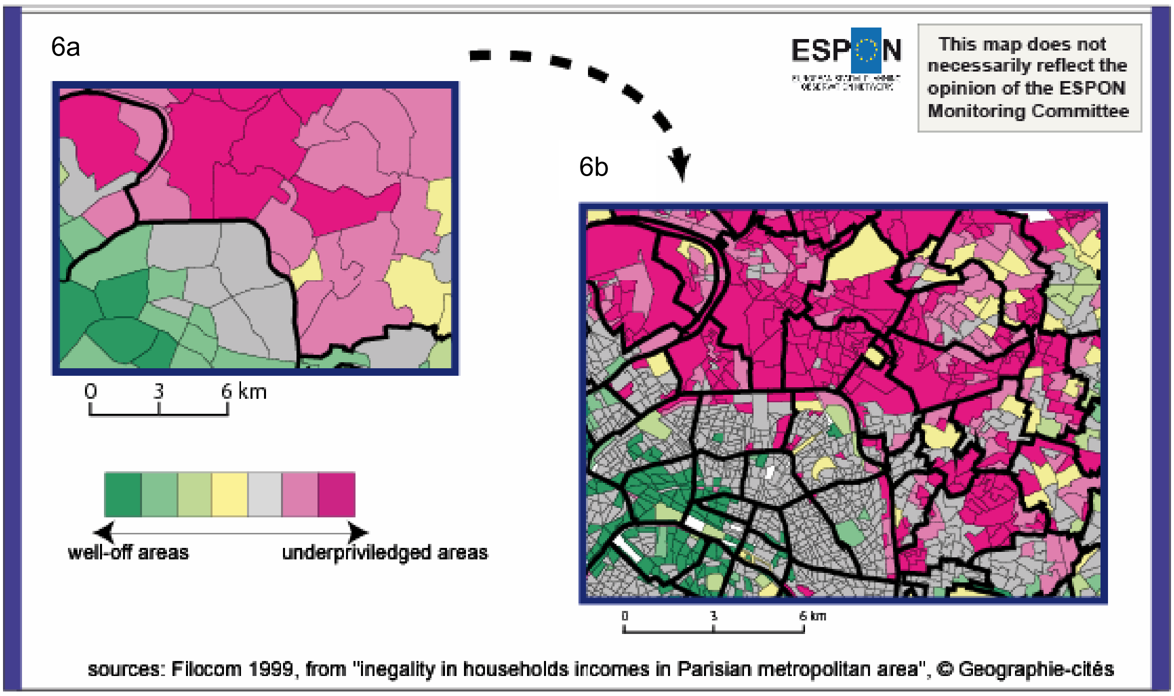


Figure 6 Social segregation to the test of scale

The scale at which spatial heterogeneity appears depends of course on the phenomena and on the geographical context. The study has shown that in the Parisian region, social mixing is observed in most communes, with the exception of extreme communes, that is the richest and the poorest ones. These communes evolve toward an increasing intra-communal homogeneity, and are the frame for the strongest mechanisms of segregation.

1.4 With different definitions of spatial entities, the forms of evolution appear different

Urbanization is a process about which planners and policy makers need to have a good perception of urban system as polycentrism is one main objective of ESDP. But in order to estimate the quantity of people living in cities and to visualize their spatial distribution and interlinked flows, it is of course necessary to be able to delimitate the cities. Such spatial entities are not associated with a complete and stable partition of space. And in a context of urban sprawl and development of polycentrism in metropolitan areas, the limits (borders) of the city are far from self evident. The question is even more complicated in a dynamic perspective.

Guérois and Paulus (2002) have shown how different choices in matter of definition of French urban units result in different images of urban evolution. In the French official statistics three definitions have emerged through time:

- the "city-center" which corresponds to the commune, the lowest administrative level in France (NUTS 5), which is the historical core of the city, which made sense until the first half of the 20th century;
- the "urban unit" (introduced in 1954) corresponds to a morphologic definition of the city and aggregate all contiguous built-up areas;
- the "urban area" (introduced in 1997) corresponds to a functional definition integrating the city and its periurban area. It is delimited according to the percentage of the labour force working in the city (with an iterative method of construction).

As shown in **figure 7**, the urbanization evolution looks in France radically different depending on the adopted delimitation: urbanization seems either to decrease, to stagnate or to increase. From a thematic point of view, such differences can lead to an interpretation in terms of counter-urbanization or of increasing urban concentration.

In the ESPON context, it means that very different patterns of FUA's could be established, producing very different vision of polycentric development of Europe. We can recall the discussion around a preliminary map of project 1.1.1. where Paris was reduced to 2 instead of 10 millions of inhabitant, as the author has chosen to use the city center instead of the agglomeration as criteria of delimitation.

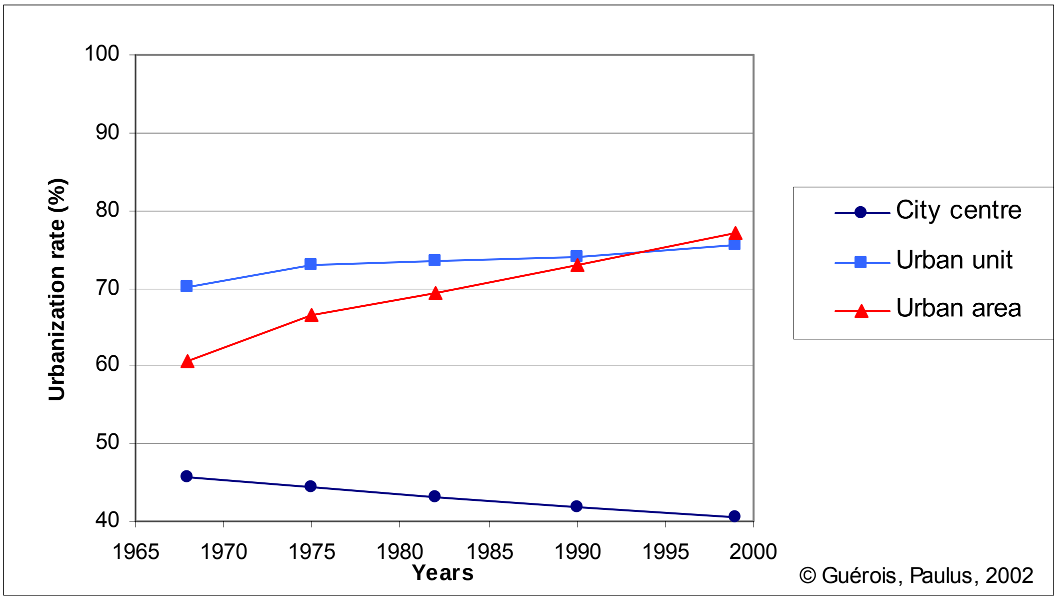


Figure 7 Evolution of the urbanization rate in France depending on the urban delimitation

Depending on the problematic, one definition will be more adapted than another one. And from a research point of view, the combination of the three curves gives the most complete information about the urbanization phenomena, showing a double process of concentration at a higher scale and deconcentration at the local level.

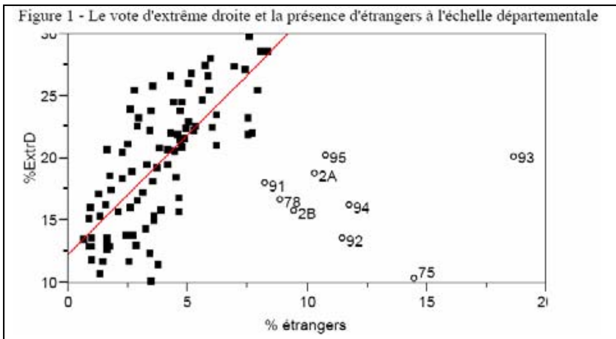
1.5 The relations between phenomena seem different depending on the scale of observation and with the spatial extent of the study region

Statistical analyses show the intensity, significance and sign of the relationships between variables. Such analyses help to explore the links between different phenomena and in the case where the statistical units are spatial entities, the links between different spatial patterns. But, the user should be aware that the value of a result (a coefficient of correlation for example) could vary according to the spatial units at the level of which the variables have been observed. It implies that the generalization of a result to other scales or to other spatial zonings most often doesn't make sense. But, it means also that, when contradictory results appear, the study of the mechanisms underlying these differences between the results will give a better understanding of spatial differentiation.

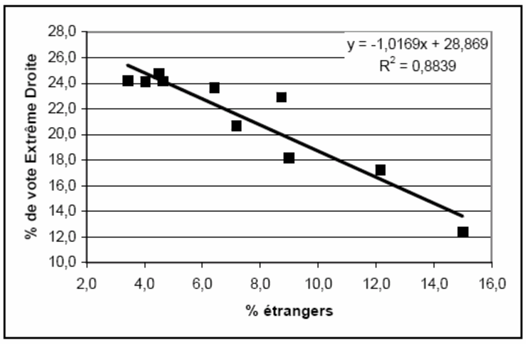
This may be illustrated by a study of Ravenel (2003). His aim was to analyse the relation between the importance of the foreign population and the vote for the extreme right. The variables are first observed at the level of the 95 French departments (NUTS 3). If one except from the departments of Corsica and the Parisian region, there is a strong positive relations between the two phenomena (**figure 8a**): the vote for the extreme right is more important in the departments where the part of the foreign population is higher. In a second analysis he chooses as spatial entities successive rings around Paris every 10 kms until 100 kms. The relation is this time strongly negative (**figure 8.b**), the vote for the extreme right registering its lower values in the circles with the highest level of foreign population.

Considering the same spatial area (a circle centred on Paris with a radius of 100 kms), but observing the variables at the level of the 3173 communes (NUTS 5) composing that area, the result is that there exist no significant relation between the vote for the extreme right and the presence of foreign population (**figure 8.c**). At last, the author concentrates on the communes located within 10 kms from the centre of Paris. The relation appears then clearly positive (**figure 8.d**).

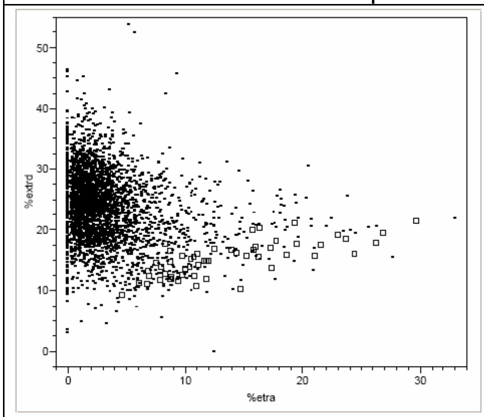
So the relations between the same couple of variables appear to be strongly positive, strongly negative, or without any significance depending on the spatial zoning and frame which are used in order to determine the spatial entities of observation. The author underlines that these variations are associated to different models of explanation which each refer to a specific spatial scale. A classical explanation is produced by a causality scheme claiming that more foreigners produce a xenophobic reaction. Another one is that a same phenomenon, as a certain socio-economic context, is simultaneously associated with high level of foreigners and high level of extreme right votes. And a socio-economic context has not either the same meaning at different scales. Indeed, in the Parisian region, there are strong gradients from centre to periphery for population of higher socio-economic groups AND for foreign population. The former ones are rarely voting for the extreme right, which explains the negative relation represented on **figure 8.b**. But at a local level, foreigners are overrepresented in the communes with lower socio-economic groups, who vote more often on the extreme right. The socio-economic context is fundamental at both levels but it has a different meaning, related to the scale at which such or such category is or is not concentrated.



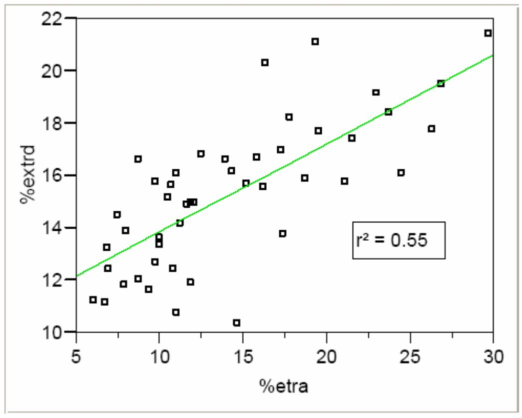
(a) % of foreigners and % of extreme right votes for the 96 French departments



(b) % of foreigners and % of extreme right votes for rings around Paris (until 100km)



(c) % of foreigners and % of extreme right for all communes at less than 100km from Paris



(d) % of foreigners and % of extreme right for communes close to Paris (<10km)

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Figure 8 Relations between extreme right votes and foreigners rate: different filters

Full examples have been developed on Swedish and Irish case studies (see §3.1 and §3.2). Indeed it is interesting to see how a correlation basically measured at the individual level (income and density for instance) is scale dependent, and change with the range and meaning of the neighbourhood which is taken into account.

1.6 And what about the effect of a boundary on the relation between phenomena

One case study explores systematically this question with a multivariate statistical analysis on socio-economic variables for Ireland and Northern Ireland (§3.2). From a theoretical point of view, the question is "to what extent do the observed differences in statistical analyses on either side of a national border result from data on either side being drawn from incompatible spatial units" or from the fact that the socio-economic processes which are operating on each side of the border are different. The authors apply the same regression model (proportion of population having a university degree being regressed on a set of socio-economic indicators) in the case of 10 different data sets corresponding on the one hand to different scales of observation and on the other one on different extents of the area being observed. They show the sensitivity of the results to these variations: for example the effect of catholic religion on educational attainment is positive in Northern Ireland and negative in Ireland; and the effects of social class on education attainment are greater in Northern Ireland than in Ireland.

1.7 In what sense is the MAUP a problem?

Cartographic representation and statistical analyses of phenomena are giving different results according to the elementary spatial entities chosen for the study, that is a fact, but is it a problem? The denomination MAUP suggests it, and in some situations it obviously is. But it is not systematically the case and Openshaw, who is a reference for this question (MAUP), underlined that "according to one given domain, geographers would agree on what constitute objects of research and if these objects would be defined in a non arbitrary way, the problem of the spatial aggregation would disappear "(Openshaw, 1981).

- why it is a false problem

Let's do a parallel with the ecology fallacy which is an associated question. As it clearly comes out from **figure 8**, the inference of a correlation computed at the level of spatial entities to the individuals is in no case justifiable and could even be dangerous[5]. Such inference consists in the deny of the spatial dimension of people's settlement. As shown in section 3 spatial mixing (co-existence of people of different categories) or, at the opposite spatial segregation of populations of different categories, could be of very varied forms according to the context. Spatial mixing and segregation can then simultaneously characterize a same phenomenon but at different levels. Such variations are in themselves an object of study for the geographer. The differences in the results of statistical analyses according to the scale are, in that sense, creating knowledge about the observed phenomena. The identification of the scales at which segregation for example does or does not exist, learns a lot about the organization of the concerned society.

- why it is a real problem

The most important problem is about international and historical comparisons: do the elementary spatial units which are used for the analysis have the same meaning in two different countries? At two different time periods? It is not easy to determine if a difference in the results is due to a difference in the processes which are underlying the observed phenomena, or simply to a difference in the meaning of the spatial entities that are used for the observation. In that sense, to work on a grid is a good alternative. But, as shown by the Swedish case study (§3.1), the information given by analysis at a grid level or at an administrative entity level are complementary. One choice is not globally *better* than another one.

[5] A very classical example from the US in the 1950s (Robinson, 1950) is that of the correlation between percentages of blacks and crime rate at the level of a city's quarters.

Conclusion

We tried in this first part to present all the ambiguity of the problem of the spatial aggregation. This characteristic is simultaneously the essence of the spatial data and its constraint.

In a *statistical* point of view, results to be reliable have to be stable and rather independent of point of measure. But as it has been often stressed, this is also a "*non geographical* position" (Openshaw, 1981) and denied of what is consistent in the spatial dimension. One progress in this question is to accept that results are zoning dependent.

Then it implies to clearly identify the question and the chosen zoning. In zoning, one do not forget that there is either the delimitation (container) and the inside (contents). Thus two approaches may be adopted: to choose the best contents coherent with the question or to prefer the a priori choice of the delimitation independently with the question but perhaps more adapted to the methodology used for the analyse. None may solve the problem, but the conscience and the reflection on of the spatial zoning definition and these two components is certainly a necessary condition to advance in this problem.

MAUP is not a problem if people working with data are aware of it.

2 State of the art

Fact that scale and aggregation have an effect on the results of statistical measures are known since long, and have been largely discussed in the literature[6]. On the one hand statisticians have early underlined that the coefficient of correlation is sensitive to the level of aggregation of data, and on the other hand, social scientists have showed the dangers of ecological fallacy, concerning the case of one specific interscalar inference, that of an aggregate level towards that of the individual one. But even if the question has been largely explored, it is still a focus of interest for researchers, as well statisticians as social scientists or environmental scientists. The development of GIS and the multiplication of databases combined with the reinforcement of confidentiality constraints, explain that interest for that domain has even increased (Paez and Scott, 2004). The title "Freedom from the Tyranny of Zones: Towards New GIS-based Spatial Models" published by Spiekermann and Wegener (1999), illustrates for example the expectations from GIS development. Indeed, the conceptual dimension of the question is particularly relevant when the scientist faces several levels of information and when techniques exist for handling such information easily.

The most developed thinking about MAUP comes from Openshaw who has deepened not only technical questions, but above all the conceptual aspects linked to the field of geography. Most texts in the domain refer to his approaches. As the literature is abundant, and as the main questions have been very well developed by Openshaw, we have chosen to present this state of the art using large quotations of the most basic and representative publications in the domain. In order to organize it, we start from the establishment that there exists an interesting distinction between two positions: 1- focusing on the "P", that is the problem, and trying then to find solutions; in that position, the differences which are obtained in the statistical treatment or the spatial modelling for two different zonings, are interpreted as an *error* that has to be solved; 2- focusing on the differences themselves and trying then to understand the underlying principles. The first approach focuses on solution finding when the second is more explorative in its spirit, the first focuses on techniques of unbiasing when the second privileges an integrative ambition. Another opposition can be found according to the role given to the individual level. In some approaches it represents *the* level of interest and of discussion, in others it is simply a possible scale (the most elementary one), among others. The choice of a given scale to observe a phenomenon plays in fact the same role as the settings that are necessary for any instrument of measure. Depending on the adjustment, some objects can or cannot be delimitated, some configurations can or cannot be shown etc... There are then two questions to solve, that of finding

[6] See the first section of this part.

out which zoning is the best adapted for studying the phenomena of interest, and that of finding the way that information observed for one zoning can eventually be transferred to another one (Marceau, 1999). We have chosen to underline the opposition between different approaches, but there are in fact many nuances which are well shown in the text presented in frame 1, quoted from Openshaw (1997).

Starting from these ideas, we have classified the main bibliographic references about MAUP in five categories. The methods consisting in developing statistical tools in order to evaluate and unbias the errors produced by MAUP are first presented (2.1). The point of view focusing on the individual level is then presented (2.2). Different ways of thinking the partition of space relatively to the MAUP question are then reviewed (2.3). The contextual and multi-level approaches are then presented. Its aim is to integrate in the method of interest the potential sources of result variations according to different zonings (2.4). At last, different ways of interpreting such differences in order to develop knowledge about the phenomena of study are examined (2.5).

Frame 1 All the nuances of MAUP: the point of view of Openshaw (1997)

"It is disingenuous to argue that the answer is to minimise the impact of the MAUP **by only using data at the lowest possible level of aggregation** (Goodchild, 1992) or doing away with zones altogether by moving **to frame independent forms of spatial data representation** and analysis (Tobler, 1988). There are problems with both approaches. In the former, there is an assumption that data for finer and finer zones are best, which is false. It ignores the **important role of a zoning system as a generalisation operator that can serve a useful spatial analysis function**, as well as add noise. Many geographic patterns of interest have an innate scale dependency to them. Finer resolution data mainly increases flexibility in usage and storage; however this is not really the problem. Increasingly tools are needed to generalise and define more abstract geographic patterns and relationship that cannot be seen (or found) at a micro scale level of detail. Fine zones merely give the user more freedom in the design of geography but the extra detail often cannot be properly exploited for analysis until zones design can be performed in a purposeful and controlled way. If frame free methods are used, it is hard to see how all relevant spatial information can be accurately, reliably, and sensibly expressed in a continuous and frameless form. **The continuous approximation of discrete information merely introduces other sorts of error, inaccuracy, and distortion**. Geographical analysis is about the variation between and within places, these are discrete limps of space. It is hard to see how and why surface representations of such phenomenon constitute a replacement technology. **There is too much detail, it is too hard to relate the surfaces back onto the real-world**, particularly in an object orientated way and of course not all (or many) phenomenon of interest can be sensibly re-expressed in this form. In a way it changes a UMAUP[7] based on a finite but large number of possibilities into an IUMAUP[8] where there is an infinite number of possible discretisations since there is no longer any spatial building block restrictions. This might be optimal for areal unit interpolation and spatial data manipulation but it will cause many other problems to spatial analysis and in the end may well prove unhelpful in a spatial analysis context unless linked to clever pattern and object recognition technology."

[7] The "U" stands for user

[8] The I stands for infinite

2.1 Statistical methods in order to correct (unbias) the "errors"

MAUP is quite universal in the different methods used in quantitative geography. Several authors have pointed out the presence and the different impacts of the MAUP on the traditional statistical based analysis (Openshaw and Taylor 1979, Fotheringham and Wong 1991, Amrhein 1995 for example), but also on others type of models such as spatial interaction models (Openshaw 1977), or location-allocation models (Goodchild 1979, Fotheringham et al 1995).

Most of the earliest works on MAUP have been done by focusing on the statistical consequences of the areal units. The first quoted study is Gehlke and Biel one's, who already in 1934 showed how the measure of the correlation varies according to the chosen geographical level.

Then, until the recent ten years, the MAUP has been mostly approached in a traditional statistical framework, based on the evaluation of the "*sensitivity of analytical results to the definition of units for which data are collected*" (Fotheringham, 1991). At first the problem was the fact that results at a given geographical level could not be inferred to other scales and, in particular, to the individual level (Robinson 1950). It became then important to evaluate the range of variability and to define the significance of a result, still in the same perspective (Blalock 1964, Yule & Kendall 1950, Fotheringham 1991, Amrhein 1995): every statistical result obtained on aggregate data was suspect. Little by little theses studies were enriched by taking into account more geographical considerations such as spatial autocorrelation: if the variability tends to decrease when data are aggregated, this is more true for instance, when data are negatively correlated than when it exists a strong positive autocorrelation. This observation allows to control and to have better prediction possibilities on the statistics to estimate (Hunt &Boots 1996, Kudsen 1987). As quoted by Bivand (1998), "*Arbia (1989) made a major contribution by studying in depth a range of links between the presence of spatial autocorrelation and the MAUP*"

Most of these studies concentrating on the MAUP as a problem lead to very pessimistic conclusions. It is worthwhile to point out that they do not always lead to exactly the same results, because most of them are empirically based and lay on specific data, or specific experience protocol. Table 1 delineates some of these results, chronologically, but with no pretension of an exhaustive review. It illustrates the different statistics and models that have been visited through the angle of the MAUP, and the different conclusions which are associated. It perhaps illustrates Amrhein's remark (1995) *" For the spatial analyst the world is not as bleak as suggested by Fotheringham and Wong (1991), but it is unlikely often to be as well as found in Armrhein and Flowerdew (1992). There is likely a long way to go before the aggregation effects are easily purged from the data, but it is of some confort to know that we can proceed in an orderly fashion".*

Table 1 Some historic of the sensitivity analysis to the MAUP

Authors	Focus	Experiment	Main conclusion
Gehlke and Bielh (1934)	Correlation coefficient	Empirical data, different type of variables, different type of grouping	Variation due to number and size of areal units
Robinson (1950)	Correlation coefficient	Empirical data; Inference from aggregate to individuals.	Ecological Fallacy
Yule and Kendall (1950)	Correlation coefficient	Empirical data	Variation due to number and size of areal units
Duncan 1961	Concentration index		Scale dependant
Blalock (1964)	Correlation and slope of bivariate regression analysis	Empirical data Different aggregation criteria (from random to proximity)	no obvious impact in the case of random; increase in case of proximity (but not systematic); great increase for grouping according to an independent variable.
Clark and Avery (1976)	Bivariate regression model: correlation and slope		Both increase with aggregation but not monotonically
Openshaw and Taylor 1977, 1979	Correlation	Artificial variables; Aggregation by proximity of 2 artificial variables (2 extreme cases : no autocorrelation. ; high positive autocorrelation)	Aggregation increases the value of the correlation, the stronger thzat the spatial autocorrelation is important
Arbia (1989)	Regression parameters and significance	Theoretical framework	analytical solution under very restrictive conditions
Fotheringham and Wong, (1991)	Multiple regression parameters	Empirical data	Dramatic variations
Amrhein (1995)	Univariate statistics	Experimental population randomly affected to 3 geographical levels	stable mean, variable variance (inverse relation with n), increasing effect with initial heterogeneity.
Hunt and Boots (1996)	Factorial analysis	Test of the first factor	MAUP effect is influenced by spatial autocorrelation.
Reynolds and Amrhein (1998)	variance	Analytical	affected by spatial autocorrelation and arrangement, and the number of aggregate cells.

It seems then that ideas about the intrinsic properties of space and the different processes dealing with spatial autocorrelation have been integrated, giving rise to very interesting work. They integrate the double aspects of the problem, and are developed by authors with complementary competency: statistician and geographer. Interesting solutions are proposed. A good example is Holt & al one's in 1996. The originality of their proposition compared to preceding work lays on two points:

- first, they propose an issue "*This is useful to understand the cause of aggregation effects but this does not solve the problem of how to adjust the results of an area-level analysis to provide reliable estimates of individual-relationships*"
- secondly the solution they propose allows to take explicitly into account geographical properties and area formation process.

Indeed, they propose to combine 2 types of models, each of them illustrating a territorial principle:

- *a bottom up logic*: "grouping models" associated to a segregation process: it is based on the hypothesis that individuals with same characteristics will, more probably than others, choose to live in the same regions;
- *a top down logic*: "group dependant models", modelling the fact that people living in the same area are "exposed to common influences" and hence may have converging characteristics.

Bivand (1998) underlies the interest of that approach: "*the use of well chosen grouping variables to adjust the area-level results may yield reliable estimates of underlying individual-level relationships, thus providing at least a partial solution to the MAUP with respect to the "ecological fallacy", the drawing of individual-level inferences based on area-level analyses*".

It should be noted that this work, which is strongly rooted in the MAUP field of research, has many common aspects with research developed around multi-level analysis and integration with contextual effects. Theses approaches will be developed in 2.4.

Many works have been developed in the same spirit as for the statistical methods emphasized here, for other kind of spatial models: for example for spatial interaction models (Tobler 1989, .Horner and Murray 2002), or for location-allocation models (Fotheringham & al. 1995, Murray and Gottsegen 1997).

If the present tendency is more to propose issues to the MAUP, there are still works about the question of "how" and "how much" change the statistics among scales, such as spatial autocorrelation for instance (Griffith & al., 2003) for among other things a better compliance between data and hypothesis, as well as a better formulation of the models.

2.2 The individual level to solve the MAUP

For many researchers the MAUP is seen as such a disturbing problem that all observation and modelling should be developed at the level of the individuals. Two questions are linked: the access to individual data and the choice of the individual level in order to develop a model dealing with spatial organisation and dynamics.

Since the 1960ies, the researchers who have developed microsimulation defend a modelling at the level of the most elementary entities (individuals, households, firms, cars..), even when the aim is to produce explanation and previsions at an aggregate level. Many models have for example being developed to simulate the evolution of population and economy according to different categories. Pioneer work was developed by Orcutt (1957), and geographers have progressively developed models where the spatial dimension is central (Holm et al. 2004, Moeckel at al., 2002, Waddell 2000). Their hypothesis is that the inter-individual diversity plays a central role in order to explain the evolution of the population configuration at more aggregate scales. This hypothesis is so strong that synthetic populations are created when access to individual data does not exist (Spiekerman and Wegener, 1999). Until the 1990ies, most spatial models, except for microsimulation, were developed at the meso-geographical level, that is the level of spatial entities as quarters, regions, cities for example. With the development of multi-agent systems (MAS), more and more models are developed at the individual level. In the introduction of their book, defending the idea of a significant break in the modelling practice with the development of agent-based modelling, Benenson and Torrens (2004) argue that one essential reason to prefer the individual level, is that it concerns *spatially non modifiable entities*. Such approach corresponds to an interpretation of the MAUP as being a central problem. This view is based on the fact that many classical spatial models where developed at the level of spatial entities which were chosen mainly for the reason of the data existence. The spatial entities where then seen as envelops, whose only role was to *contain* aggregations of individuals. But spatial entities could also be defined as proper geographical objects which make sense at a meso-geographical level, and in that case, of course, the MAUP does not exist anymore (see Openshaw, frame 1).

In fact the question of the choice of a certain level to observe or to model a phenomenon should be treated independently from that of the access to data. As shown by the developers (users) of microsimulation, the stake associated to the individual level is so important that it is worthwhile to build synthetic populations from different cross-data available at an aggregate level when individual data do not exist. But this does not mean that each time it is technically possible to develop a model at the individual level, this is the best solution. For modelling the evolution of system of cities for example, the city represents a spatial entity which makes sense according to the hypothesis that inter-urban interactions represent the driving force of the urban system (Bura et al. 1996, Sanders et al. 2006).

The access to individual data is of course the ideal situation, not because the individual level is in all cases the most appropriate one to observe or model a phenomenon, but mainly because it gives the choice to observe information at all possible levels and for all forms of spatial partitions. That way it authorises multi-level exploration , in the way it has been showed in this report for the Swedish case (§3.1).

2.3 The search for an optimal spatial partition

There exist an infinite number of ways of partitioning space. Some are completely artificial, as in the case of a grid, others correspond to administrative definitions, as in the case of countries or regions (European NUTS for example). From a conceptual point of view, one has in the first case to reflect on the best adapted scale according to the nature and variability of the studied phenomenon, and in the second one on the adequation of the administrative entities according to the question of study. In order to find a methodological solution to the MAUP, some researchers have developed techniques in order to find out an optimal partition of space. Befote presenting them shortly, it can be suggested that the reference to optimality in this domain is ambivalent. For the statistician it means robustness, for the cartpgrapher it means spatial entities with comparable size in order to obtain readable representations of the phenomenom, and for the social scientist, it means that the spatial entities make sense relatively to the nature of the studied phenomenon. So the notion itself of optimality has to be handled precautiously.

Many of the studies quoted in §2.1, are based on calculus which are summarized on a large number of zonings corresponding to a same level of resolution. These different experiments are very computer intensive but they allow to test the sensitivity of the different measures. It is tempting to adopt such strategies in order to identify which zoning is *the best*. It is a field that has been dominated by Openshaw and his colleagues and encouraged by the development of GIS and the improvement of computer capacities.

These authors are at first convinced that the problem is much more conceptual and geographical than methodological and statistical (see frame 1). The framework of their purpose is the new" freedom" of the user facing all the new technical capabilities in order to avoid the official and classical zoning and design zonings that are much more adapted to underlying processes that operate at more local scales. The aim is then to develop a methodlogy allowing to start with a set of units of a low scale and to create a new set of upper regions, by aggregation, suitable for a specific purpose.

This question has been solved at first by some regionalisation algorithms based on structure similarity (multivariate classification with contiguity constraint) or functional links (aggregation based on flows).

This question may also encounter some aspects of the question of location-allocation, which is a question of partitioning also impacted by the MAUP as already mentioned.

Openshaw proposed an Automatic Zoning Procedure (AZP) whose principal was to aggregate a given set of N zones in M regions under contiguity constraint, and according to a principle of optimization of a given objective function F, related to the question and the aim of the partitioning. The firts algorithm was based on a heuristic procedure and knew improvment over time. It has been finally implemented in ArcInfo as a Zone DEsign System and has successful empirical applications (Openshaw 1997, see frame 2).

A particular useful application has been done by Martin (2000) to response to the Census Offices for England and Wales that adopted a strategy whereby the 2001 output geography is to be created separately from the EDs used for census data collection. Martin designed Output Areas (OA) based on a weighted function of 3 criteria: equal population, compact zone shape, internal homogeneity.

Frame 2 MAUP as a spatial analysis tool; the improvements allowed by technical developments

Openshaw, 1997, Developing GIS-relevant zone-based spatial analysis methods.

"Fotheringham and Ding (1994) clearly have the right concept when they describe a Spatial Aggregation Machine (SAM), although it does no more than randomly generate zoning systems. Openshaw and Rao's (1995) Zone Design Systems (ZDES) deals with the optimisation problem as well but not with the related spatial analysis tools. This chapter suggests how both the SAM and ZDES now need to be extended to provide a full set of spatial analysis tools for zonal data analysis. The pieces exist. The data almost exists and the latest generation of high performance computer is just about fast enough. The challenge now is to do it and investigate further how best to exploit zone design as a powerful, explicitly geographical spatial analysis tool relevant to GIS." ./..

These approaches underline that "*to best control for modifiable areal unit effects, it is necessary to design your own zoning scheme, but this minimizes rather than removes the generic problems associated with zonal geographies*" (Martin 2000)

But Martin concludes also that the use of grid squares as elementary spatial units instead of constructed units as previously presented, is still preferred because of their statistical properties (identical) and their potentiality of extension for international comparison. (see §3.1)

2.4 The integration of the scalar properties of space

Another strategy in order to deal with MAUP can be found in the methodologies developed for integrating spatial analysis and space characteristics in a classical statistical framework, highlighting their role as an active agent of the different spatial organisations. Such approaches will be summarized in this part. They may either focus on horizontal relations with the introduction of neighbourhoods in the methods, or vertical ones by introducing explicitly the different levels of the hierarchy, and making hypothesis on the interscale relations.

The aim of all these methods is to integrate the nested hierarchical organization of space, lower level spatial entities being part of units of upper levels in the model. The idea is to try to decompose the observed variability into two components: the inner aggregate variability and the inter-aggregate one. As a simple example of this type of approach, Wong (2003) may be quoted. The segregation indexes are typically measures that only exist at aggregate levels, and for which one has to learn from putting in relation segregation with geographical levels. In that spirit, Wong proposes to draw part of the ambiguity linked to the choice of the appropriate level: the indexes may be spatially decomposed into different geographical levels, regional and local. Because the distribution of population at the regional level constraints the distribution at the local level, segregation at the local level is thus measured taking into account the specificity of the distribution at the regional level. Then segregation values at different level may be linked together.

In the same family of methods than the one used by Holt, more and more applications use contextual, multilevel and variance components models. These multilevel models are also referred to as hierarchical, mixed and random effects, covariance components, or random-coefficient regression models. These models based on classical formulation of the linear model such as regression, allow to contrast different geographical level: individual level and aggregate level (see frame 3). Thus, effects related to each level are tested simultaneously. That is very simply done, instead of making the hypothesis of the existence of one relation among the whole studied population, with single source of variations (residuals), the deviations may have as many sources as there are levels integrated in the model. This means that if effects are significative, there may be as many models as there are types of embedded contexts.

These formulations are a very important improvement in the way of considering the different levels of aggregation that compound space. This has been possible by a simultaneous evolution in statistical techniques and software for multi-level or hierarchical modelling. But it has been possible also due to the way geographers introduce contexts as explicative factors and their awareness of the lack of positive apprehension of the scale effect of the MAUP.

Many empirical applications introducing geographical contexts in the models exist. Some domains, such as health researches, have been very driving in the development of such methodologies that valorise the multiscalar interactions in the processes of spatial structuration, as well at the individual level as at the aggregate levels (Duncan, 1997).

Frame 3 Example of formulation of a multilevel model

In the case of 2 levels: i individuals, j region

$yij = \beta^*(xij) + \alpha(Wj) + uj + eij$,

where

yij is the measure of the dependant variable for the individual *i* in region *j*;

xij is the measure of the independent variable for the individual *i* in society *j*

Wj is the a contextual variable measured at the level of the region *j*

β^* estimate the nature of the relation between *yij* and *xij* within the region j

$\alpha_{.}$ estimates the effect of contextual measure on the variation of *x* having taken account of the individual relation.

Most of these research has been developed for explicative models (regression, logit..), but the same types of developments exist for descriptive statistical methods. Benali and Escoffier (1990) for example have proposed smooth factorial analysis and factorial analysis of local differences also based on the decomposition of the correlation matrix into two levels. The idea is to decompose the differentiation structure at the lowest level into an inter-aggregate differentiation (higher level) and an intra-aggregate differentiation (lowest level). Such methods are very interesting to link the levels and understand if and how contexts influence or have effects on lower levels. An empirical example has been developed by Grasland (1997)to study the local structure of demographical differentiation of the European regions.

The methods developed by Fotheringham are a good example for illustrating the first type of methods (Fotheringham & al. 2001, Brundson & al. 2002). Their spirit is close to that of the first family presented above, in that it refers also to the regression framework, but make the decision of local spatial statistics. These authors propose the geographically weighted regression (GWR) to be a potential solution for the scale effect. To compare with the multilevel models, the model lies on localised statistics; that is all global statistics are replaced by local ones, as a summary of surroundings values in inverse proportion of their distance to the points. Thus the method provides a set of localised regression models that is different sets of regression parameters corresponding to different locations in studied space. (see §3.2 and §1.3.2)

All these methodologies assess the fact that to try to develop issues to the MAUP integrating the different scales help to highlight the intrinsic characteristics of the process of spatial organisation of the studied phenomena. This goes in the direction that Tobler (1989) as well as Openshaw (1984) advocate: aggregation is not only a quantitative process; it changes dramatically the main point of the units as well as the variables. The question of the MAUP must be posed before the treatment rather than during it.

2.5 MAUP as a tool to explore the multi-scalar structure of a phenomenon

As suggested in several occasions above, the fact that statistical treatments' results and models' outputs vary according to the zoning which is used to define spatial entities, is not systematically a problem. It can, at the opposite, mean useful information on the phenomenon and the process under study. Let's imagine that a certain statistical treatment (for example a simple correlation measure) is applied to variables observed for a set of nested scales. Let's imagine two situations: 1. all the measures are about the same for all scales; 2. there is a significant difference in the results (the correlation varies for example from significantly positive to significantly negative). From a statistical point of view, we will conclude robustness in the first case, instability in the second one, and perhaps "prefer" the first one, because it is the only reliable one from that point of view. From a thematical point of view, the conclusion will be that in the first case the variables under study are (or are not) linked whatever the scale of observation, when in the second case the relationships obey obviously to a more complex multi-scalar structure. And from that point of view, the second case is perhaps more interesting because it shows a complex structure which is of interest (see examples in the first section of this part). That way, the variations of results which are in focus in the MAUP constitute an exploring tool giving an insight in the structure of space rather than a problem. Indeed, showing these variations creates knowledge on the associated processes.

Openshaw (1996) argues in that direction, interpreting even the zoning as an interpretative framework which facilitates the understanding of space : "One of the nicest features about zones is that they provide a major simplification of real world complexity that is naturally geographical. Frameless continuous space representations are more mathematically appealing than geographically relevant. **The real problem** at present is not really the clumsiness of a discrete zonal representations of space **but that geographers have not yet faced up to the problems they present**. **There is a need to bring the MAUP under control and to change attitudes towards it. It is important also to drop the -P, the MAU issue is only a MAUP whilst we ignore it**! Openshaw (1978a) argued that it is not a problem to be removed by sophisticated means but a potentially extremely useful spatial analysis tool." From a theoretical point of view (which can be summarized in the drop of the "P"), the position of Tobler has the same roots, even if it leads him to different conclusions. It can be illustrated by his position relatively to the correlation coefficient for example: "The fallacy in all of these studies is the assumption that the correlation coefficient is an appropriate measure of association amongst spatial units. Clearly it is not - the appropriate measure is the spatial cross - coherence function (see Rayner, 1971) and the association between the two variables may be different in different locations - but all of these authors put the blame on the spatial units."

Tobler in a sense, as Openshaw, has a view of the MAUP that is beyond the statistical framework. They are certainly the two authors who have the most original position about the MAUP issues. The personal idea of Tobler lays on the fact that the "common fact of geography is that places influence each other" (Tobler 1979) and that thematical problems can never be studied independently of their support (that is space) as Openshaw. But they are also in opposition. While Openshaw defends a multipartitioning of the space, that is one optimal partition for one question, Tobler since 1979, advocates a continuous view of space, and proposes the pycnophylactic interpolation as a solution to both effects of the MAUP but also to the problem of incompatible zonings (see §3.3). Other proposition has been made in this direction by Grasland and al. (2000). This position opens other perspective from a multiscalar point of view. The authors defend a multi representation of space associated to different ranges of functioning; each representation contributing to a knowledge.

As underlined above (Paez and Scott, 2004), GIS open wide ways to explore such contributions. Marceau (1999) underlines more generally the role of the new Technologies of information sciences: "The advanced capabilities of computers, and the widespread use of technologies for spatial data acquisition and analysis, such as remote sensing and geographic information systems (GIS), provide unprecedented means to achieve significant progress in relation to the scale issue. ../.. In a complementary fashion, GIS provide opportunities **to create multiscale representations** by incorporating and linking digital maps at **different scales**, and through the development of statistical and mathematical functions to deal with scale as a generic issue. GIS are particularly beneficial for analyzing the relationships between variables at different scales, and for assessing the impact of scale in modelling." This author presents several examples in natural sciences for explaining the interest of scale issues. The aim is to find out the intervals of scale where the results of analyses are quite stable, and the thresholds at which they change significantly. These stabilities and breaking points bring knowledge on the spatial organisation of the landscape that the methods associated to scaling laws can help to investigate.

Following the fundamental position of Openshaw, and the contributions of Arbia (1989), and more recently of Gotway Crawford and Young (2004), it seems fruitful to replace the reflexiono on the MAUP in the more general framework of multi-source geographical information. This position, developed in health research, propose the term of COSP as more general (see frame 4). This framework is fruitful in the sense that it opens the question, from a discrete perspective to a continuous one from a methodological point of view, from a territorial perspectiva (based on zoning) to a spatial one from a geographical point of view.

Frame 4 MAUP within the COSP perspective

"With the recent advances in GISs, the scale and zoning problems in the MAUP and the ecological inference problem are now almost routinely encountered in analyses that use spatial data. They can occur naturally or be artificially induced by the measurement process or analytical considerations. Frequently, the spatial process of interest is inherently of one form, but the data we observe are of another form. For example, sometimes the data are just not available at the desired scale of interest. Meteorologic processes occur over a continuum, but we can record only point observations along such a surface. At times, individual-level inference is desired, but to ensure data confidentiality, only aggregate data are available. These situations are special cases *of the change of support problem* (COSP) in geostatistics. The term support refers to the geometrical size, shape, and spatial orientation of the regions associated with the measurements (see e.g., Olea, 1991). Changing the support of a variable (typically by averaging or aggregation) creates a new variable. **This new variable is related to the original one, but has different statistical and spatial properties**. The problem of how the spatial variation in one variable relates to that of the other variable is the COSP. The COSP often results from the different forms of spatial data: points, lines, areas, and surfaces. Thus, both the ecological inference problem and the MAUP are COSPs.

…

"…in addition to the MAUP and the ecological inference problem, numerous other terms have been introduced to describe one or more facets of the COSP as well as various "solutions" to it: Spatial Data Transformations; The Scaling Problem; Inference Between Incompatible Zonal Systems; Pycnophylactic Geographic Interpolation; Block Kriging; The Polygonal Overlay Problem; Areal Interpolation; Inference with Spatially Misaligned Data; Contour Reaggregation; and Multiscale and Hierarchically-Scaled Modeling. We choose to use the term change of support to describe the problems inherent in all of these approaches because it provides a unifying framework and offers many insights into possible solutions."
Gotway Crawford, Carol A. and Linda J. Young. 2004

As a conclusion, we want to underline that, even if MAUP is an old issue, even if there doesn't exist a miraculous solution permitting to infer a result obtained for a given spatial zoning to another one, the MAUP issue is still a promising domain of consideration, with a high potential of knowledge creation. Indeed, the accumulation of work on this topic, combined to the performing technological environment offered by contemporary GIS, creates an ideal framework for methodological advances as is illustrated by the three case studies and the part 2. On the other hand, when it is well integrated in the methodological and conceptual framework of an application, it appears that the "P" of MAUP, rather than referring to a problem, would be better associated to "potential", "possibility" and "progress".

3 Case studies on Ireland, Sweden and Germany

3.1 Case study on Sweden

An administrative border will, in certain cases, act as a functional border. Taxation levels, local regulations, and other politically decided parameters often give rise to geographical differences that coincide with the boundaries of the administrative units. On the other hand, when summarizing other phenomena by administrative regions, artificial dissimilarities that are due to aggregation may appear. Discontinuities may exist in the area, but not where they are found on the map. The most tangible discontinuities may arise between coast/inland, urban regions/rural areas, or city centers/suburbs and not where the administrative borders happen to be situated. Although grid maps do not solve this problem, they are perhaps likely to provide a higher degree of homogeneity within each unit since the surfaces are of equal size. Still, aggregation of data into squares is a rigid method that doesn't take into consideration the distribution of the underlying process or phenomenon.

No matter whether data are shown as grids or summarized by administrative regions, it is difficult to compare large sparsely populated areas with small densely populated ones. Also use of uniform geographical areas will inevitably in most cases generate undesirable variation in the size of the population. In addition, the level of aggregation has a vast influence on the appearance of an indicator. A high-resolution map with a minimum of aggregation will often be fuzzy and hard to interpret. Increased aggregation levels out variation. Conspicuous outliers will disappear within the increasing amount of data around the total mean. All in all, it is complicated to determine how well a final map mirrors the target phenomenon.

Northern Sweden is one of the most sparsely populated areas in Europe. Consequently, the sizes of NUTS 2 and NUTS 3 territorial units are very large. This produces a problem of unit heterogeneity compared not only to the rest of Europe but also within Sweden. The aim of this study is to investigate the modifiable areal unit problem in the Swedish context. Specifically, the aim is to explore the impact of spatial scale as well as grid contra administrative region effects on map representation and interpretation. Beyond the problem of cheating with maps lurks an eventual bias in results of a causal analysis. Similar analyses might end up with different (biased) results and answers only because of the choice of high or low resolution in used spatial data.

The study is carried out by examining and comparing the visual appearance of three indicators in different map types with varying levels of aggregation. The indicators are 1) population density (2002), 2) population change 1990–2002, and 3) mean disposable income (2002). The distribution of the indicators – as well as the number of people – in the map classes are also summarized separately. In addition, descriptive statistics of the underlying distribution of values are presented. The variable disposable income is treated a bit more in-depth. First, a close-up look at the data beyond what is visible on the maps is presented. Also, an attempt is made to provide an estimation of the error that is introduced when full information is not available, by means of a simple experiment based on OLS regression.

Spatial Modelling Centre (SMC) at Dept. of Social and Economic Geography, Umeå University is in possession of a database – ASTRID – that contains Swedish individual register data for the years 1985–2002. The database can be used for specific research purposes only. It contains constant personal data such as birth year, gender, and country of origin as well as time-dependent data such as civil status, education level, and incomes. In addition, the database contains the geographical coordinates of all individuals' place-of-residence with a resolution of 100 meters. Thus, the database provides a good platform for trying out different mapping solutions (grids, administrative territories, smoothing methods, etc.) of the selected indicators.

In the study, the chosen indicators are presented in grid maps and territorial maps – each at four different levels of aggregation. The *grid maps* consist of squares covering the whole country. However, for obvious reasons squares intersecting the national border will not have the predetermined area. This is most evident at the lowest resolution (100 km): only around one third of the squares are even close to the stipulated area of 10,000 km^2. Uninhabited squares, which are most common at the highest resolution (10 km), are not displayed. The grid maps have the following resolutions:

- 100 km squares (N=68 or 69)
- 50 km squares (N=226 or 228)
- 30 km squares (N=562 or 565)
- 10 km squares (N=3,876, 3,954, or 4,040)

The *territorial maps* are based on existing administrative or statistical units. The highest resolution is found in the maps based on the 284 municipalities that existed in Sweden in 1990.[9] The next level is one commonly used definition of local labor market regions – aggregations of municipalities into functional regions based on commuting patterns. The territorial maps that will be shown are:

- National areas, i.e. NUTS 2 (N=8).
- Counties, i.e. NUTS 3 (N=21).
- Local labor market regions (N=81).
- Municipalities, i.e. LAU level 2 (N=284).

[9] Subsequently, six additional municipalities have been created from parts of existing ones. However, since one variable involves data for the years 1990 and 2002, the lowest resolution – i.e. the smallest number of municipalities – was used in the study.

Since the 10 km square maps have the highest resolution (and therefore the most extreme minimum and maximum values), the distribution of the variables at this level formed the basis for the classification of all maps. The attributes of the 10 km squares were divided into six groups with an approximately equal number of squares in each. The same class breaks were then been applied to the other seven maps of the concerned phenomenon. As will be revealed later this might be one reason for the emergence of different interpretation problems.

3.1.1 Population Density

In Figure 9 and 10, population density (inhabitants/km^2) for the year 2002 is displayed in territorial and grid maps, respectively.[10] The territorial map with the highest resolution – i.e. the Swedish municipalities – exhibits higher population densities along the coasts and in southern Sweden compared to the inland of northern Sweden. A similar pattern can be recognized for the labor market regions, but at this level there is a contiguous densely populated area between Stockholm and Gothenburg. At the municipality level, this high-density area only appears as a number of scattered heavily populated municipalities. This high-density belt remains in almost unchanged form at the NUTS 2 and NUTS 3 levels. With increased aggregation, the heterogeneity of the map decreases substantially. In the NUTS 2 map, there are only three classes. The main cities Stockholm, Gothenburg, and Malmö and their surroundings are densely populated, while northern Sweden exhibits the lower values. The denser populated costal areas have incorporated the areas with very low population density in the inland of northern Sweden and the final result is a map where more than half of Sweden has a medium dense population.

A somewhat similar picture is discernable in the grid maps. The 10 km square map is irregular and fuzzy, but some low-density areas are seen in southern Sweden and minor high-density areas can be identified in the north. The higher the aggregation of the squares, the more the characteristics from the thematic maps can be recognized. It should be noted, however, that the lowest density class (<0.19 inhabitants/km^2) – which was not present at all in the territorial maps – is represented in all grid maps. Comparing the 50 km square map (N= 226) and the municipality map (N=284), a much more diversified picture is apparent in the grid map. The area corresponding to the low-density municipalities in the inland of northern Sweden is represented as a mosaic of the three lowest density classes.

[10] Water surfaces are not included in the area used to calculate the indicator. The actual land area for each municipality has been collected from Statistics Sweden (<http://www.scb.se/statistik/ MI/MI0802/2005A01A/mi0802tab3.xls>). The other territorial groups are all aggregations of municipalities and their land area were acquired by adding the area of the comprising municipalities. The land area of each square was calculated by addition of the comprising 100 m squares from the Corine Land Cover 2000 data [Corine data: ©EEA, Copenhagen, 2005]. A few the 10 km squares have a land area of 1,000 km^2, but none of the larger squares reach this level.

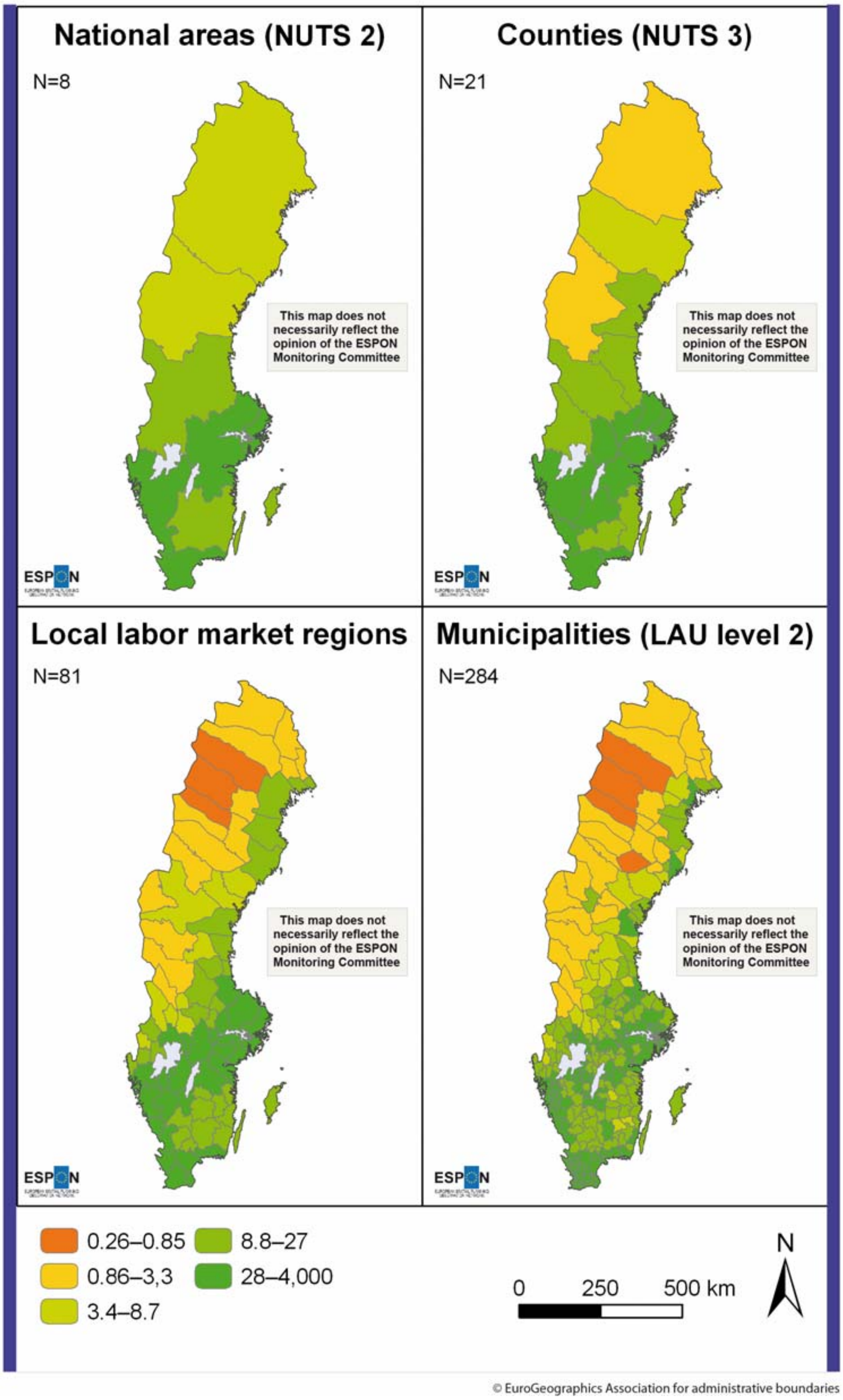


Figure 9 Population density (inhabitants/km^2 2002) – regions.

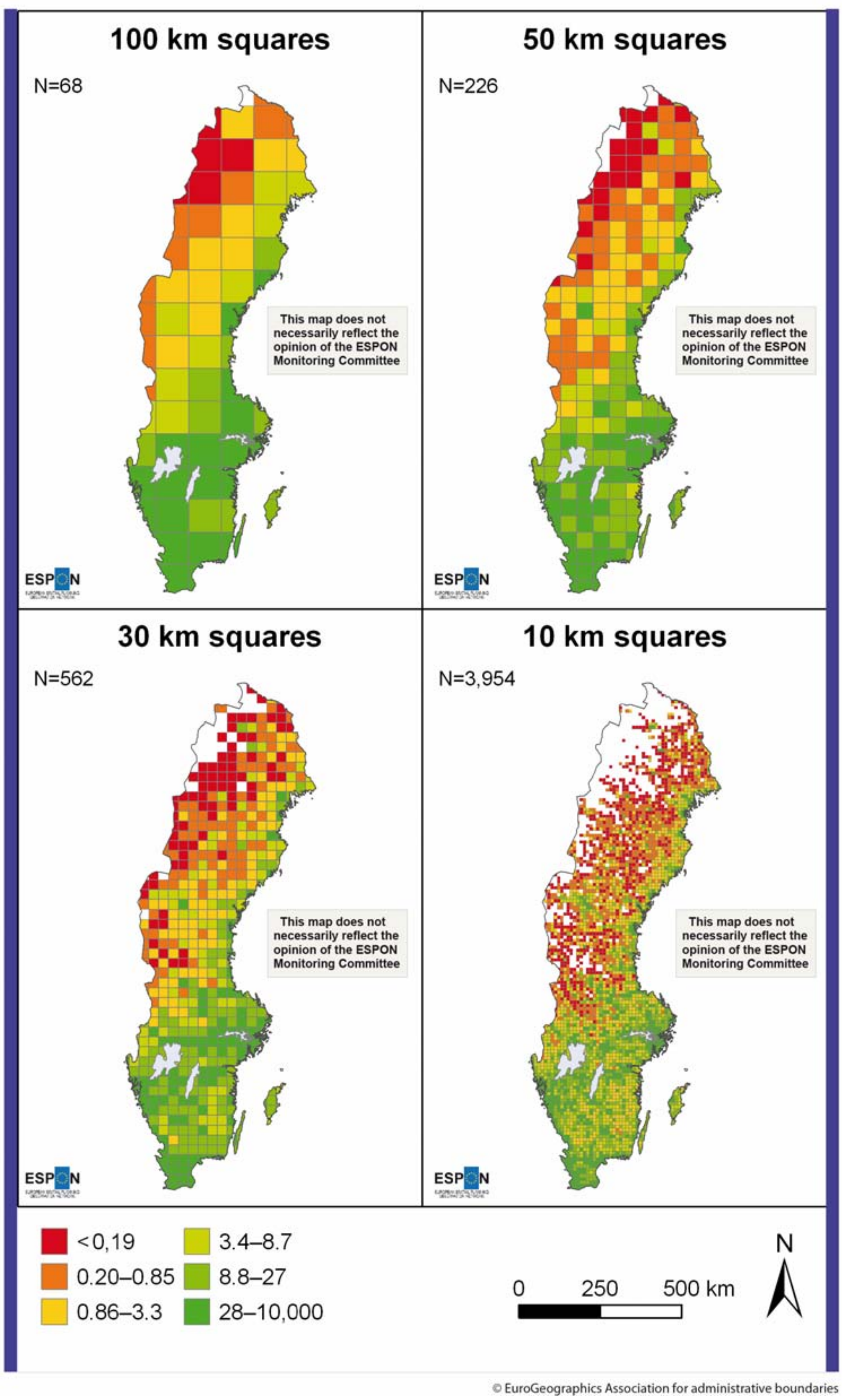


Figure 10 Population density (inhabitants/km2 2002) – squares.

Figure 11 summarizes the proportion of units in the different population density classes. The number of units in the high-density classes increases with aggregation. Moreover, these classes are generally more frequently represented in the territorial maps compared to the grid maps. Since larger urban localities are present in more or less all regions in the territorial maps, but not all of the squares, this is hardly surprising.

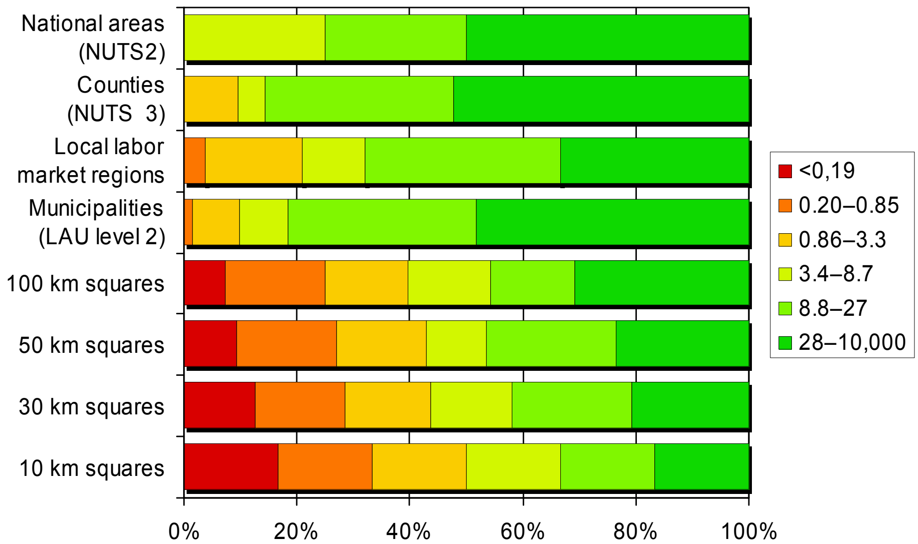


Figure 11 Population density (inhabitants/km2 2002): proportion of units in the different classes. Note that the 10 km square class has an equal amount of squares in each population density class.

Figure 12 displays the percentage of the population living in different unit classes of population density. The population distribution is more or less the same independently of aggregation level and map type. About 80% of the population lives in the most densely populated class. Even though half of the 10 km squares are found in the three classes with lowest population densities only approximately 1.5% of the population lives there.

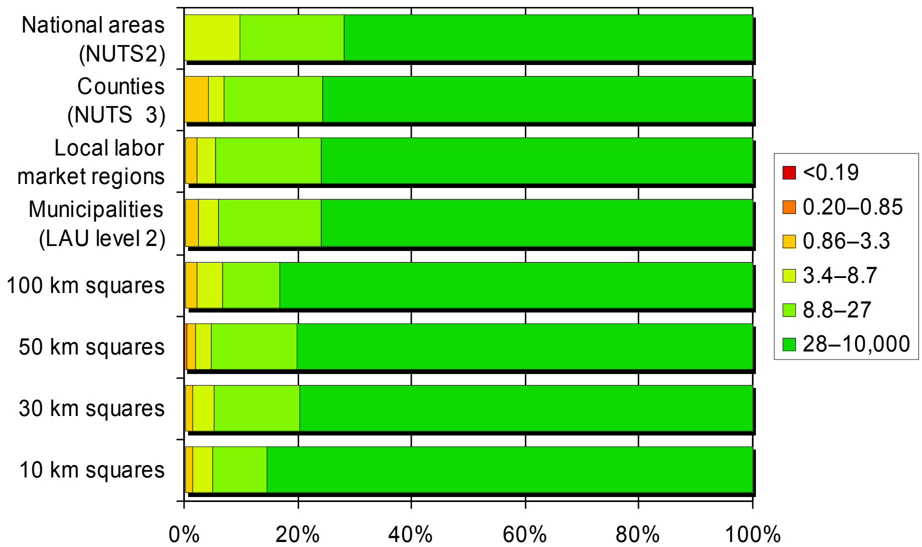


Figure 12 Population density (inhabitants/km2 2002): share of population in the different unit classes.

Table 2 contains descriptive statistics such as mean and standard deviation for the indicator population density. In general, range (maximum value-minimum value) decreases with increased aggregation. For instance, the 10 km squares have by far the highest range. Notably, the municipality level (N=284) exhibits the second highest range and the highest standard deviation, while the smallest range and the lowest standard deviation appear at the local labor market level (N=81). The municipalities also have the highest mean and local labor market regions the lowest. The main explanation for this is that the local labor market subdivision represents an attempt to depict functional regions; many densely populated municipalities with a net influx of commuters are therefore aggregated with sparsely populated municipalities in the vicinity. The distributions are consistently skewed to the right, i.e. there are comparatively few regions and squares with very high-density values.

Table 2 Descriptive statistics, population density (inhabitants/km^2) (2002).

	N	Min.	Max.	Range	Mean	Median	Std. dev.	Skew-ness	Kurtosis
National areas (NUTS 2)	8	3.3	283.7	280.4	65.2	31.4	93.4	2.3	5.6
Counties (NUTS 3)	21	2.6	283.7	281.1	42.9	31.2	60.2	3.5	13.9
Local labor market regions	81	0.3	234.8	234.6	28.0	17.1	38.6	3.3	13.2
Municipalities (LAU level 2)	284	0.3	4,036.2	4,036.0	126.7	26.3	423.0	6.9	54.6
100 km squares	68	0.01	691.4	691.4	36.7	7.5	95.4	5.4	34.0
50 km squares	226	0.001	801.5	801.5	31.3	7.2	86.2	5.9	41.0
30 km squares	562	0.001	2,666.3	2,666.2	35.2	5.7	149.7	12.3	188.1
10 km squares	3,954	0.01	10,344.3	10,344.3	36.4	3.3	250.0	26.1	901.4

3.1.2 Population Change

Figure 13 and 14 show population change in Sweden between 1990 and 2002 in territorial and grid maps, respectively. As with population density, the reduction of heterogeneity is considerable when changing the aggregation from the 10 km squares (N=4,040) to the 100 km (N=69) squares. The reduction is even more substantial when the 284 municipalities are compared to the eight NUTS 2 regions. Looking at the NUTS 2 map, the reader gets the impression that the population redistribution has been rather limited during the period. However, the grid maps – especially the 10 km square map – show that numerous areas have suffered from a reduction of inhabitants, while a few areas have gained and often gained a lot.

In the sparsely populated inland of northern Sweden, every birth, death, and move has a big influence on the demographic situation. Consequently, all degrees of change, from -100% to more than +8.2%, are found here. A small number of previously uninhabited squares in northern Sweden have been inhabited between 1990 and 2002. However, only a few people live in these places. (In total, there are 181 inhabitants in the 51 newly inhabited 10 km squares.)

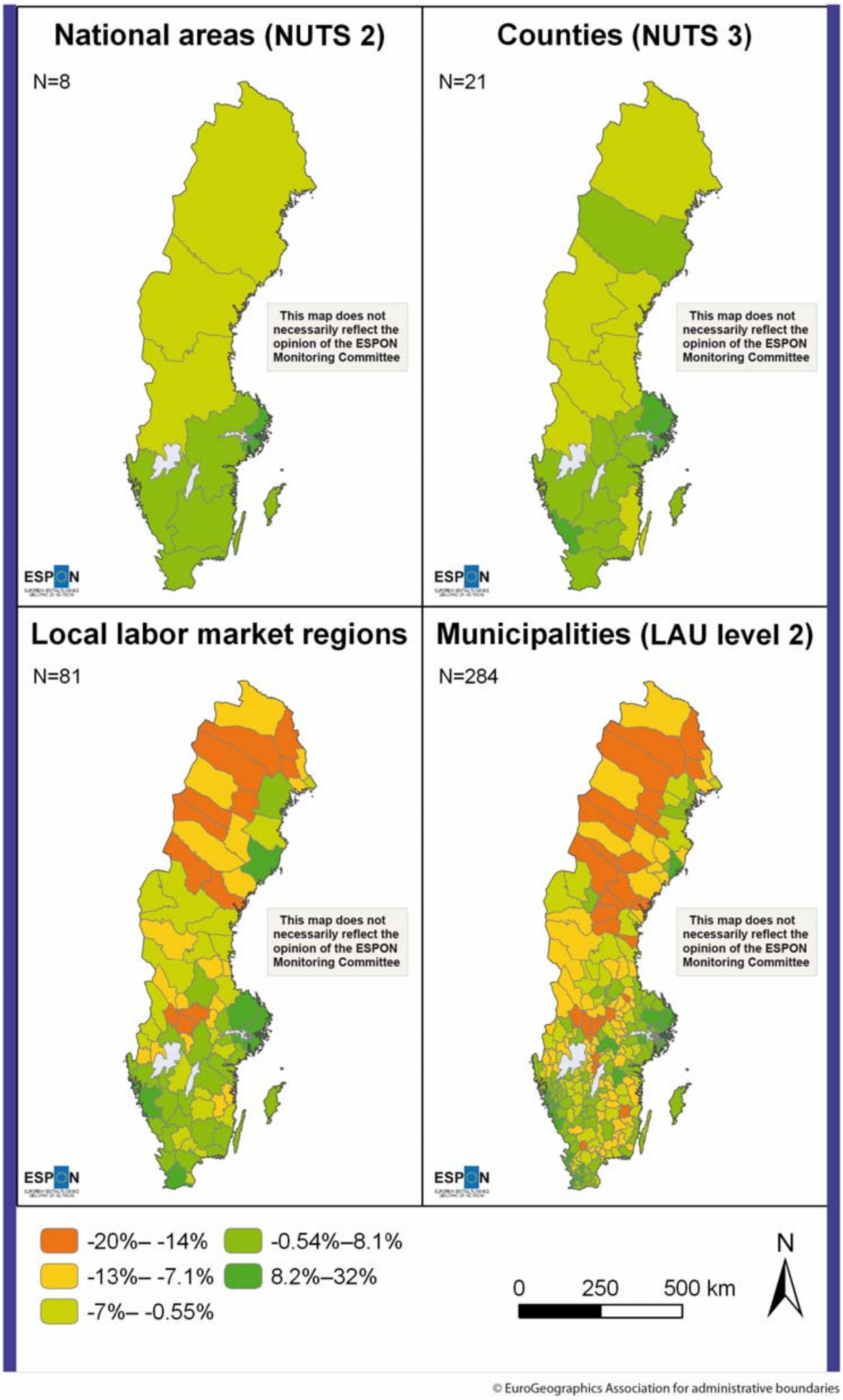


Figure 13 Population change 1990–2002 – regions.

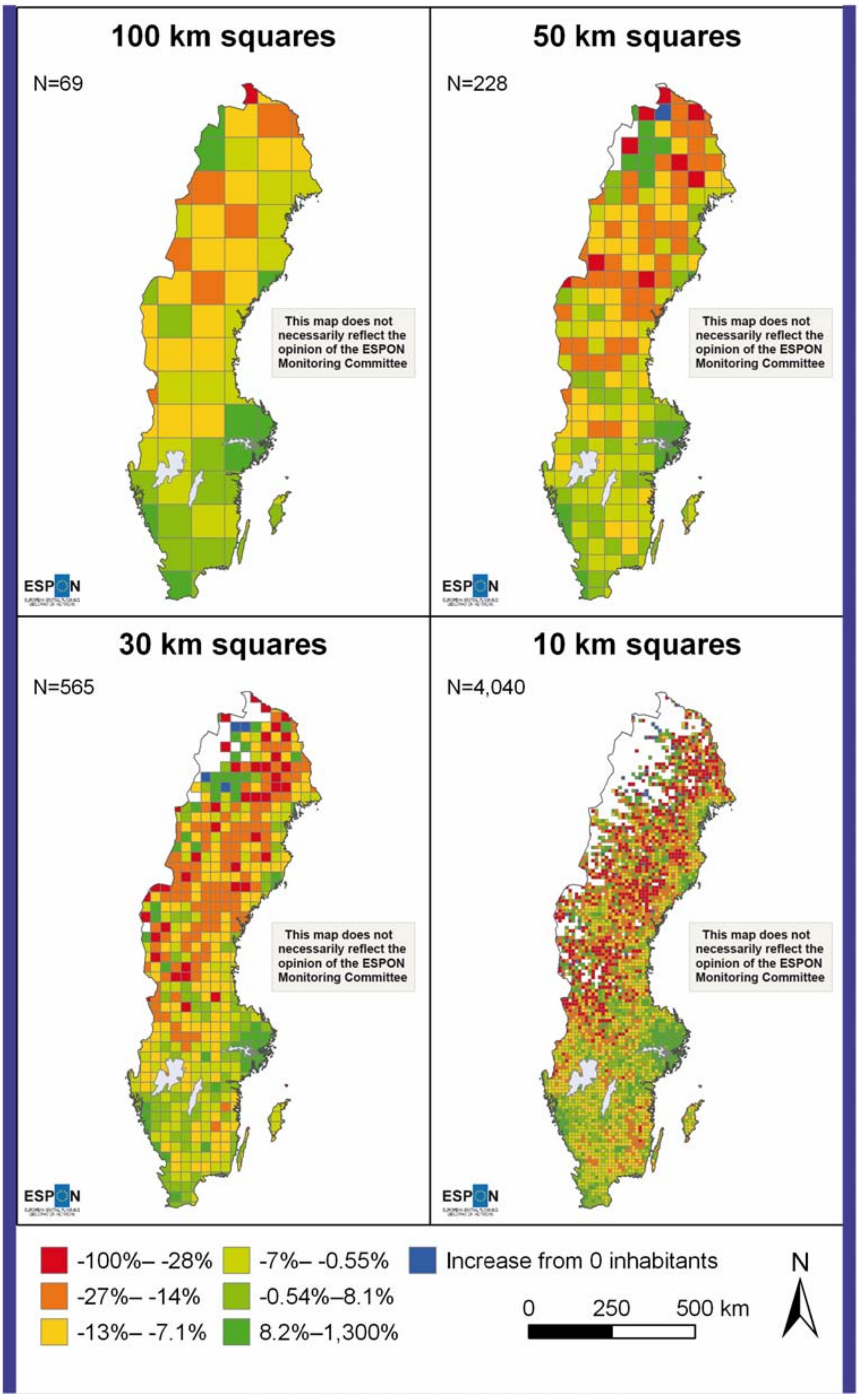


Figure 14 Population change 1990–2002 – squares.

Figure 15 summarizes the proportion of units in the different classes of population change. The majority of the NUTS 2 and NUTS 3 regions are found in the two classes with the least change (-7%–8.1%), while many local labor market regions and municipalities exhibit larger population losses. Of course, this means that the most populated – and therefore most influential – parts of these NUTS 2 and NUTS 3 regions have a close to constant population or exhibit a population increase that outweighs population losses in other parts of the territories (cf. Figure 13 and 14).

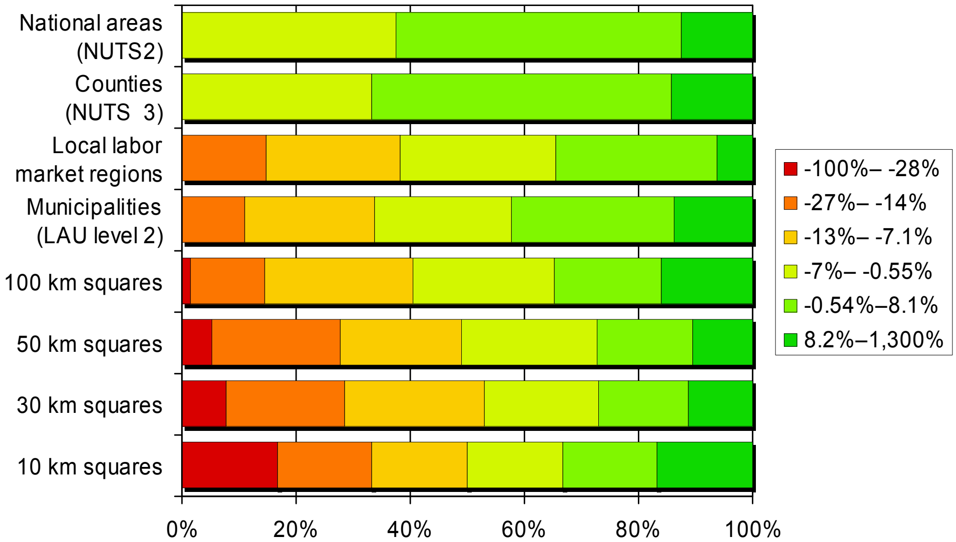


Figure 15 Population change 1990–2002: proportion of units in the different classes[11]

Figure 16 displays the percentage of the population living in different unit classes of population change. Compared to the population density variable where approximately 80% of the population lived in the areas with high population density, the population is less concentrated to the class with the highest increase of inhabitants (cf. Figure 16). Only around 40% live in these areas. Contemporary place attraction (change 90-02) is obviously more selective compared to the result of long-term attraction (cross-section 2002). The number of inhabitants that reside in the 10 km squares with the highest population loss is negligible (0.22%) and the squares with the next highest loss also have a tiny population (2.7%).

11 Excluding squares with an increase from zero inhabitants.

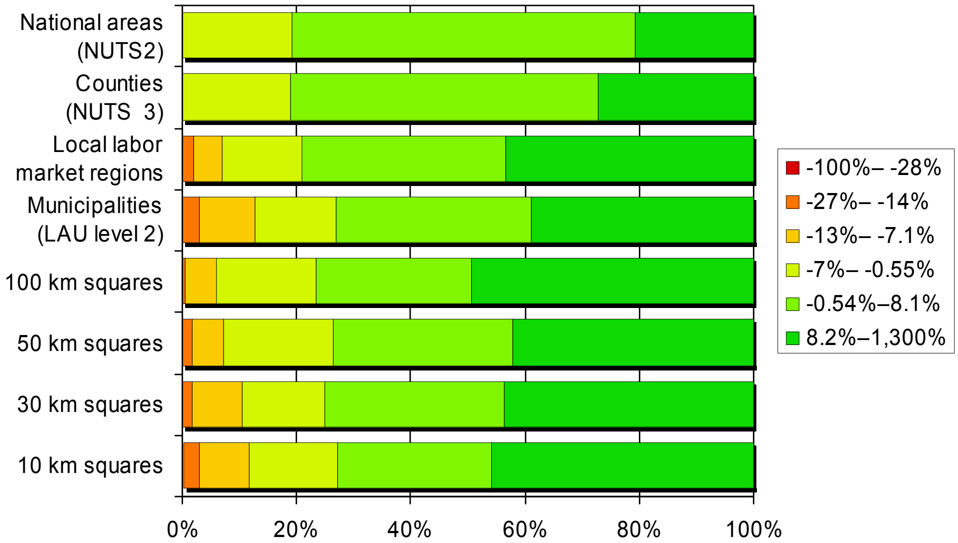


Figure 16 Population change 1990–2002: share of population (2002) in the different unit classes.[11]

Table 3 Descriptive statistics, population change 1990–2002.[11]

	N	Min.	Max.	Range	Mean	Median	Std. dev.	Skew-ness	Kurtosis
National areas (NUTS 2)	8	-6.6	11.4	17.9	1.6	1.3	5.9	0.3	-0.5
Counties (NUTS 3)	21	-6.9	11.4	18.2	0.7	0.4	5.1	0.6	-0.3
Local labor market regions	81	-20.3	11.4	31.7	-4.9	-4.8	7.7	-0.002	-0.7
Municipalities (LAU level 2)	284	-20.3	32.5	52.8	-2.3	-2.9	9.2	0.4	0.1
100 km squares	69	-100	26.5	126.5	-5.2	-4.5	15.6	-3.2	19.6
50 km squares	227	-100	400	500	-4.9	-6.7	34.2	8.0	90.8
30 km squares	561	-100	406.3	506.3	-5.1	-7.9	39.2	8.1	81.6
10 km squares	3,989	-100	1,250	1,350	-6.0	-7.1	48.3	8.7	159.1

3.1.3 Disposable Income

Figure 17 and 18 show mean disposable income in Sweden for the year 2002 in territorial and grid maps, respectively. Disposable income is total earnings when taxes are deducted. The mean is calculated for inhabitants between 20 and 64 years of age and displayed in the Swedish currency (SEK). In the municipality map, the wealthiest areas can be found in southern Sweden, particularly in the vicinity of Stockholm. Most inland municipalities in northern Sweden are comparatively poor. However, the class with the lowest mean income is not present in the territorial maps, and even the second poorest income class is rarely represented. Interestingly, in the far north of the country there is a "wedge" of comparatively wealthy municipalities that stretches from the coastal municipalities towards northwest into the inland. Just like with the other two indicators, heterogeneity decreases with increased aggregation. At the NUTS 2 level, only the three highest income classes are still visible. At this aggregation level, the high-income belt in northern Sweden has disappeared. Due to the impact of the poorer districts in the south, this NUTS 2 region ends up as a territory with quite moderate mean disposable incomes.

The grid maps reveal that the aforementioned "wedge" can be attributed to a limited number of wealthy and densely populated 10 km squares. The squares in question are mainly located in areas with large deposits of iron ore and associated mining activity, the "iron belt." In addition, a number of areas in the inland of northern Sweden that have very low mean incomes are clearly visible up to the 50 km level.

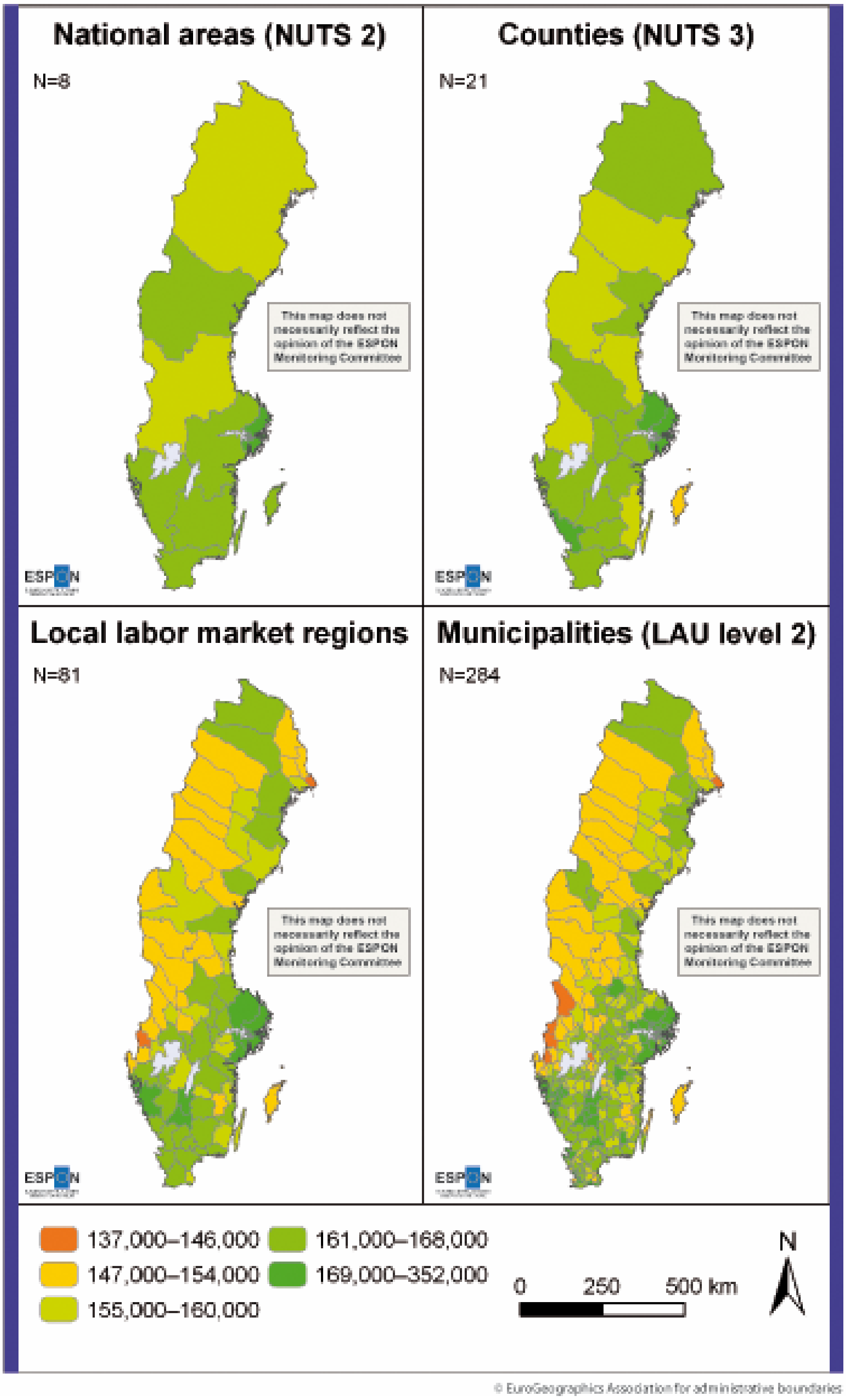


Figure 17 Disposable income (SEK)/inhabitant (20–64 years) (2002) – regions.

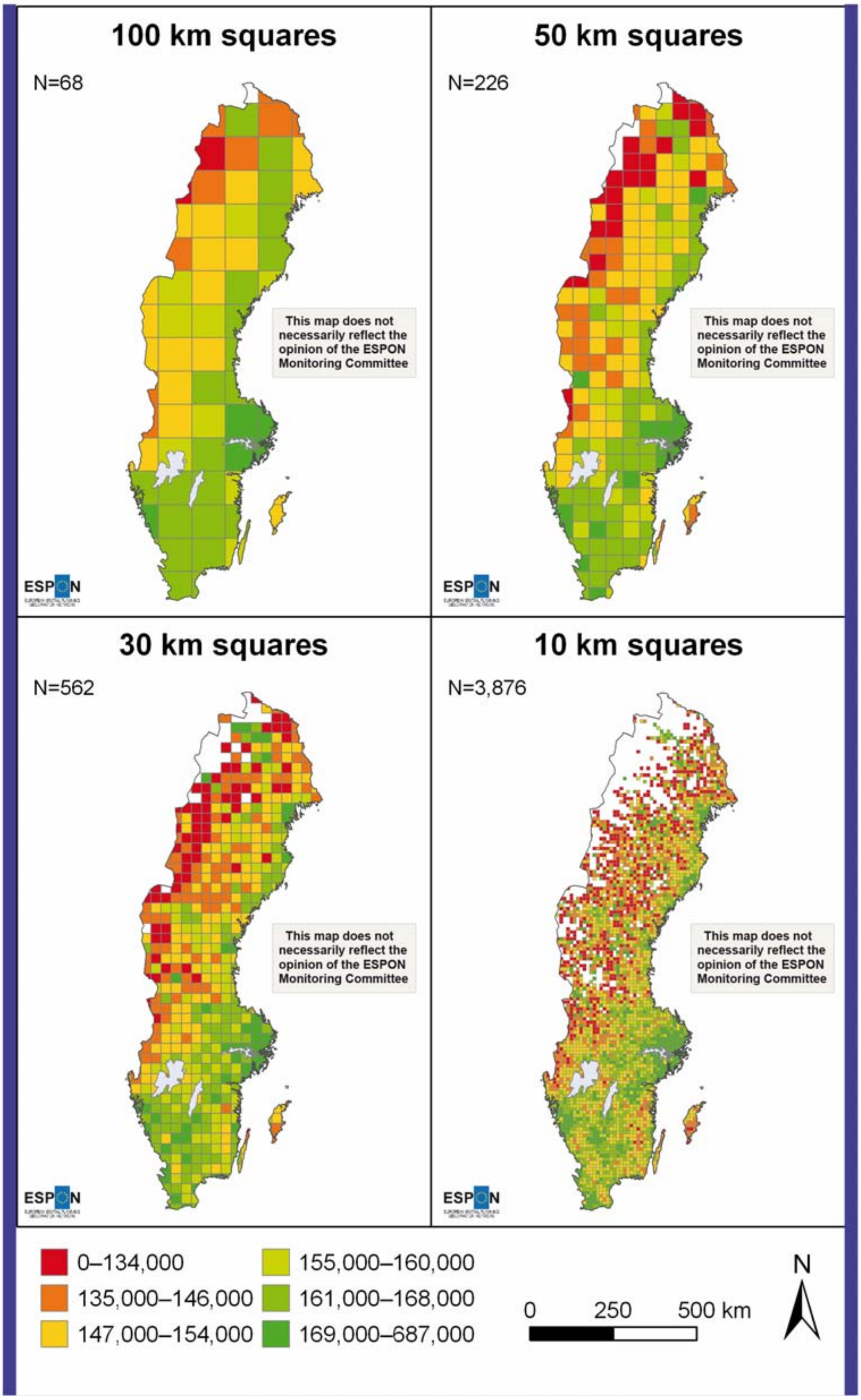


Figure 18 Disposable income (SEK)/inhabitant (20–64 years) (2002) – squares.

Figure 19 summarizes the proportion of units in the different income classes, while Figure 20 shows the percentage of the population living in different unit classes of mean income. As is the case with the population change indicator, the proportion of inhabitants living in the squares with the lowest incomes is very small.

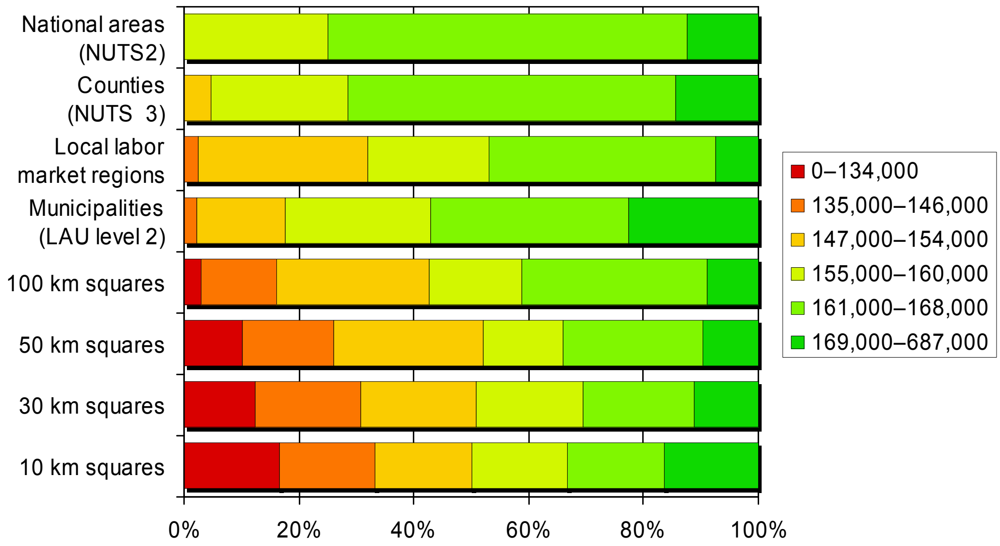


Figure 19 Disposable income (SEK)/inhabitant (20–64 years) (2002): proportion of units in the different classes.

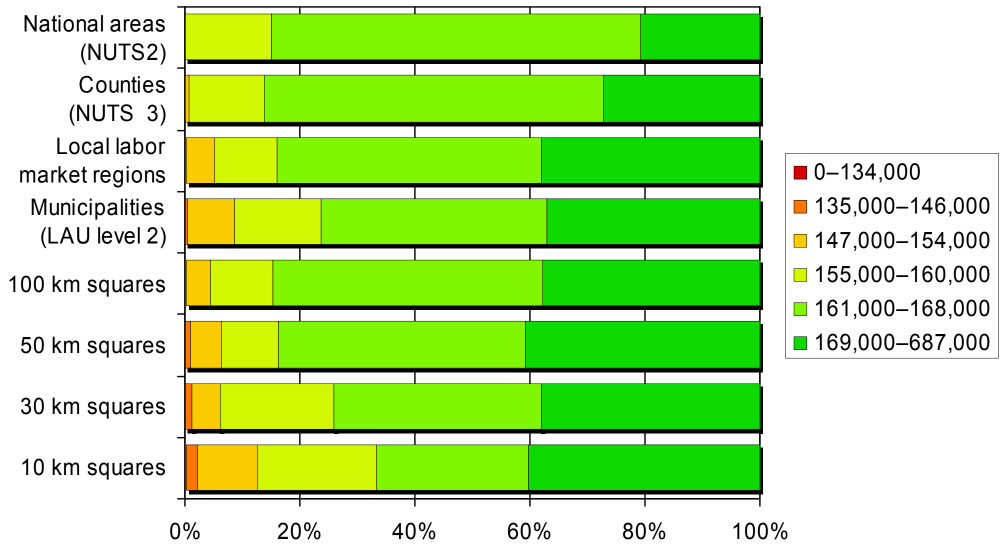


Figure 20 Disposable income (SEK)/inhabitant (20–64 years) (2002): share of population (all ages) in the different unit classes.

Table 4 contains descriptive statistics for the disposable income indicator. The reduction in range is still considerable, but the least conspicuous compared to the other variables. The minimum and maximum values converge with higher aggregation, while the means – and also the medians – are quite similar for all groups. The grids have slightly lower means/medians compared to the territorial maps. This is mainly due to the fact that administrative areas tend to contain both richer urban and poorer rural areas, while many grid squares are wholly rural in character.

Table 4 Descriptive statistics, disposable income (SEK)/inhabitant (20–64 years) (2002).

	N	Min.	Max.	Range	Mean	Median	Std. dev.	Skew-ness	Kurtosis
National areas (NUTS 2)	8	158,400	195,400	37,000	166,700	163,700	12,000	2.5	6.5
Counties (NUTS 3)	21	150,000	195,400	45,400	163,900	163,000	8,900	2.2	7.6
Local labor market regions	81	137,200	195,200	58,000	158,400	159,000	8,600	0.7	3.4
Municipalities (LAU level 2)	284	137,200	352,400	215,200	164,500	160,600	18,600	4.7	38.7
100 km squares	68	124,200	20,7400	83,200	156,465	158,500	13,300	0.8	3.2
50 km squares	226	800	251,100	250,300	152,366	153,100	19,300	-2.0	20.4
30 km squares	562	800	476,500	475,700	152,120	153,400	23,700	3.9	67.1
10 km squares	3,876	0	686,800	686,800	151,387	153,600	27,900	2.3	48.5

In the Hypercarte Project, Grasland showed the discontinuity that appears along the French-Belgian border when mapping population change between the years 1980 and 1990. For the reader it is impossible to compare the differences in population change between the two sides of the border, since the NUTS regions are so differently sized. In similar maps of population density, the heterogeneity of the NUTS regions becomes less troublesome, due to higher spatial autocorrelation – greater similarity between neighboring areas – at the concerned level of resolution. Tests for spatial autocorrelation (Moran's *I*)[12], show that – in the Swedish context, too – the process of population change in many cases tends to exhibit lower spatial autocorrelation compared to population density (Table 5). At the 10, 30, and 50 km square levels, as well as in the municipality maps, population change exhibits the lowest spatial autocorrelation of the three indicators. Naturally, the wide variety of degrees of population change in northern Sweden is an important factor contributing towards this result. Interestingly, comparing the grid maps at the different levels, mean disposable income is consistently the indicator that has the highest value for Moran's *I*.

Table 5 Tests for spatial autocorrelation (Moran's I).12

	Population density	Population change	Disposable income
National areas (NUTS 2)	Not significant	Not significant	Not significant
Counties (NUTS 3)	Not significant	Not significant	Not significant
Local labor market regions	0.098	0.145	0.126
Municipalities (LAU level 2)	0.389	0.230	0.332
100 km squares	0.040	0.073	0.123
50 km squares	0.064	0.021	0.117
30 km squares	0.037	0.016	0.077
10 km squares	0.022	0.014	0.065

3.1.3.1 A Close-Up Look

When maps are interpreted, it is very important be aware of the weaknesses – that they may present a distorted picture, or at least conceal some aspects. The maps that have been shown until now display a sparsely populated and quite poor area in northern Sweden that contrasts with a more well-off southern part of the country. However, a closer look at the data behind the squares reveals that there is more to the picture than meets the eye.

[12] Moran's *I* is the perhaps most commonly used test statistic for spatial autocorrelation – degree of similarity between adjacent regions. The possible values of Moran's *I* range between -1 and 1. Positive values indicate clustering, while negative values indicate dispersion. In these calculations, an inverse distance function was used to conceptualize the spatial relationship between the map units.

There are, in total, twenty-three 50 km-squares in the poorest income class (mean disposable income <134,000 SEK) (cf. Figure 18). In these squares, totaling a land area of over 40,000 km^2, only 3,124 inhabitants in the age 20–64 years reside (6,185 in total). By contrast, in Malmö municipality there are twelve contiguous 1 km squares with a similarly low mean disposable income (Figure 21). In this small area, 42,129 individuals in the age range are found (50,807 in total)! The area is centered on "Rosengård," a council estate with a high proportion of foreign-born and second-generation immigrants. Similar pockets of poverty – albeit perhaps not quite as extreme – can be found in Stockholm and Gothenburg as well as several other large Swedish cities. Obviously, such low-income enclaves disappear in the crowd of more wealthy people in the surroundings when data is displayed with squares of higher resolution.

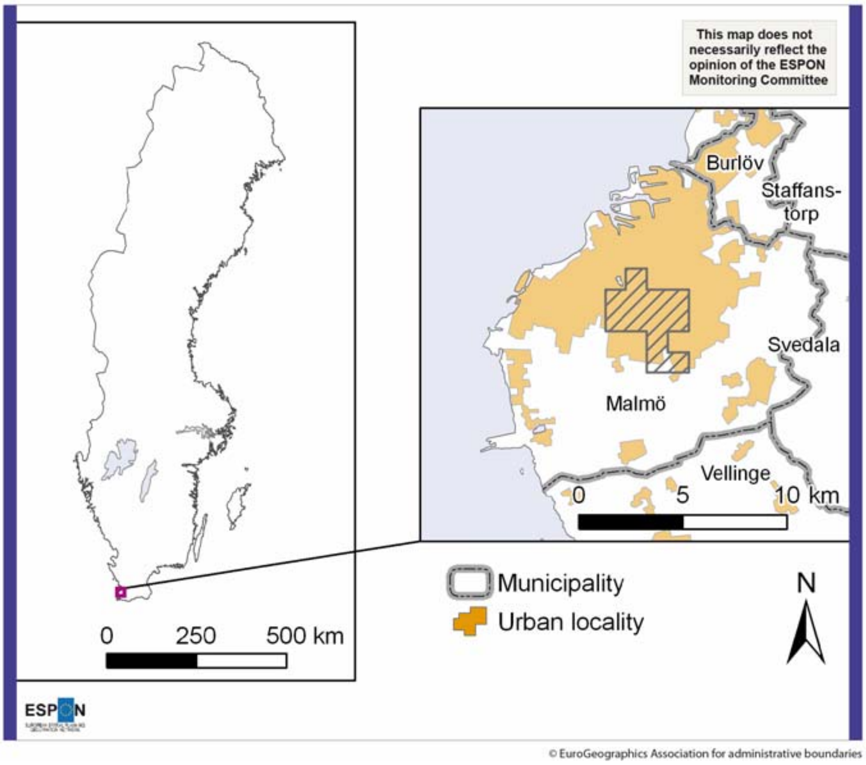


Figure 21 Twelve contiguous 1 km squares in Malmö municipality with a mean disposable income <134,000 SEK.

As stated above, the twenty-three poorest 50 km squares –all with a mean disposable income below 134,000 SEK – contain 3,124 individuals between 20 and 64 years. The mean income of these few thousand individuals is about 128,500 SEK. In the richest 50 km square – which is centered on Stockholm – there are about 60 times as many inhabitants with similar low disposable incomes. If the richer part of the 20–64 years old in this wealthiest 50 km square in Sweden decided to move away, the population in the concerned age group would drop from 611,595 to 182,889, and the mean income from 205,003 SEK to 77,898 SEK. Thus, especially low incomes might not be the biggest "problem" in the poorest 50 km squares, but rather a severe deficit of rich people, which contributes to keeping average incomes at low levels.

3.1.3.2 A Small Experiment

In Table 6, the mean disposable income for the different map types and levels of resolution is displayed. In addition, the mean value is displayed for squares with a resolution of 1 km and at the individual level (population 20–64 years). In a sense, the empirical means at the different levels constitute overall measures of the errors that are introduced in the different maps. When aggregating income levels from very small grids, the mean value decreases at first until somewhere between 10 and 30 km whereupon it increases. In the beginning of the aggregation process, there are lots of uninhabited squares outside urban areas. Therefore, the comparatively small number of rich squares concentrated in urban and densely populated areas decrease at the fastest rate. When the squares reach a certain size, however, the process is reversed, since densely populated richer squares will increasingly incorporate sparsely populated poorer ones.

Table 6 Mean disposable income at different levels.

Level	Mean disposable income
National areas (NUTS 2)	166,700
Counties (NUTS 3)	163,900
Local labor market regions	158,400
Municipalities (LAU level 2)	164,500
100 km squares	156,465
50 km squares	152,366
30 km squares	152,120
10 km squares	151,387
1 km squares	160,100
Individuals	170,800

In another approach to estimate the error that is introduced when full information is not available, an, as simple as possible, OLS regression was employed. It serves the purpose of representing any member of the set of possible, more realistic causal models. Population density was used to predict disposable income at the different levels represented in the maps (Table 7). The density values used varied depending on map type and level of aggregation. Not surprisingly, R^2 is higher but significance lower at more aggregated levels. The intercept and – in particular – the slope coefficients exhibit different values in the various regressions.

Table 7 Population density as a predictor of disposable income at different levels.

Level	Density value	N	R^2	Parameters		Sig.
National areas (NUTS 2)	National area	8	0.95	Const.: B:	148,073 112.87	3.15E-05
Counties (NUTS 3)	County	21	0.76	Const.: B:	151,013 31.43	2.61E-07
Local labor market regions	Local labor market region	81	0.45	Const.: B:	149,880 79.46	5.58E-12
Municipalities (LAU level 2)	Local labor market region	284	0.44	Const.: B:	153,497 80.83	1.68E-37
100 km squares	Square	69	0.34	Const.: B:	153,462 169.03	2.13E-07
50 km squares	Square	227	0.13	Const.: B:	154,202 149.42	4.36E-08
30 km squares	Square	561	0.04	Const.: B:	158,390 129.09	2.03E-06
10 km squares	30 km radius[13]	3,989	0.09	Const.: B:	158,577 125.10	2.61E-82

The regression equation was then applied to all individuals (20–64 years); each individual was assigned the density value of the 10 km square they belong to. The empirical individual mean (170,800 SEK) was subtracted from the estimated means, producing a form of residual values (Table 8). Expressed in this way, the "error" is the smallest at the 100 km square level, followed by the 10 km square level.

[13] The calculation of area in this context was carried out in a somewhat simplified way, compared to the procedure described in footnote 10.

Table 8 Regression equations applied on individuals (mean: 170,800 SEK.)

Regression	Estimated mean	Residual
National area regression	185,683	14,883
County regression.	186,361	15,561
Local labor market region regression	186,578	15,778
Municipality regression	190,088	19,288
100 km square regression	171,010	210
50 km square regression	167,097	-3,703
30 km square regression	157,822	-12,978
10 km square regression	172,529	1,729

Density impact on income is obviously scale dependent and seems to increase with square size. Neighborhood density is something different from density in larger regions. The construction of municipalities and local labor market regions seems to internalize a large part of the variation. On regions as large as NUTS 2 and 3, the meaning of density becomes blurred and whatever results arise, might be the effect of pure chance.

3.1.4 Discussion

For the studied indicators, an increase in unit aggregation is associated with decreased heterogeneity on the maps, as well as smaller ranges and lower standard deviations. This finding is hardly surprising. The general effect of aggregation on mean and median values is less straightforward. In the twenty-four maps that have been presented, increased aggregation is associated with higher means and medians. In the case of these statistics, however, other indicators, map types, and aggregation levels may yield other outcomes. For instance, when aggregating income levels from very small grids, the mean and median values decrease at first.

Both territorial and grid maps have advantages as well as disadvantages. When comparing administrative systems and the consequences of different political decisions, territorial maps should be used. Preferably, the maps should be constructed with comparable areas for the whole area of interest. Even when this is feasible, however, the areas will still be difficult to compare. Different population densities and different population distributions within the areas complicate all socio-economic comparisons. When unique and atypical areas in Europe should be identified, it might be necessary to use an equal area method, for instance a grid map. Most localities that exhibit rare or exceptional values will appear in such a map if only the resolution is high enough. A high-resolution map can, however, easily become difficult to interpret due to a cluttered appearance.

A comparison between the territorial and the grid maps can be done by looking at the 50 km square maps (N=226 or 228) and the municipality maps that are divided into approximately the same number of units (N=284). Regional dissimilarities are quite obvious in the grids, but harder to discern in the municipality maps. All municipalities have a principal city or town where population densities and incomes are higher and population change often positive compared to their rural areas. When average values are displayed at the municipality level, the extreme values that actually are found in some places in most municipalities will disappear. Only a few squares will contain the – for the municipalities – dominating principal city, which leads to bigger differences in the grid maps. None of the territorial maps have units with the lowest class values, while in the grid maps such extreme values are quite common – especially in remote and sparsely populated areas.

Even with a resolution of 10 km squares, there is a scale problem. This is illustrated when the proportion of squares in the different classes are compared to share of the population in the different unit classes. The squares have been homogenized when it comes to area, but the population distribution is extremely irregular. With increased aggregation, the proportion of squares in the extreme ends tends to decrease while the "mainstream" squares increase. A similar but even more conspicuous change is seen concerning the percentage of individuals living in the different kinds of squares. At the highest map resolution (10 km squares), each classification group contains the same number of squares; the classification was defined this way. Already on this level, the population distribution is irregular due to varying population densities, but aggregation causes additional population redistribution. For instance, at the 10 km square level, about 0.3% of the whole population lives in the poorest 1/6 of the squares. When aggregated to 50 km2, a mere 0.00083% lives in the about 3% squares of this type. This phenomenon explains a great deal of the difficulties in illustrating socio-economic data on maps in a satisfactory manner.

What this study has shown is that even with a high geographical resolution and equally sized units, the information displayed on the maps to some extent can be inadequate or even misleading. Moreover, high-resolution maps are unpractical to use even at the national level: the grid maps with the resolution of 10 km squares are fuzzy and quite hard to interpret. Yet, the advantage of micro data is that the user is free to aggregate it as he/she pleases and that it is possible to estimate the errors of the chosen aggregation.

The target for most social, economic, and geographic studies is human individuals – not pieces of land. That is just one out of several attributes of the core entity at study, the individual in his/her spatial and socioeconomic context. While an equal area-based classification, like the one used here, is well suited for visualization of e.g. the morphology of natural resources it might not be the best choice for attributes of individuals. A classification based on equal number of people per class should better represent the distribution of individuals. However, that alone doesn’t help much in avoiding the problem of hiding large minorities with extreme characteristics in dense regions and exaggerating similar extreme attributes for small minorities in sparsely populated regions. When the distance to the socially constructed border of the administrative region is less important compared to i.e. the cognitive distance to friends, relatives, and activities, it might be more informative to use transformed maps based on equal density per region for visualizing attributes of individuals.

3.2 An Example of Statistical Analysis using Spatial Units from Ireland and Northern Ireland

The Modifiable Areal Unit Problem (MAUP) is a generalised term for several related problems in which the results of some type of analysis vary substantially when the spatial units used in the analysis vary. For instance, statistical information may be available for a series of different scales of spatial units such as NUTS level 2 or 3 zones or there might be a variety of ways of aggregating smaller units into larger units so that the results of the analysis when using the larger zones depend on how those zones have been aggregated from the set of smaller zones. A third type of modifiable areal problem occurs when the results of an analysis are sensitive to the definition of the spatial extent of the study region. Spatial analysis based on these areal units and extents should not ignore the MAUP issue (Fotheringham, 1998; Fotheringham and Wong, 1991; Nelson, 2001; Openshaw and Clarke, 1996).

This report examines the effect of the MAUP in a particularly sensitive area of analysis – that of the border region between Ireland and Northern Ireland. Different sets of spatial units are defined on either side of the border, yet there is a growing need to understand the social processes on the region which straddles the border. Here, we examine the effects of the border on the analysis of the determinants of educational attainment by constructing a statistical model in which the proportion of people with a university degree in a small area is related to a series of socio-economic characteristics of that area. We utilise both a traditional 'global' regression model and the recently developed local technique of Geographically Weighted Regression (GWR). The results highlight the effects of the MAUP and the need for a consistently defined set of spatial units for statistical analysis throughout Europe.

3.2.1 Background

Within Europe most countries share a land border with at least one other country. Such borders are interesting for understanding the processes operating within such countries because they highlight potential differences in socio-economic processes caused by the different institutional, political, social and economic frameworks within different countries. An important research question is: "Are such differences diminishing under the umbrella of the European Union and the general movement towards globalisation?" The border regions are also interesting, however, for statistical analysis because often the reporting units for data will be different on either side of the border. A research question here is then: "To what extent do observed differences in statistical analyses either side of a national border result from data on either side being drawn from incompatible spatial units?" To some extent, the EU is tackling this problem by developing a consistently defined set of spatial units (NUTS units) but much work remains to be done particularly in terms of obtaining pan-European data sets for small spatial units.(NUTS levels IV and V).

The border between Ireland and Northern Ireland (the latter being part of the United Kingdom) provides perhaps the best study region in Europe for examining the effect of a national border on socio-economic processes and for examining what statistical problems are created by using different spatial units on either side of the border to examine these processes. Both countries were part of the United Kingdom until 1926 and both have much in common despite the presence of a national border for the past 80 years. Indeed, the border, once quite tightly controlled, is now virtually invisible.

As well as having an ideal set of data for which to examine the effect of different spatial units on statistical analysis, this project takes advantage of recent developments in Geographic Information Systems (GIS) and spatial statistics to improve our understanding of the modifiable areal unit problem (MAUP).

3.2.2 The Study Area

The study area consists of spatial units within two countries: Northern Ireland and the Republic of Ireland (Ireland). Ireland is an island on the western fringe of Europe. Its greatest length, from Malin Head in the north to Mizen Head in the south, is 486 km and its greatest width from east to west is approximately 275 km. Since 1921 the island has been divided politically into two parts:

Northern Ireland in the North and the Republic of Ireland in the south with a land border (Figure 22), the former is under the governing of United Kingdom.

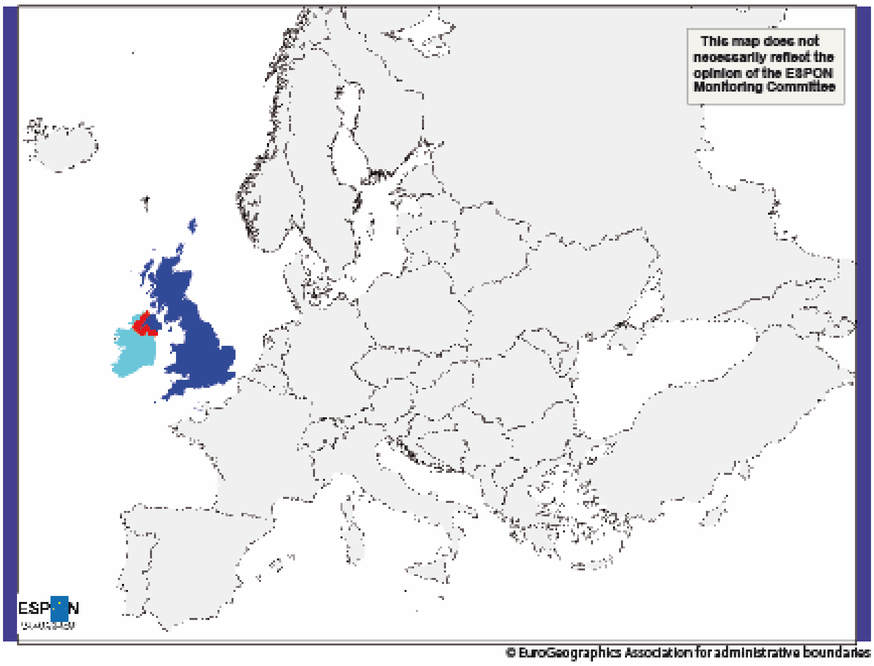


Figure 22 Republic of Ireland and N. Ireland in Europe

The Republic of Ireland has a different hierarchy of spatial statistical units for reporting population census data than does Northern Ireland; the latter follows the system of United Kingdom. Northern Irish data can be downloaded from the Northern Ireland Statistics and Research Agency (http://www.nisra.gov.uk/census/) whereas the Irish population census data are available through the

National University of Ireland, Maynooth (http://www.nuim.ie/staff/dpringle/saps/index.htm).

The hierarchy of spatial units in the Republic of Ireland is as follows (from largest to smallest) (Figure 23):

- County (and county Borough)
- UD (Urban District) and RD (Rural District)
- DED (District Electoral Division)

The DED is the smallest unit for which population census data are generally available, with 3440 covering the whole country in 2002.

The hierarchy of spatial units in Northern Ireland is as follows (from largest to smallest) (Figure 23):

- County
- District
- Ward
- Output Area (OA)

The OA is the smallest unit for which population census data are generally available with 5023 covering the whole country in 2001 (Northern Ireland is much smaller than the Republic of Ireland so the data reported for OAs in N. Ireland convey much more detail than do the DEDs of the Republic. The average size of an OA is 2.8km^2 whereas the average size of a DED is 20.4km^2

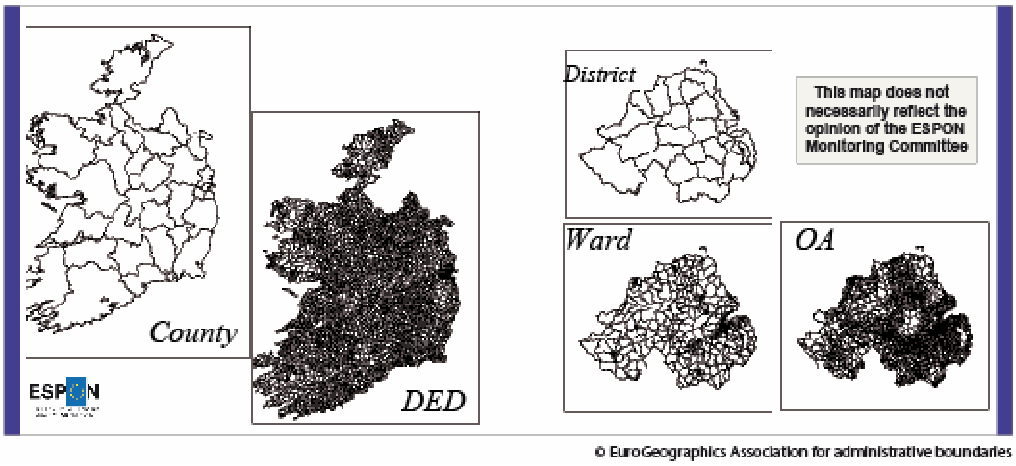


Figure 23 Spatial units in the Republic and the Northern respectively

The population census survey is held every 5 years in the Republic of Ireland, and every 10 years since in Northern Ireland. A population census was held in Ireland 1981, 1986, 1991, 1996 and 2002; the next one is scheduled to be held 2006. The reason for the delay in holding the census in 2002 was because of

Foot and Mouth disease which prevented the census from being taken in 2001. A population census was held in Northern Ireland 1951, 1961, 1971, 1981, 1991 and 2001. As a result, the latest census survey from the two countries (2001 from Northern Ireland and 2002 from Republic) are reasonably temporally comparable.

Consequently, there are two reasonable choices that could be made regarding the spatial units either side of the border:

1. Use DEDS in the Republic of Ireland and OAs in Northern Ireland
2. Use DEDs in the Republic of Ireland and Wards in Northern Ireland

Finally, as well as the susceptibility of analytical results to the definition of the spatial units either side of the border, there is also a decision to be made in examining any cross-border issues of how far from the border should one define the spatial units which will provide the data for the analysis. To examine this effect, we chose three definitions:

1. All of the Republic of Ireland and all of Northern Ireland
2. Those spatial units within 100kms of the border (this includes both capital cities of Dublin and Belfast)
3. Those spatial units within 50kms of the border (this definition excludes both Dublin and Belfast)

3.2.3 Modelling Educational Attainment Levels

3.2.3.1 Data

In order to demonstrate the sensitivity of analytical results to the definition of spatial units, we first construct a plausible model in which the proportion of population aged 18 years or over having a university degree is regressed on a set of socio-economic indicators which are given in the following Table 9 and their spatial patterns are mapped in Figure 24.

Table 9 Variables used in the analysis

Variable	Meaning
BScPer Educational Attainment	Percentage of people over 17 yrs old with post secondary school education
Cars2H	Percentage of households with 2 and more cars;
Socc1P	Percentage of people in social class 1 over the population (between 16-74 for Northern and over 15 for Republic)
Erate	Percentage of people in employment over the population in the same age group (16-74 or >15)
PopDen	Total population divided by the total area
CathoPer	Percentage of population with Catholic religion

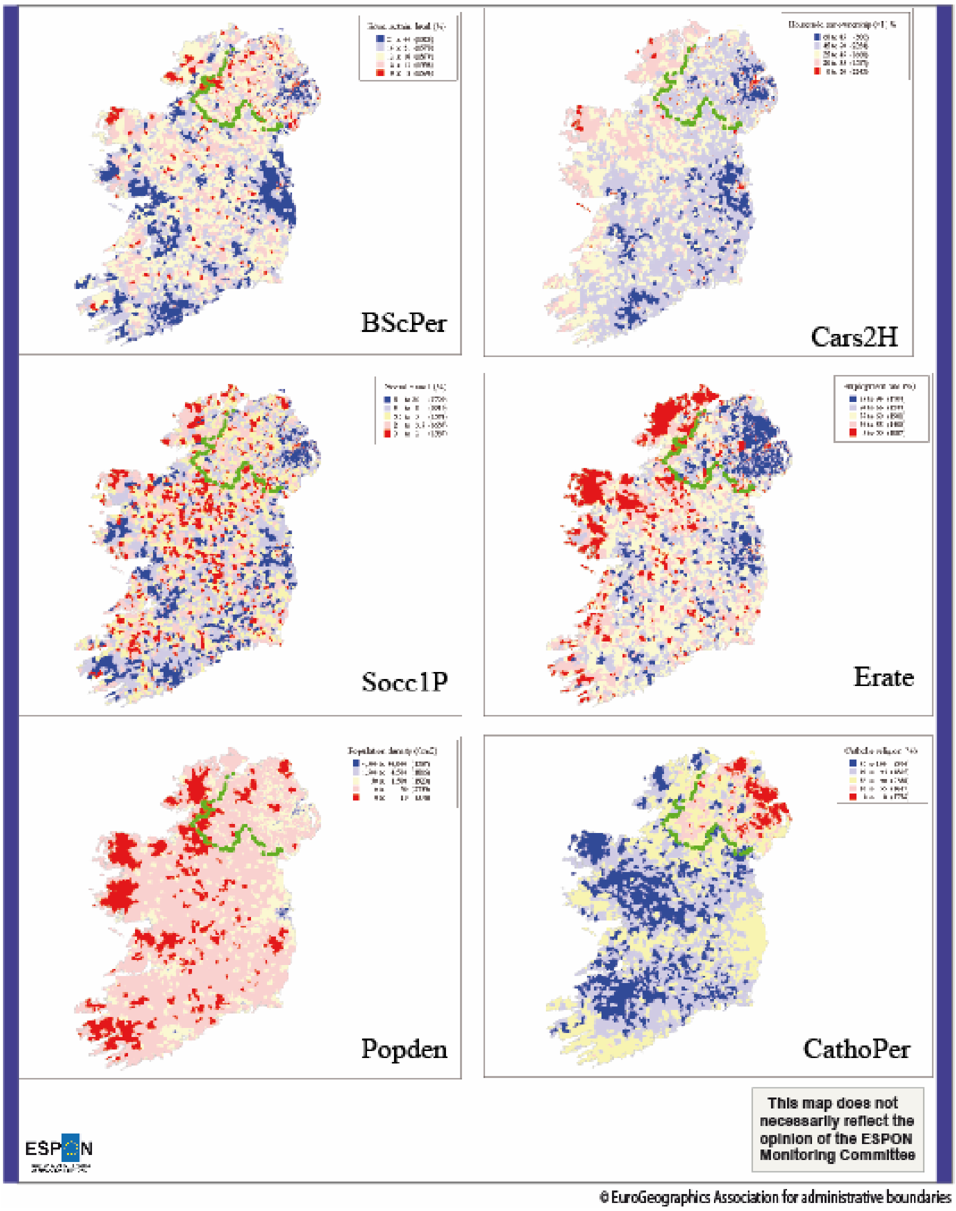


Figure 24 Spatial patterns of the defined variables

3.2.3.2 Methodology

A model was constructed in which educational attainment was related to the variables listed above in the following way:

$$\text{BscPer} = \alpha + \beta_1 \text{ Cars2H} + \beta_2 \text{ Socc1P} + \beta_3 \text{ Erate} + \beta_4 \text{ Popden} + \beta_5 \text{ CathoPer} \quad (1)$$

and the parameters of the model are estimated with data reported from the following sets of spatial units:

1. All OAs in Northern Ireland and all DEDs in the Republic of Ireland
2. Only those OAs in Northern Ireland
3. Only those DEDs in the Republic of Ireland
4. Only those wards in Northern Ireland

5. All wards in Northern Ireland and all DEDs in the Republic of Ireland
6. Only those OAs in Northern Ireland and those DEDs in the Republic of Ireland within 100kms of the border
7. Only those OAs in Northern Ireland and those DEDs in the Republic of Ireland within 50kms of the border
8. Only those OAs in Northern Ireland within 100kms of the border
9. Only those OAs in Northern Ireland within 50kms of the border
10. Only those DEDs in the Republic of Ireland within 100kms of the border
11. Only those DEDs in the Republic of Ireland within 50kms of the border

A comparison of the results from the model calibration using the units defined in 1 and 5 indicate the effect of using wards instead of Output Areas (smaller units) in Northern Ireland in an all-Ireland analysis.

A comparison of the results from the model calibration using the units 1, 2 and 3 and also the units in 3, 4 and 5 indicate the effect of the border on the determinants of educational attainment and whether the measurement of this effect is influenced by the choice of spatial units in Northern Ireland.

A comparison of the results from the model calibration using the units 1,6 and 7 and those in 2, 8 and 9 and those in 3, 10 and 11 indicate the effect of the spatial extent of the study region on the analytical results.

In addition to these different sets of spatial units, the model in equation (1) was calibrated both by traditional global regression and also by Geographically Weighted Regression (selected cases) and the results of both types of model calibration compared to further examine the effects of the MAUP on statistical analysis of spatial data.

3.2.4 Global Regression Results

3.2.4.1 4.1 Using Data from all OAs in Northern Ireland and all DEDs in the Republic of Ireland

BscPer = -8.64 *(0.36)* + 0.01 Cars2H *(0.005)* +1.55 Socc1P *(0.014)* + 0.2 Erate (0.007)+0.0003 Popden (0.00002)+0.06 CathoPer *(0.0016)* (2)

$R^2 = 0.75$

The figures in parentheses are the t-statistics of the parameter estimates. The R-squared value of the above model is 0.75, which indicates that the model explains 75% of the variance of the educational attainment variable across these spatial units.

From these results we would infer the following conclusions about the determinants of educational attainment:

a. All five explanatory variables are significant in determining educational attainment levels.

b. Educational attainment is positively related to the percentage of people in high socio-economic groups and to the percentage of people with 2 or more cars – both measures of 'wealth'.

c. Educational attainment is positively related to the rate of employment in an area – a measure of the local economic situation.

d. Educational attainment is positively related to the proportion of Catholics in an area.

e. Educational attainment is positively related to population density, an indicator of higher educational attainment in urban area than in rural areas.

3.2.4.2 Using Other Data Sets

The same model was calibrated with 10 other data sets described above and the results are presented in Table 10. These show the sensitivity of the results of the model calibration on the definition of the spatial units for which data are reported and the spatial extent of the area being examined.

For instance, it is clear that the effects of Catholic religion on educational attainment are remarkbly different between Northern Ireland (positive) and the Republic (negative) (compare the parameter estimates for data sets 2 and 4 with those for data set 3). This table also accounts for the weaker coefficient when a combination of DEDs and wards rather than DEDS and OAs is used because when wards are used the number of spatial units in the analysis from the North is far fewer than when OAs are used and hence the influence of the processes in Northern Ireland are greatly diminished in the analysis (compare the parameter estimates between data sets 1 with 5). Equally, it is clear that the effects of social class on education attainment are greater in N. Ireland than in the Republic.

The results (data sets 1, 9, 10, 11) also show the effect of changing the spatial extent of the study region on the analyses.

Table 10 Global regression models

Case	1	2	3
Unit	DED/OA	OA	DED
Extent	Ireland	N. Ireland	The Republic
Sample	3414 /5022	5022	3414
R^2	0.75	0.83	0.62
α	-8.6 (0.36, -24.3)	-7 (0.35, -20)	12.5 (1.3, 9.7)
β_1	0.01 (0.005, 2.4)	0.03 (0.005, 5.7)	-0.003 (0.009, -0.31)
β_2	1.55 (0.014, 115)	1.63 (0.015, 109)	1.17 (0.025, 47)
β_3	0.2 (0.007, 30)	0.16 (0.007, 23)	0.26 (0.016, 16.6)
β_4	0.0003 (0.00002, 13)	0.0002 (0.00002, 12)	0.0008 (0.00006, 13.8)
β_5	0.06 (0.0016, 37)	0.05 (0.002, 27)	-0.18 (0.011, -16.3)

β_1: car ownership; β_2: social class I; β_3: employment rate; β_4: population density; β_5: Catholic religion.

Table 10. Global regression models (continued-1)

Case	4	5	6
Unit	WARD	DED/WARD	DED/OA
Extent	N. Ireland	Ireland	100 km
Sample	582	3414/582	1465/5022
R^2	0.89	0.6	0.81
α	-4.7 (0.96, -4.9)	-9.5 (0.8, -11.7)	-8.3 (0.35, -24)
β_1	-	0.003 (0.009, 0.38)	0.02 (0.005, 3.7)
β_2	1.86 (0.035, 53)	1.35(0.023, 57.6)	1.7 (0.014, 120)
β_3	(0.02, 5.4)	0.25 (0.015, 16.9)	0.18 (0.007, 27)
β_4	0.0003 (0.00007, 3.8)	0.0009(0.00006, 16.4)	0.00023 (0.00002, 12.6)
β_5	0.05 (0.0036, 14)	0.054(0.004, 14)	0.06 (0.0016, 38)

Table 10. Global regression models (continued-2)

Case	7	8	9
Unit	DED/ OA	OA	OA
Extent	50 km	100 km	50 km
Sample	662/2551		2551
R^2	0.70		0.75
α	-6 (0.5, -12)	As 2	-6 (0.53, -11.3)
β_1	0.066 (0.007, 9)		0.07(0.008, 8.7)
β_2	1.48 (0.03, 56)		1.57 (0.03, 56)
β_3	0.13 (0.01, 13.6)		0.12 (0.01, 12)
β_4	0.00015 (0.00004, 3.7)		0.0002 (0.00004, 5.2)
β_5	0.05 (0.002, 22)		0.05 (0.003, 19)

Table 10. Global regression models (continued-3)

Case	10	11
Unit	DED	DED
Extent	100 km	50 km
Sample	1465	662
R^2	0.79	0.36
α	7.9 (1.66, 4.8)	2.77 (2.03, 1.36)
β_1	-0.026 (0.013, -2.1)	0.007 (0.022, 0.32)
β_2	1.62 (0.033, 49)	0.9 (0.07, 12.6)
β_3	0.24 (0.02, 12)	0.2 (0.032, 6.3)
β_4	0.0005 (0.00007, 7.7)	0.0023 (0.0006, 4.15)
β_5	-0.13 (0.014, -9)	-0.03 (0.017, -1.94)

However, the results in Table 10 are generally encouraging in that broadly similar conclusions would be reached from each of the sets of spatial unit definitions (in N.Ireland) and the spatial extent of the defined study area (all-island; 100 km of the border; and 50 km of the border). The exception to this is the relationship bewteen educational attainment and Catholic religion (β_5). In the combined Republic /N.Ireland data sets, the relationship appears to be positive; as the proportion of Catholics in an area increases, the proportion of people with a university education increases. The result is reinforced by the result from N.Ireland. However, the results for the Republic are very different; here, as the proportion of Catholics in an area increases, the proportion of people with a university education decreases. It is difficult to say that this is a causal relationship in any way; it could simply reflect an urban/rural division in the Republic because the proportion of Catholics tends to decrease in urban areas (Figure 24).

The results so far indicate the not unexpected result that processes either side of an international border may be different. However, these results emanate from a global model. We now examine whether a local model can shed further light on this issue of multi-scale variation.

3.2.4.3 Calibrated by Local GWR Modelling

GWR is an innovative local spatial exploratory analysis method, which incorporates spatial weight, based on distance decay function, into global regression equation. It can optimally search for an adaptive bandwidth based on a cross-validation procedure. Previous studies have proven its effectiveness in exploring spatial non-stationarity and also the possibility in searching local determinants. In this project, GWR modelling is implemented based on GWR 3.0 (http://ncg.nuim.ie/ncg/GWR/), with a loose coupling with GIS (MapInfo). To test the spatial non-stationarity of the determinants affacting educational attainment, we make five combinations of units with varied resolutions or extents, corresponding to the units 1,3,5,6,7 defined above. Major outcomes from the GWR modelling are listed in Table 11.

Table 11 Outcomes from GWR local modelling

Case	1	3	5	7	6
Unit	DED/OA	DED	DED/WARD	DED/ OA	DED/OA
Extent	RoI/NI	RoI	RoI/NI	RoI/NI 50km	RoI/NI 100km
Sample	3414 /5022	3414	3414/582	662/2551	1465/5022
Global-R^2	0.75	0.62	0.6	0.7	0.81
GWR-R^2	0.85	0.79	0.81	0.79	0.88
Spatial variability	α, β_1, β_2, β_3, β_4, β_5	α, -, β_2, -, β_4, β_5	α, -, β_2, -, β_4, β_5	α, β_1, β_2, -, β_4, β_5	α, β_1, β_2, β_3, β_4, β_5
Bandwidth	433	205	205	185	334
Global Moran I	0.33	0.33	0.34	0.27	0.31
GWR Moran I	0.173	0.12	0.13	0.16	0.168

Note: '-' is not locally significant; RoI: Republic of Ireland; NI: Northern Ireland, β_1: car ownership; β_2: social class I; β_3: employment rate; β_4: population density; β_5: Catholic religion.

Table 11 reports GWR results for 5 of the data sets described in section 3. The first three rows describe the nature of these data sets. They are: 1) DEDs in the whole of the RoI and OAs in the whole of NI; 2) DEDs in the whole of the RoI; 3) DEDs in the whole of the RoI and Wards in NI; 4) only those DEDs in the RoI and OAs in NI within 50 km of the border; and 5) only those DEDs in the RoI and OAs in NI within 100 km of the border. The fourth and fifth rows describe the increase in the amount of the variation in educational attainment explained by the GWR model compared to the global model. The sixth row lists for each data set the local parameter estimates that exhibit significant spatial variation. The seventh row gives the optimal bandwidth for each GWR calibration. This represents the number of nearest data points used in the GWR calibration which receive a non-zero weight in the local regressions. These weight range between 0-1 depending on the distance between the regression point and each data point. The bandwidth indicates the scale of the local regressions with smaller bandwidth indicating more detailed analyses. The final two rows describe the degree of spatial autocorrelation in the residual of the models. Typically, residuals from GWR models exhibit very little spatial autocorrelation, as is the case here. The relatively high values of Moran's I for the global models cast doubts on the inferences made from these models, although general the t-values are very high.

However, the main output from the GWR calibrations are geocoded sets of local parameter estimates which can be mapped to display possible spatial variation in the relationship each parameter describes. As an example, consider the distribution of the local parameter estimates describing the relationship between educational attainment and social class I in Figure 25 derived from DEDs in the RoI and OAs in NI. The effect of the boundary on social processes is clearly seen with educational attainment generally being much more sensitive to variations in social class I in NI than in the RoI. Within the RoI, educational attainment is clearly sensitive to variations in social class I only in the two main urban areas of Dublin and Cork. Within NI the relationship is much more complex although the values are generally much higher than in the RoI.

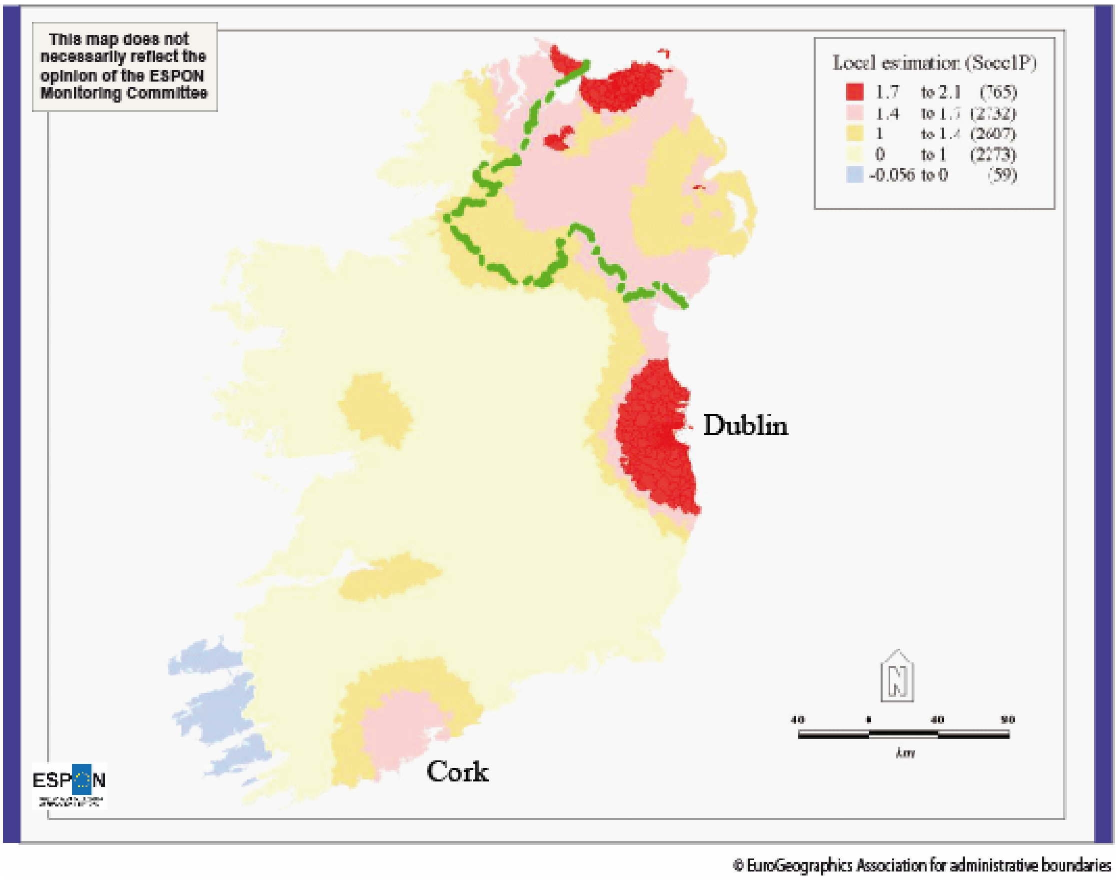


Figure 25 A surface of parameter estimates (Social class 1 - Socc1P) from GWR

This relationship, and the effect of the border, are explored further in Figure 26 where the local parameter estimates from four data sets are displayed in the border region. Note that parameter estimates are obtained for other areas in some of the data sets but for consistency we only repeat the results for the spatial units within 50km of the border. Figure 26a and 26b indicate the effect of using Wards in NI instead of OAs. This has its effect of producing less detailed spatial patterns due to the coarser nature of the spatial units employed.

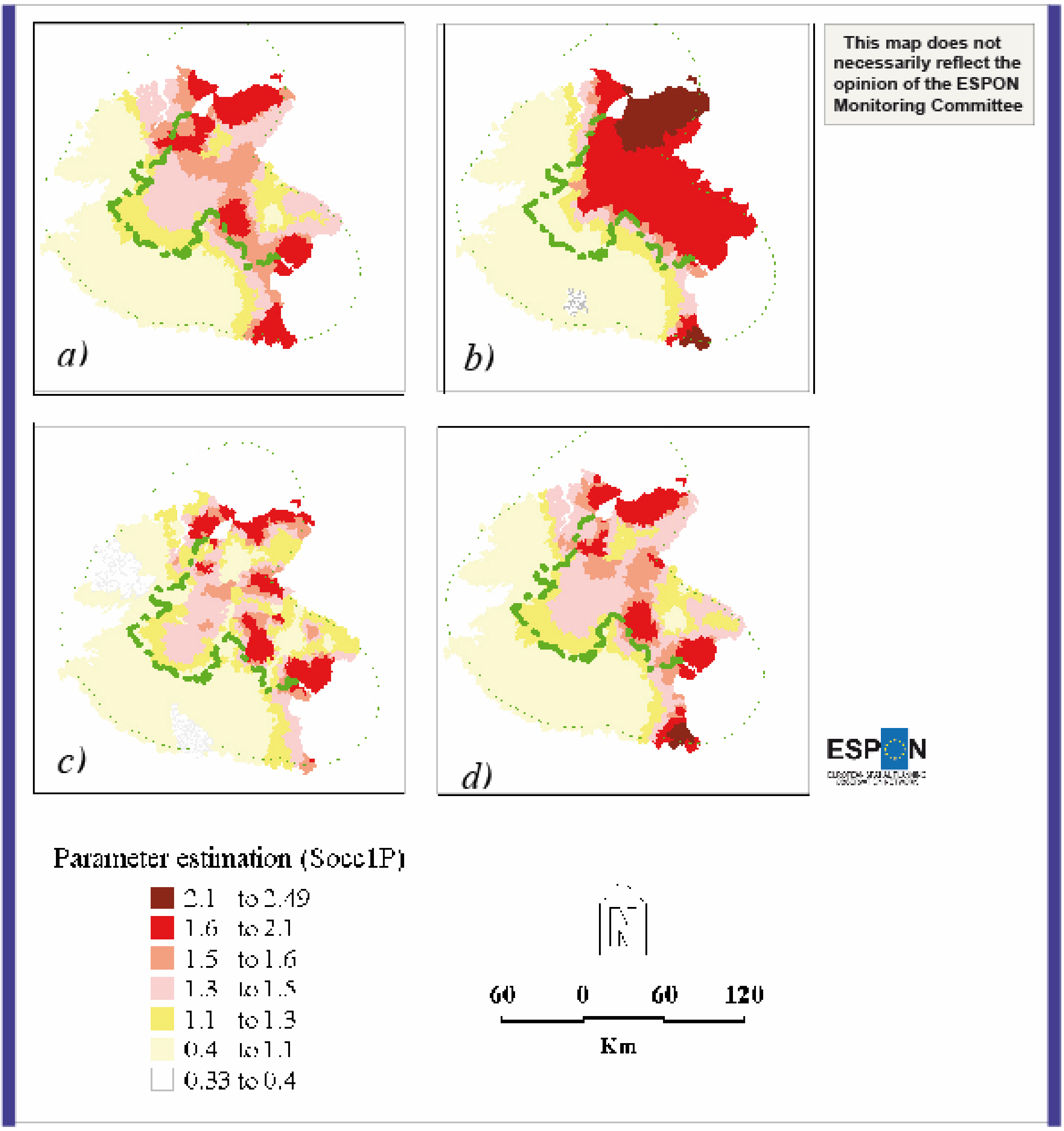


Figure 26 A surface of parameter estimates (Social class 1 - Socc1P) displayed for the border region from the data sets (a) DED/OA (all-ireland); (b) DED/Ward (all-Ireland); (c) DED/OA 50 km and (d) DED/OA 100 km

In both Figure 26a and 26b the results are obtained from all-island data sets. In Figure 26c the results are obtained from OAs in NI but using data from spatial unit within 50 kms of the border whereas in Figure 26d the results are obtained from spatial unit within 100km of the border. Thus a comparison of Figure 26a, 26c, and 26d indicates the sensitivity of the result to variations in the definition of the spatial extent of the study region. In each case, the effect of the border is very clear – quite different relationships between educational attainment and social class I appear to exist either side of the border.

However, it is also clear that more detailed spatial patterns in the relationships are obtained when the spatial extent of the border region is restricted to 50kms, from the border. Figure 27 shows the similar spatial effects for the variable of Catholic religion.

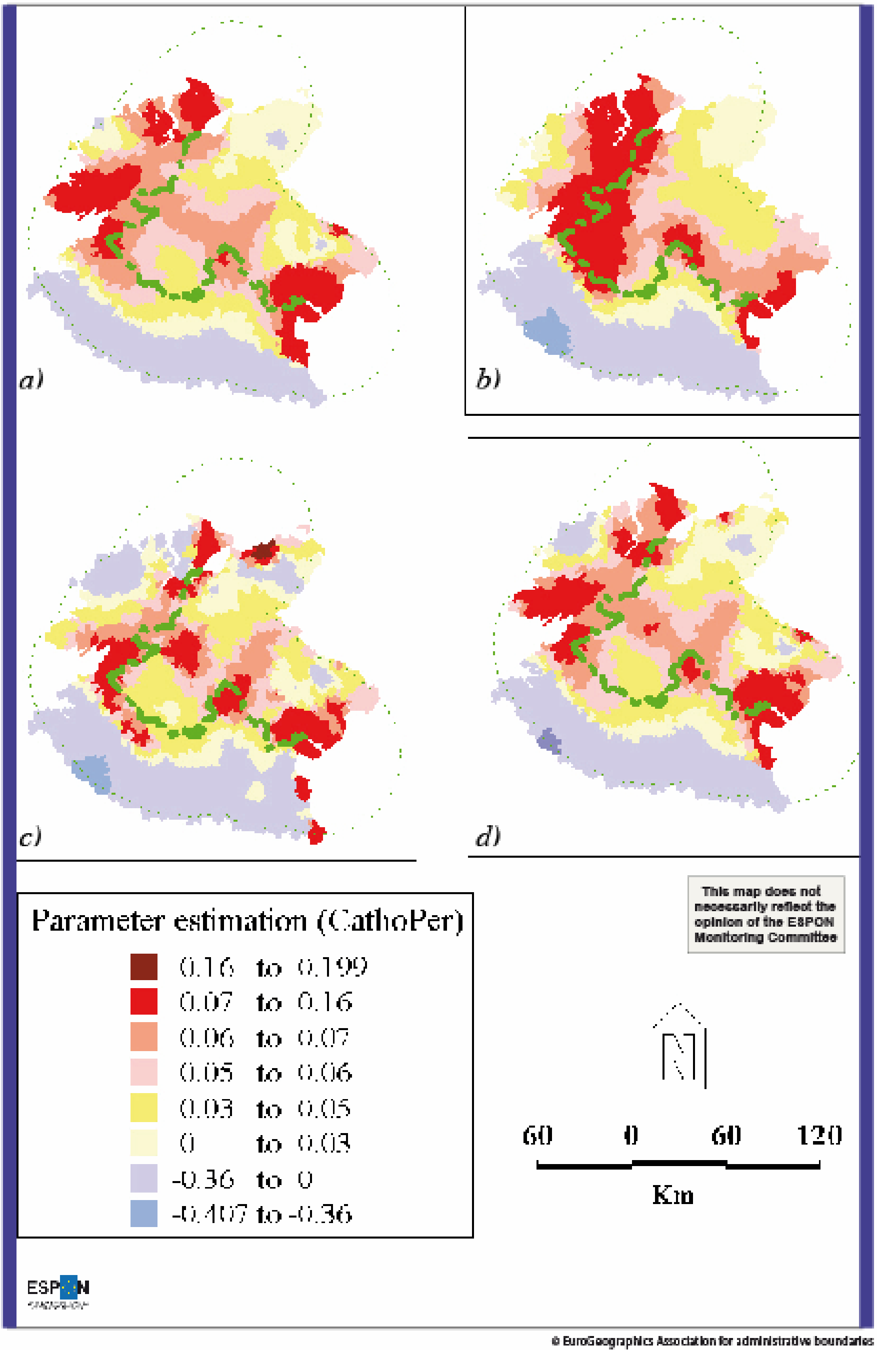


Figure 27 A surface of parameter estimates (Catholic religion - CathoPer) displayed for the border region from the data sets (a) DED/OA (all-ireland); (b) DED/Ward (all-Ireland); (c) DED/OA 50 km and (d) DED/OA 100 km

3.2.5 Conclusions

Cross-border studies are receiving considerable attention recently and international boundaries become weaker as barriers to movement and as multi-national data sets, such as those assembled for the European Union, become increasingly common.

This report has sufficiently showed the MAUP effects on the determinants of educational attainment level, caused by the changes of the resolution of units and the extents of analysis based on a specific field of cross-border case study. 'Global' and local regression (GWR) modelling are all able to detect these effects; however, GWR has higher discriminability and exploratory capability to examine spatial processes in cross-border regions. These effects further strengthen the requirements of developing consistent spatial units across countries and regions.

3.3 Case study on Germany: Volume-preserving interpolation from polygon-based data

The interpolation of continuous surfaces from discrete points is supported by most GIS software packages. Some packages provide additional options for the interpolation from 3D line objects, for example surface-specific lines, or contour lines digitized from topographic maps. Demographic, social and economic data can also be used to construct and display smooth surfaces. The variables are usually published as sums for polygonal units, such as the number of inhabitants in communities or counties. In the case of point and line objects the geometric properties have to be maintained in the interpolated surface. For polygon-based data the geometric properties of the polygon boundary and the volume should be preserved, avoiding redistribution of parts of the volume to neighbouring units during interpolation. The pycnophylactic interpolation method computes a continuous surface from polygon-based data and simultaneously enforces volume preservation in the surface patches above the polygons. The size of the polygons and the resolution of the grid should be in adequate balance, to ensure a good visual appearance of the surface, acceptable error rates and reasonable requests for computing resources. A possible solution for problems caused by polygons with a large deviation in size is the use of an irregular triangular network (TIN) instead of the regular grid.

3.3.1 Conceptual surfaces

Surfaces with only one possible height value at a location in the plane (also known as 2½D surfaces) are usually generated from discrete geometric elements, such as points or lines with a height information. The height values between the data points or lines are interpolated following rules based on global or local properties of the data, mathematical models, experience, or expert knowledge about the formation of the real surface. The most common example for the model of a surface and its visualization is the surface of the earth as displayed on topographic maps.

Surfaces derived from environmental, demographic, social or economic data are used more and more in spatial analysis. The invisible surfaces are conceptual models which can only be detected by their influence, not by their actual physical presence. They exist only as numbers and files in a computer system. These models are called *conceptual surfaces* (Rase 1998). The resolution of the original data and the resolution of the generated surface necessary to obtain a high-quality map differ considerably in most cases.

The visualization of conceptual surfaces can be a very useful complement to the usual choropleth maps in spatial analysis. In the case of most environmental variables, for example, the abrupt change in value at the boundary of a polygon on a choropleth map is not appropriate, because the boundaries of natural phenomena coincide rather seldom with administrative boundaries. A continuous surface or its visualization also has a certain amount of uncertainty or fuzziness compared to the strictness of boundary lines. This feature of interpolated surfaces is highly appreciated, for example, to visualize concepts in spatial development or planning on the supranational (European) level to avoid direct references to the existing political and administrative boundaries. A conceptual surface can also be considered under certain conditions as a probability surface which can be used for fuzzy reasoning or map algebra (Tomlin 1990).

In contrast to a model of the earth's surface which is calculated from point and line data, conceptual surfaces have to be derived from polygon-based data as well. The data from a poll, a census or from administrative procedures are often published only as totals for spatial units of a certain size to ensure the privacy of individuals or trade secrets of companies. The use of a geometric proxy for the polygon, e. g. the centroid, is common practice, but has some shortcomings. For example the preservation of the volume associated with the polygon cannot be assured in a point-based interpolation method, and the polygon boundary is not present in the surface model.

3.3.2 Volume preservation

Polygon-based data, for example the number of inhabitants in an administrative unit, may be considered as a volume which can be visualized by a prism in the perspective view of a choropleth map (Figure 28). The height of the prism is calculated by dividing the volume by the area of the reference polygon. The volume of the depicted prisms is proportional to the number of inhabitants, the height (volume divided by the polygon area) is proportional to population density. The color of the prism tops represents density classes to demonstrate the relationship to a choropleth map in 2D.

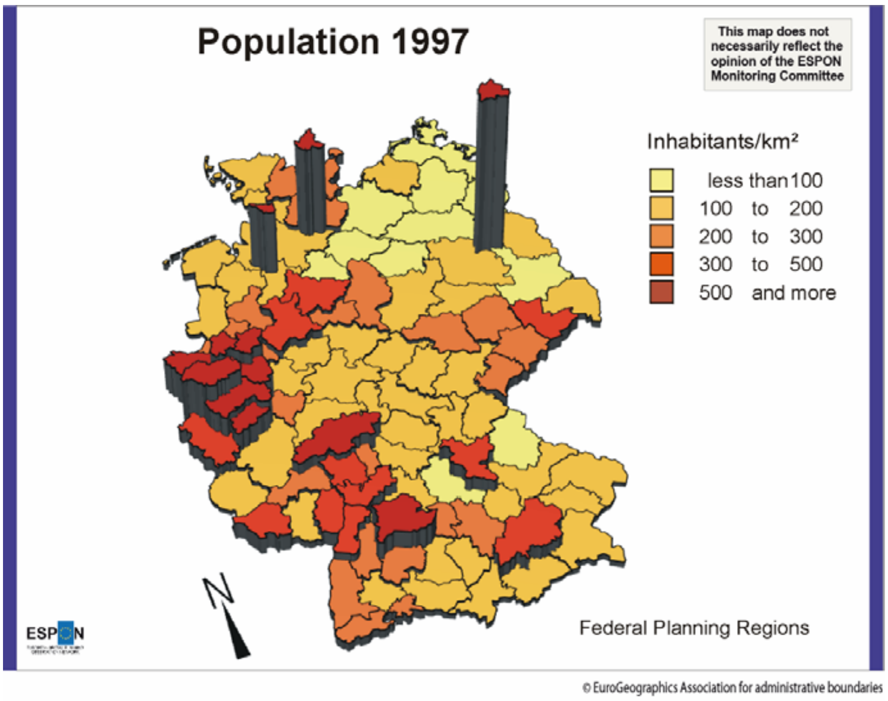


Figure 28 Perspective representation of choropleth map

During interpolation (the calculation of the smooth surface) parts of the volume should not be redistributed to neighboring units. The volume of the prism above a polygon should remain constant before and after the interpolation of the smooth surface, in the example of Figure 28 the number of inhabitants. If the centroid of the polygon is used as a geometric proxy the redistribution of the volume cannot be controlled if the usual interpolation algorithms are applied. To enforce the preservation of volume for each polygonal unit the interpolation algorithm should use the polygon outline as the geometric reference. For data not available as a volume the height can be multiplied by the area of the polygon to receive a "virtual" volume suitable for the volume-preserving interpolation method.

3.3.3 The pycnophylactic interpolation method

To ensure volume preservation for polygon-based interpolation Tobler developed a procedure which he dubbed *pycnophylactic interpolation* (Tobler 1979). Pycnophylactic, from Greek *pyknos* = mass, density and *phylax* = guard, is just another word for *volume-preserving* (it is rumored that Waldo Tobler invented the term to impress the reviewers of the seminal paper). The procedure consists of two main steps. In the first step the polygons and the associated volume data are converted to a regular grid with height values assigned to the grid points (rectangular columns, Figure 29b). In the second step the heights at the grid points are increased or decreased individually to make the surface smooth, while simultaneously enforcing the volume-preserving condition. The second step is repeated until a user-selected threshold is reached, resulting in a smooth surface, smooth within the limits set by gridding the polygons (Figure 29c).

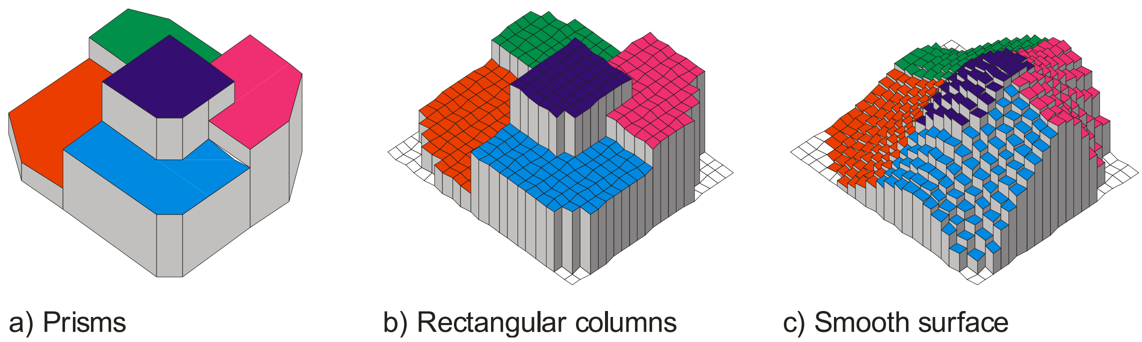


Figure 29 Main steps in the volume-preserving interpolation procedure

Each cycle during the iteration consists of two main steps:

- Smoothing the surface by averaging
- Redistribution of the differences in volume for each polygon

In the first step an average value is computed for each point from the z-values of the neighboring grid points. Tobler applied two kinds of filters for averaging. The first filter, derived from the Laplacian equation, uses the immediate four (rectangular grid) or six neighbors (regular triangular grid). The second filter is a relative of the biharmonic equation. The average is computed from three rings of neighbors with different weights for each ring (Figure 30). Other filters and smoothing procedures can be used as well, dependant on the data and its properties (Dyn et al. 1979).

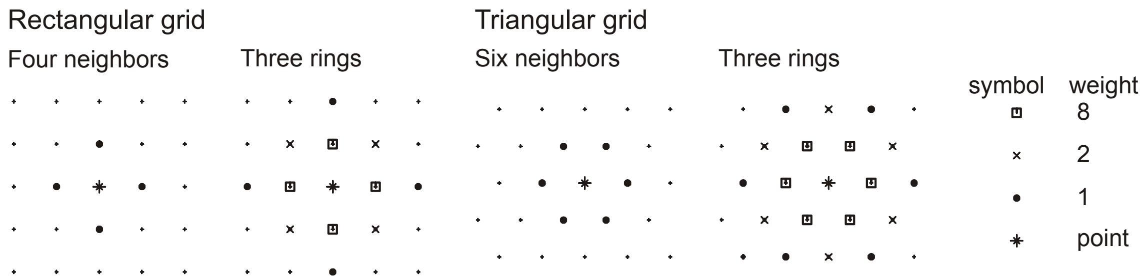


Figure 30 Filters used for smoothing in Tobler's original algorithm

In the second step the difference between the original volume of each polygon and the new volume changed by the smoothing step is calculated. The difference is redistributed by changing the height of the columns for each polygon proportionally. A measure representing the roughness of the surface (complement of the smoothness) is calculated at the end of each cycle. The iteration is terminated when the remaining roughness is lower than a preset threshold, or the specified number of iteration cycles is reached.

The shape of the outer boundary can be either a "sand beach", with a zero or minimum height value at the border line or the grid points in the neighborhood of the boundary, and a gradual increase of height to the inside of the adjacent polygon. The second option is the equivalent of a rock coast, with steep cliffs at the outer boundary. Both options are easily implemented by presetting the according values to the outer boundary.

Figure 31 shows the first seven iteration steps for a simple test example. The value of R represents the relative roughness of the resulting surface. Although the roughness measure still decreases, the changes in the height of the grid points are barely visible for the last four cycles of the iteration. The steep coast option had been selected for the example.

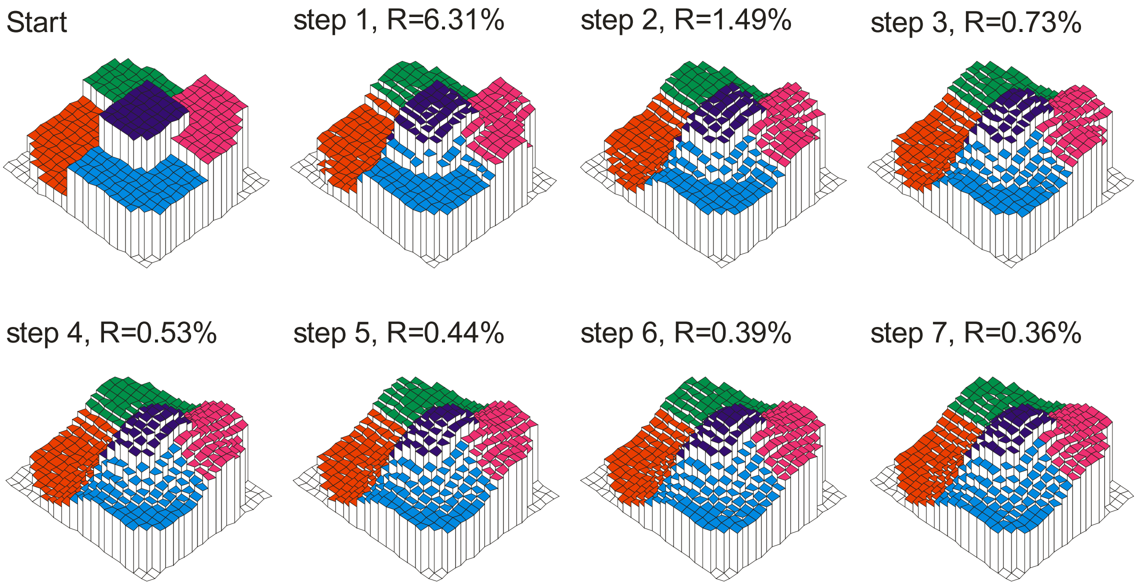


Figure 31 Iteration cycles for the test surface. R = "roughness" measure

3.3.4 Smooth surfaces of gross domestic product in Germany

The pycnophylactic interpolation method has been used to generate smooth surfaces of the variable "gross domestic product" per capita. Figure 32 shows the classic choropleth map with NUTS3 regions (counties) in Germany. Figure 33 depicts the smooth surface constructed from the same polygonal data, rendered with virtual light sources by a ray-tracing program (POVRay 2006) to enhance the visual comprehension. The underlying geometric structure of the polygons is still visible. The deviation of the volume above the polygons from the original volume is very close to zero, measured in the grid point domain. The small islands in the North and Baltic Sea were omitted from the interpolation to avoid artifacts and misleading interpretations.

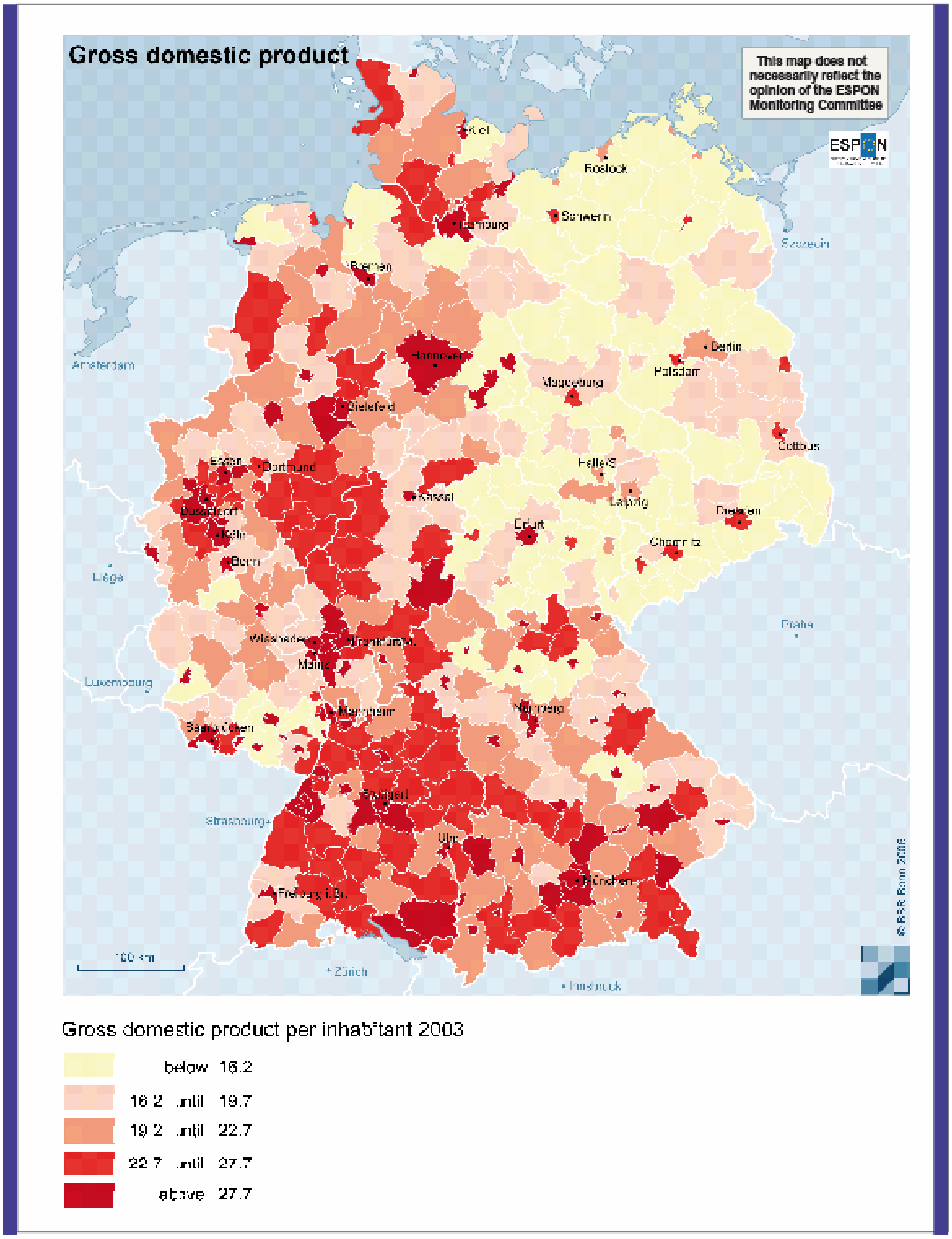


Figure 32 Choropleth map of cross domestic product 2003 in Germany, 440 counties/NUTS3

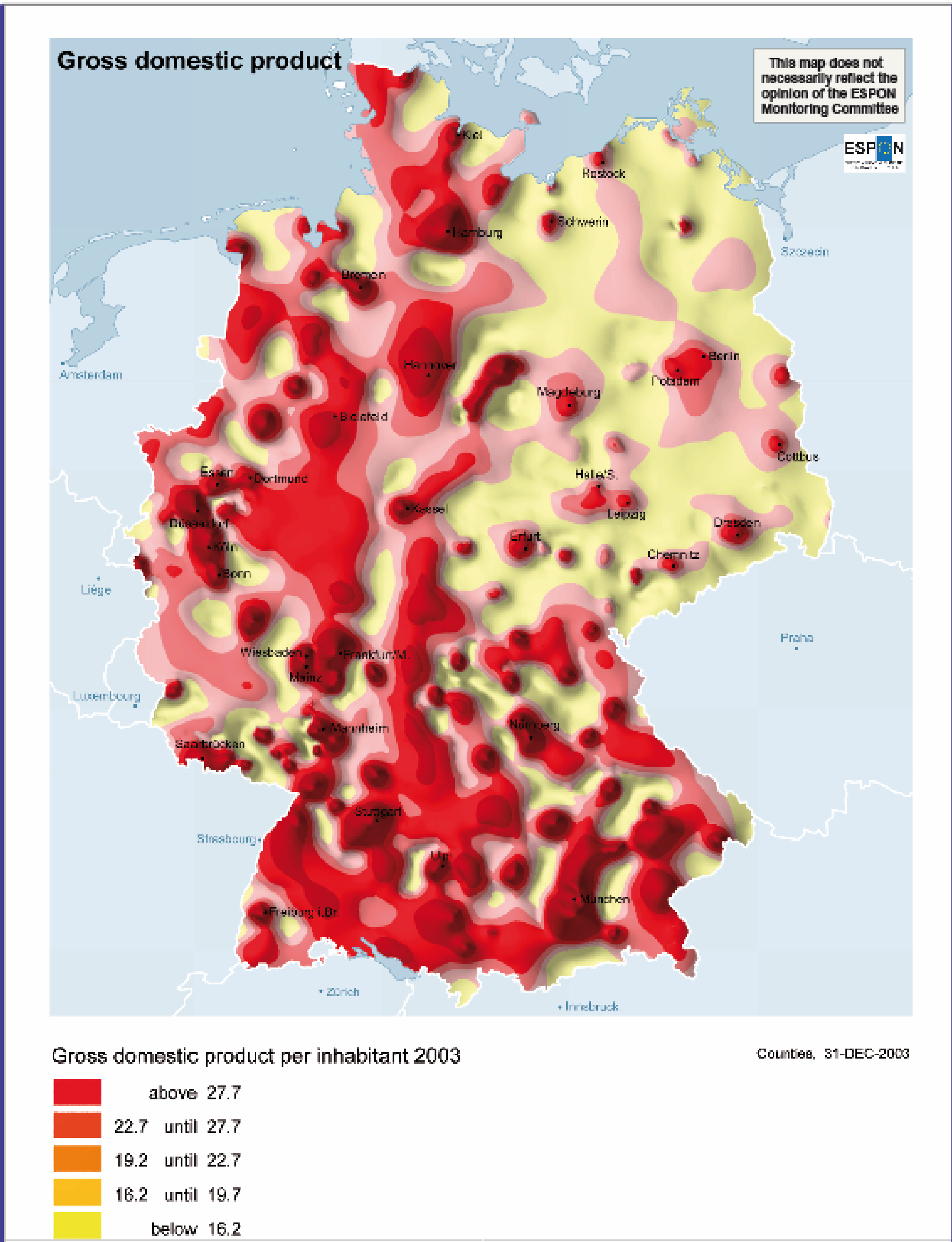


Figure 33 Surface of gross domestic product 2003 in Germany, interpolated from 440 counties/NUTS3

To demonstrate the effect of spatial aggregation and the difference in the smooth surface derived from larger polygons the surface in Figure 34 was interpolated using the 97 Federal planning units in Germany (no NUTS equivalent). The relative size range of the polygons is much smaller than in the case of the counties. As expected the resulting surface is smoother and less undulating. The generalization, in comparison to the surface in Figure 33, is achieved by aggregating the numerical values and the geometry of adjacent counties, and subsequent interpolation of the larger polygons.

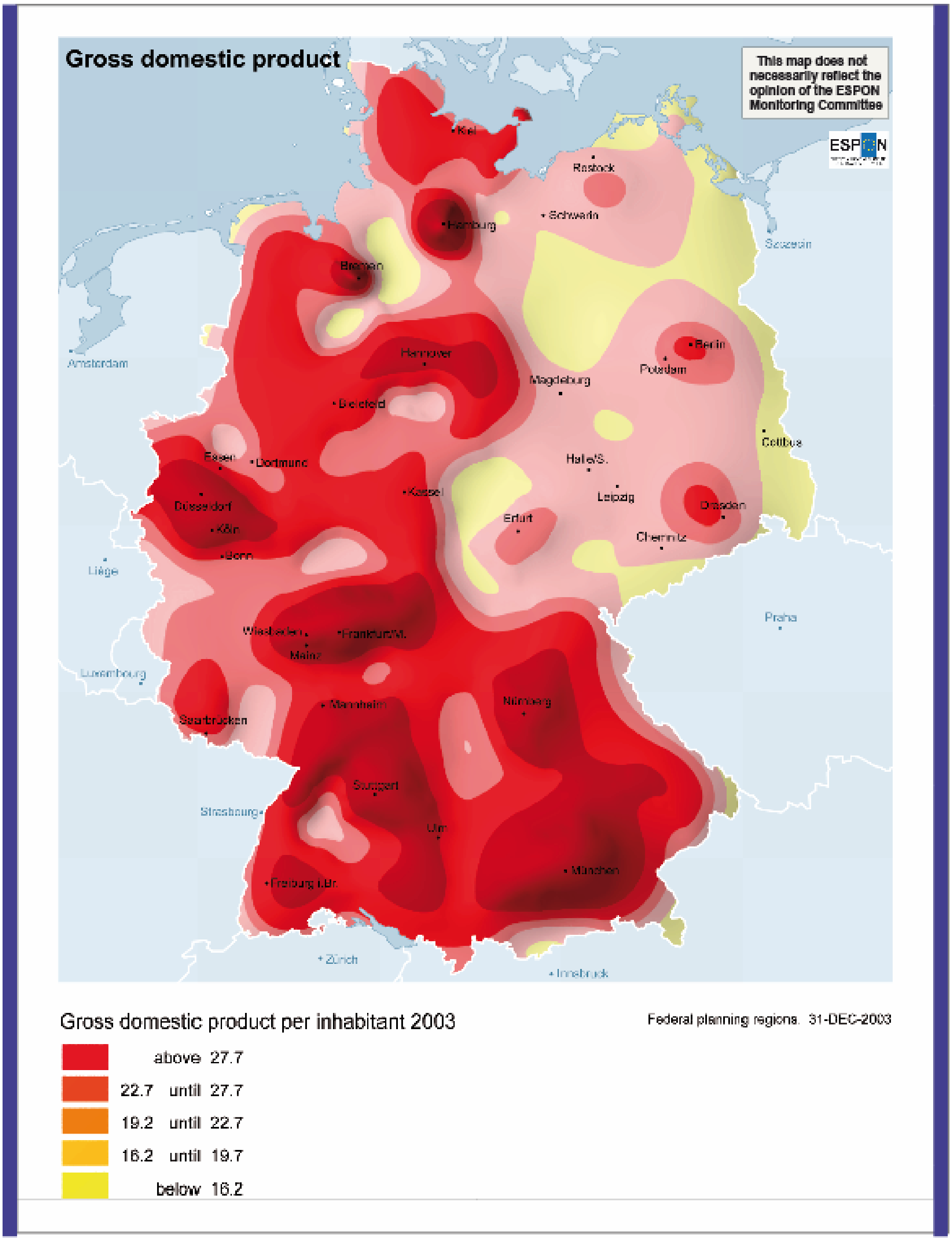


Figure 34 Surface of cross domestic product 2003 in Germany, based on 97 Federal planning regions

3.3.5 Deficiencies of the interpolation based on a regular grid

The pycnophylatic interpolation method generates a smooth surface from polygon-based data, and ensures that the volume of the prisms above the polygonal units remains constant, within a certain error range. The distribution of the height values within a polygon, however, does not reflect the actual distribution of the data, e. g. the population, in the real world. The interpolation method does not use any information about the real distribution, for example the settlement structure, but only the aggregated value for each polygon. Thus the use of three-dimensional surface patches above the polygons seems not to be advantageous for subsequent processing, e. g. spatial disaggregation, compared to the 2D representation.

The pycnophylactic interpolation method based on a regular grid has several deficiencies which must be taken into account:

- The grid generation and the constructing the rectangular or hexagonal columns, the latter in case of a triangular grid, introduces error in the computation of the volume.
- The range in size of the polygons (difference between minimum and maximum area), the shape of the polygons, and the grid resolution have mutual influences which may generate unwanted side effects.
- The original geometry of the boundaries is lost.

The problems of computer resources, e. g. higher memory requirements and computing time caused by an increasing grid resolution, have become less prevalent due to the advancement in information technology in recent years.

3.3.5.1 Error introduced by gridding

The conversion of the polygons to a regular grid induces a certain amount of error for the computation of the volume and the correction steps. The sum of the rectangles (or hexagons) for one polygon is not equivalent to the original area of the polygon calculated with the original boundaries. The difference depends both on the geometric resolution of the boundary lines and the resolution of the grid. The differences are balanced out for all polygons in most cases and seem to be negligible, except for very small or odd-shaped polygons.

3.3.5.2 Relation of polygon size and grid resolution

To obtain acceptable surfaces, in terms of a good visual quality and acceptable figures from the error statistics, the selected grid resolution has to be in appropriate balance with the size and the shape of the polygons. If the resolution is too coarse the polygons contain not enough height points to generate a smooth surface, or even no grid point is located within a polygon, because it is too small or has an irregular shape. If the resolution is too fine the smoothing takes place mainly in the immediate neighborhood of the polygon boundaries, and the inner parts of the polygons stay flat. If the size of the polygons varies considerably, the resolution of the grid must be chosen very carefully. In such cases compromises between visual appearance and error statistics have to be accepted.

3.3.6 Pycnophylactic interpolation in a triangular irregular network

The incompatibility between a large variation in polygon sizes and inadequate grid resolutions can be solved by an adaptive grid. The triangular irregular network model (TIN) allows the preservation of the original data points in the model of the surface (Peucker et al. 1978). The data points are the *nodes* of the irregular grid. The nodes are connected by *arcs* or *edges*, forming a mesh of triangles of different size and orientation. The Delaunay triangulation is considered to achieve optimal TIN configurations (Ruppert 1995). Some implementations of the Delaunay triangulation provide support for *constrained lines*, allowing the definition of a concave outer boundary, or holes and barriers inside the network (*constrained Delaunay triangulation*, CDT, Renka 1996). The initial Delaunay configuration is modified slightly by forcing certain arcs to coincide with the polylines. The slight deviation from the ideal Delaunay triangulation can be tolerated.

In contrast to a regular grid the TIN adapts to varying local resolution requirements. For boundary lines with high resolution or for regions of high relief energy (rapid change in numerical value) the mesh can be made denser. The TIN may be *decimated* by eliminating redundant triangles and nodes, for example in flat areas where the nodes have only small differences in height. To expand the TIN additional points are inserted (Steiner points). The insertion is controlled by rules, such as the size of the mesh triangles (average or maximum), or minimum angle values to avoid skinny or elongated triangles (Shewchuk 1997). The rule-controlled expansion is of special importance for the pycnophylactic interpolation to ensure an appropriate overall and local resolution for the smoothing and redistribution steps.

For the transfer of the pycnophylactic interpolation from the regular grid to the TIN the same basic steps can be used. The smoothing or averaging step requires different algorithms than the filters presented for the regular grid, because the number of neighbors and their distances varies at each point. Modified inverse distance weighting (Renka 1988, 1999a, 1999b) is one of several methods applicable for averaging the points and smoothing the surface.

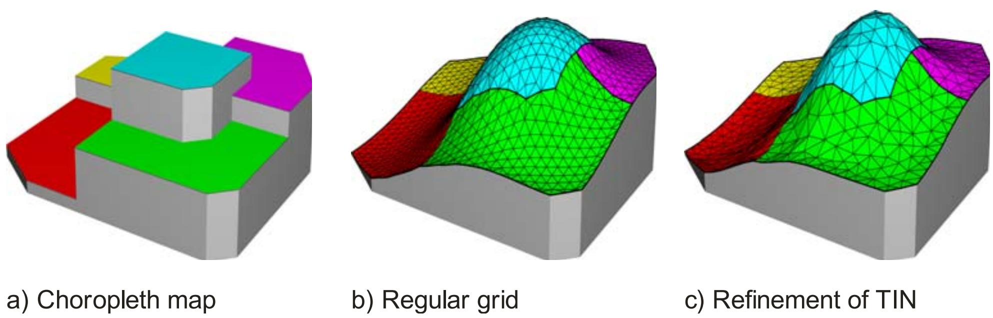


Figure 35 Regular grid and TIN

3.3.7 Conclusions and further work

The pycnophylactic interpolation – or a similar method with volume-preserving properties – is mandatory for the construction of a continuous surface from polygon-based data. An usual interpolation method using the centroid of the polygon as a geometric proxy cannot assure volume preservation during the interpolation.

The error resulting from converting the polygons to a regular grid in the "classic" version of the pycnophylactic interpolation is avoided by using a TIN instead of the regular grid, especially for a set of polygons with an extended range in size and resolution. The geometry of the boundary polylines can be preserved to the necessary precision in the data structure of the surface. The number of triangles can be kept lower than the number of rectangles in a regular grid, by selection of the resolution, and by decimating the triangular mesh, if appropriate.

Triangles or triangle meshes are the basic geometric objects for some high-performance graphic devices. The use of triangles can speed up the display process for real-time applications. The TIN model, on the other hand, is more difficult to implement than a grid. It requires additional code and more complex data and program structures. The first experiments to apply pycnophylactic interpolation using a TIN are promising. But more developments are required to test alternative options and algorithms for smoothing and redistribution of the differences to ensure volume preservation.

Part 2: ESPON and the MAUP

Introduction

The question of the potential influence of changing territorial divisions on applied research in the field of spatial planning has been regularly discussed in the framework of the ESPON program and even before.

A working paper called "Objective 13-bis" was presented in 1998 by C. Grasland in the Study Program on European Spatial Planning (SPESP) which is the ancestor of ESPON and was published as an annex in the report of the working group I.4 Spatial integration[14]. This provocative paper was based on the fiction of new structural funds allocated to regions with decreasing population (the so-called "objective 13-bis") and tried to examine how Belgium could maximize its benefits according to the choice of various levels of territorial division from NUTS 0 to NUTS 5. It demonstrated that the choice of the optimal level was not obvious and that the maximum amount of population eligible to this fictive objective was obtained at a medium level of territorial division and not necessary with the larger or smaller territorial units. Furthermore, this paper proposed an alternative approach of identification of target areas based on multiscalar smoothing methods. The results of this research were further developed and published in a scientific journal[15].

This question was not immediately recognised as important by ESPON which defined NUTS 3 as target level of analysis for all projects in their terms of reference. NUTS 2 level was admitted as alternative target level only when data collection was obviously impossible at NUTS 3 level. Many lead partner complained that the obligation to develop analysis at NUTS 3 level had terribly hampered their research because of time necessary to elaborate regional data base which did not necessary exists in the European statistical systems, especially Eurostat where most data are available at NUTS 2 and, only a small proportion at NUTS 3. Typically, the teams in charge of elaboration of synthesis results (like ESPON projects 3.1, 3.2, 3.3 or 2.4.2.) has all decided to use NUTS 2 as reference level because they would have been obliged to eliminate more than half of the information available in the ESPON database if they had chosen the NUTS 3 level as reference. This lead to a first question:

[14] http://www.mcrit.com/SPESP/SPESP_REPORT/spatial_integration.pdf

[15] C. Grasland, H. Mathian, J.M. Vincent – "Multiscalar analysis and map generalisation of discrete social phenomena: Statistical problems and political consequences", *Statistical Journal of the United Nations*, ECE, 17, IOS Press, 1-32. 2, 2000

Question 1: What is the advantage of choosing NUTS 3 level instead of NUTS 2 as reference for ESPON results?

At the same time, a more general debate appears in the ESPON program about the opportunity to use systematically official NUTS divisions instead of building specific *ad hoc* division for each relevant topic of interest. The discussion on this point emerged during the ESPON seminar of 2003-2004, especially in the debates around the presentation of the results of projects 1.1.1. (Polycentrism) and 1.1.2 (Urban-Rural relations) because it was very clear that all variables related to the measure of urban phenomena were very sensitive to the question of territorial delimitation. Firstly, it appears that the delimitation of relevant urban units (FUA) implies the use of lower level of territorial units than in the other ESPON studies (NUTS 5). But at this level, information was very scarce and in many cases the economic attributes of MEGAS were based on NUTS 3 information, producing scale conflicts and debatable approximations. Secondly, the construction of typologies based on the presence of FUA or megas in European regions appeared clearly biased at NUTS 3 level because the size of territorial units is clearly correlated with the potential number of towns located in a given area. More generally, the population density and the variation of population are strongly correlated with the size of NUTS units because intra-urban, peri-urban and rural territories are generally strongly different in terms of territorial dynamics. In countries with large NUTS 3 divisions like France or Spain, the three categories of spatial structure (intra-urban, peri-urban, rural) are always "mixed" and the result is a "mean value" with small inter-regional differences. In countries with smaller NUTS 3 units like Germany or Belgium, each category of spatial structure can be isolated by the territorial division and the result is a very high statistical and cartographical heterogeneity of the distribution of population densities or population dynamics. It is not possible to assets that one scale of analysis is better than the other (depending on the target of the analysis) but it is obvious that the combination of units of different scales in the same table or the same map is a mistake because it produces confusion and give the false impression that some parts of the European territory are more differentiated and heterogeneous than the other. It is true that NUTS units are **politically relevant** because they are associated to political levels of decision but they are **not empirically relevant** because they introduce a confusion of scales, especially at NUTS 3 level where urban-rural differentiations are visible in certain states but not in the others. This leads to the second question:

Question 2: Is it possible to base political decision on territorial units which are officially relevant but display in practice a biased perception of reality?

Last but not least, it has been also underlined during several ESPON meetings, (especially the one of Matera) that MAUP is not only a cartographical problem but also a statistical one because correlation between units can be modified when territorial units are modified. This problem which is less "visible" appears as the major one because correlations are often a basis for policy recommendations and for studies of Territorial Impact Assessments. For example, the existence or non existence of a correlation between accessibility and economic competitiveness (growth of GDP/inh.) is a crucial input for the elaboration of political decisions related to the development of Trans European Network. The existence or non existence of correlation between Common Agriculture Policy funds (Pillar 1 or Pillar 2) and other structural criteria (GDP/inh., Unemployment, Population growth) is also of crucial importance for the evaluation of positive or negative effects of CAP on the objective of territorial cohesion. Major issues related to policy options proposed by the ESPON projects are really based on such identification of correlations between indicators established at NUTS level. This lead to the third question:

Question 3: What is the stability of correlation results established by the ESPON as regards to the level of territorial division? Would we have obtained different results with other territorial divisions? If yes, what are the consequences for political decision?

The objective of the first section of this part is to clarify these questions through the analysis of selected examples of analysis of ESPON indicators. We will use the most classical or emblematic variables (GDP/inh. PPS, Unemployment rate, ...) to provide examples which will be organised in an order of growing complexity, from simple univariate analysis to spatial analysis tools. Part of these results was firstly elaborated in ESPON project 3.1 (Dictionary of Tools, Final report) but have been here completed and presented in a more systematic way.

1 Examples of the MAUP in ESPON

1.1 How MAUP influences the univariate analysis

We consider here the analysis of a single indicator, namely the GDP per inhabitant in 1999 expressed in parity power purchase (pps) for all ESPON units with the exception of ultra-peripheral regions of Spain, France and Portugal. We use the official NUTS division of 1999 which is different from the most recent one (2003), especially for new members states which had not established NUTS1 levels units at this time.

1.1.1 Influence of NUTS division on cartographic perception of results

Cartography is a major tool for political decision in the ESPON program. But the choice of (1) territorial divisions and (2) statistical divisions has an important influence on the perception of results. As an example we propose to compare three maps presenting the distribution of regions with low level of GDP/inh. PPS in 1999 at NUTS 1, NUTS 2 and NUTS 3 levels and with three different statistical thresholds for the identification of low level (index 90, 75 and 50 with 100 equal to the mean of UE25). The comparison of the maps established at level NUTS**,** NUTS 2 and NUTS 3 which are presented in Annex 1 reveals very different patterns of regions with low level of GDP/inh. which can be illustrated by the examples of Portugal and Germany.

- **Portugal (Figure 36)** is defined as a single territorial unit at level NUTS 1 with a GDP/inh. comprise between 75 and 90 % of European mean, mapped in light blue. At level NUTS 2, we have a very different pattern with the capital region of Lisbon above European mean (red) and three other regions with a low level of GDP/inh. comprise between 50 and 75% of European mean (medium blue). At level NUTS 3 a completely different picture is revealed with a mixture of units providing all possible levels (and all possible colors from deep blue to red). The capital region of Lisbon which appeared as a relative large red area at NUTS 2 is transformed into a mosaic of micro-regions generally above European mean, with the exception of the urban agglomeration of Lisbon which is now reduce to a very small area.
- **Germany (Figure 37)** is certainly one of the most spectacular examples of modification of the perception. At NUTS 1, all Länder from eastern Germany except Berlin have relative low values (light blue, between 75% and 90% of EU25 mean) and all other Länder from western part have relative high values (red, above 100% of EU25 mean) producing the vision of a complete West-East opposition. This feeling of opposition begins to change at NUTS 2 with the apparition of local differentiations in western part (in yellow or light blue) as well as in eastern part (with area in medium blue). At NUTS 3 level, a completely different picture appears with a mosaic of colors indicated by very different levels both in eastern part

(where some urban Kreis are above EU mean) and western part (where many rural Kreis are in blue).

Figure 36 Changing cartographic perception of areas with low GDP/inh. pps (1999) in Portugal

(Maps established with the ESPON Hyper-atlas)

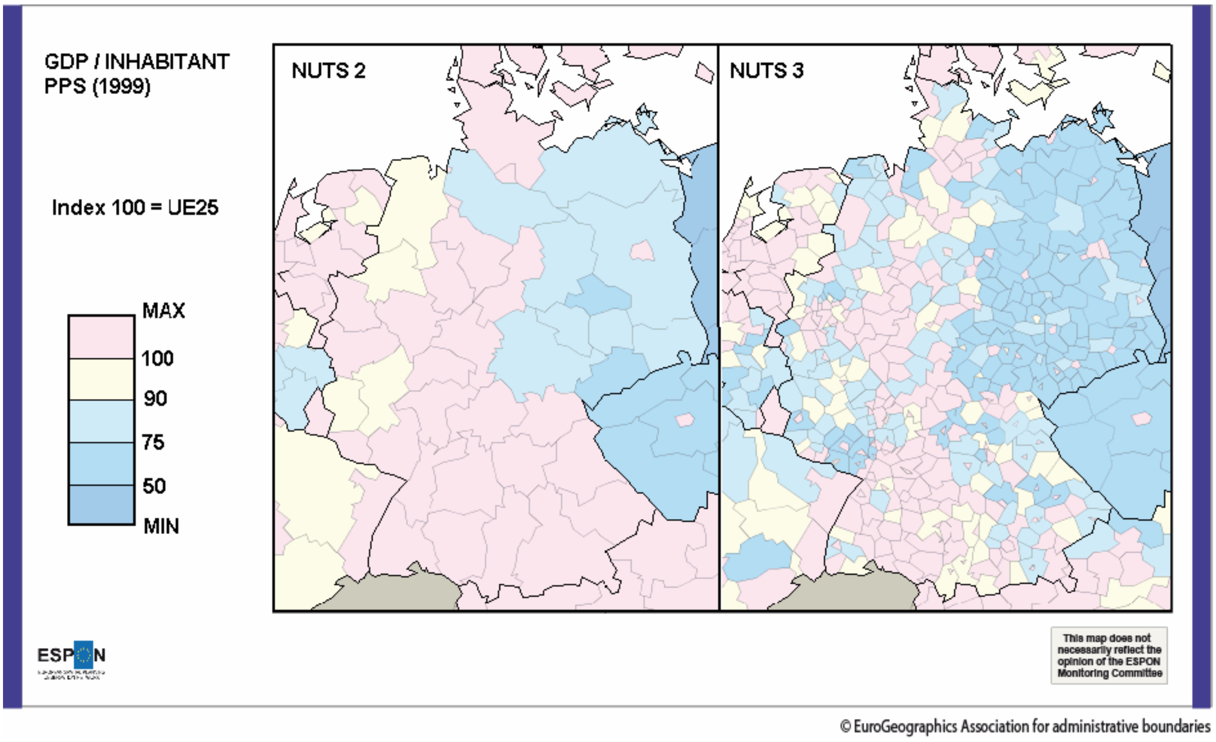


Figure 37 Changing cartographic perception of areas with low GDP/inh. pps (1999) in Germany

(Maps established with the ESPON Hyper-atlas)

Cartographic changes in visual pattern are not always as dramatic as in the cases of Portugal and Germany, but it is perfectly clear that **policymakers which try to analyse spatial patterns of regional development will receive completely different information according to the level of spatial aggregation.** The experiments on visual perception proposed by CESA (Tours) could be of major interest for the analysis of this phenomenon.

1.1.2 Influence of NUTS division on statistical analysis of results

Let us now consider the effect of territorial division on the realisation of statistical tables presenting synthetic results useful for policy makers. As an example, we have chosen to analyse the amount of regions of each European state which are located under the level of 75% of the mean of EU25 for the criteria of GDP/inh. pps in 1999. It is theoretically the criteria used for allocation of structural funds, but it is important to keep in mind that **this example is a fiction** as (1) some peripheral regions have not been included in the analysis and (2) the mean of UE25 is applied to 1999 at a moment where UE was restricted to 15 countries[16]. We do not discuss here the complete results which are presented in **Tables 3**, **4** and **5** of the Annex 1 and we focus on selected examples.

- **The shift of allocation of funds between old and new member countries** presented in **Figure 38** indicates a general tendency of reducing the share of new member countries when the number of territorial units increases. This is logical if we consider that increasing territorial divisions will produce the apparition of local peaks of poverty in richest countries of western Europe (increasing their share of eligible regions) and reversely produce the apparition of local peaks of wealth in poorest countries of Europe (reducing their share of eligible regions).

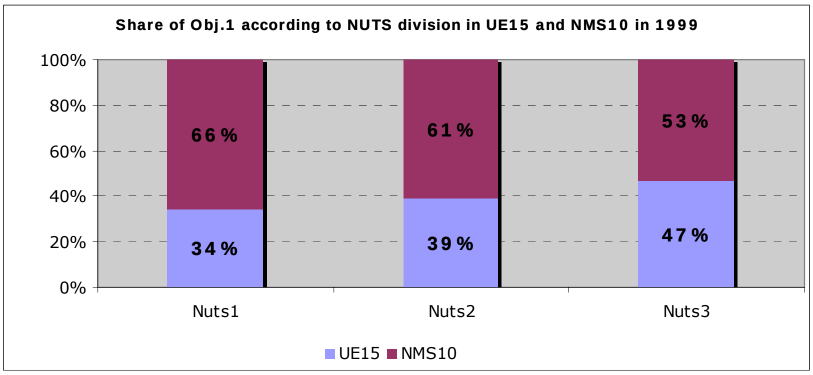


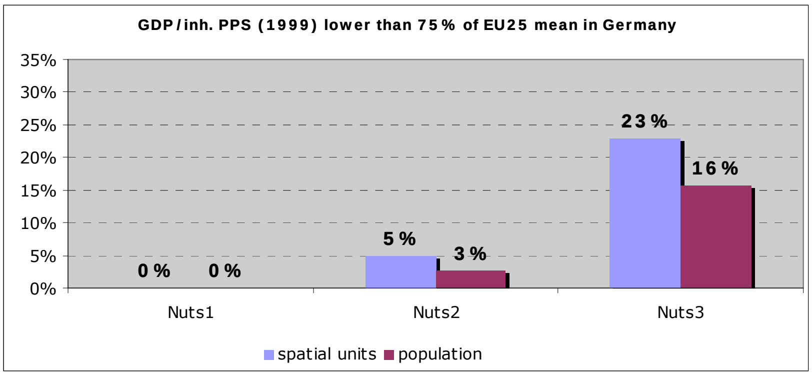
Figure 38 Influence of NUTS division on the allocation of structural funds in UE15 and NMC

[16] We have intentionally chosen to present an example which is not directly applicable to actual debate on reform of structural funds in order to avoid reactions related to the defence of national interests. But the example is sufficiently close to actual "hot cakes" of political debate in order to show the importance of the MAUP. It would indeed be very easy to apply the same method on actual data...

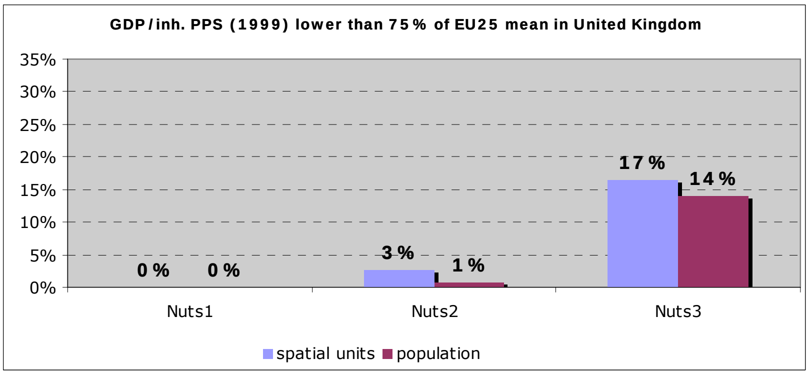
- **The national examples** presented in **Figure 39** demonstrate clearly that the choice of the territorial level is an important challenge for European states as far as ESPON results can be used for the allocation of structural funds. In the case of Germany and United Kingdom, the number of regions eligible to Objective 1 is equal to 0% at NUTS 1 but rises to 1-5% at NUTS 2 level and could eventually reach 10-20% at NUTS 3 level. The situation is different in Italy where it is at NUTS 1 level that the most important proportion of regions would be eligible and where we observe a decrease at NUTS 2 and NUTS 3 levels. In Greece, we have a more complicated situation where the maximisation of benefits is obtained either at NUTS3 (82% of regions representing 49% of population) or at NUTS1 (only 50% of regions but representing 58% of population).

This example is of course a fiction (see. Above) but it demonstrates clearly that the choice of territorial units is not innocent and that it is without any doubt an important topic for political negotiation. It is certainly not by chance that some states has chosen small or large territorial units when they have established their NUTS divisions...

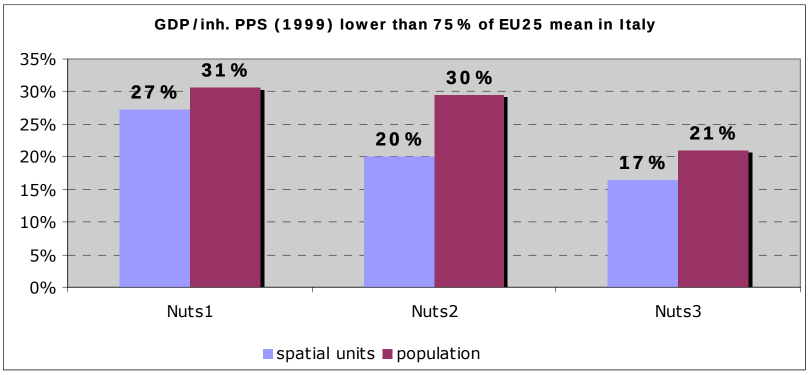
(a) Germany



(b) United Kingdom



(c) Italy



(d) Greece

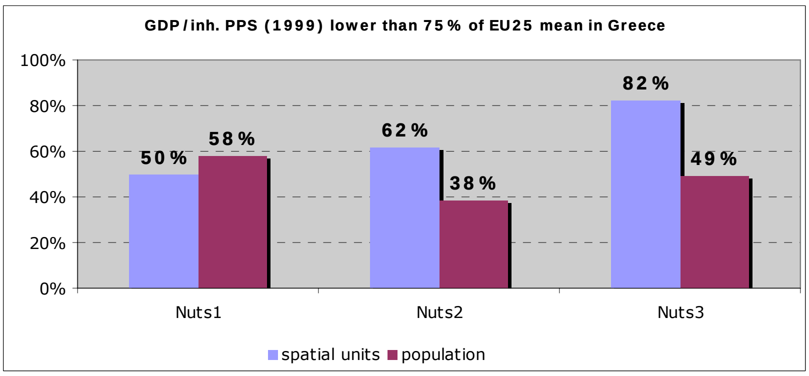


Figure 39 Simulation of the percentage of regions and population eligible to structural funds in different states according to the choice of NUTS division in 1999

1.2 How MAUP can be seen for Cross Typologies?

In the ESPON projects, typologies are often used, especially those combining of several phenomena (such as crossed typologies or other more complex clusters of regions). These typologies are often based on data at the NUTS 2 level and their results are then compared to several classical socio-economic indicators.

In order to explore further the possible influence of the NUTS level on the results, we have investigated the stability of these typologies to changes in the NUTS level used to establish them. To do so, we choose the urban-rural typology, based on population density, FUA ranking and land cover data, proposed in the project 1.1.2[17]. This choice is motivated by several reasons:

- Firstly, the latter typology, which is presented as a final goal in the project 1.1.2 summary, was used to produce one the emblematic maps of ESPON (see the Map 1 of Annex 2). This typology divides these European NUTS 3 data into six classes as a function of the urban influence (low/high) on one hand, and of the human intervention (low/medium/high) on the other hand (see Annex 2).
- Secondly, this typology is chosen because it is based on data at the NUTS 3 level and it was thus interesting to study the consequences of a change from NUTS 3 to NUTS 2 level on the cartographic renderings and on the associated statistical results.
- Finally, we choose this typology because their authors themselves tried to evaluate the consequences of a scale change on the robustness and on the validity of their analysis. For example, they slightly discuss the statistical biases that can arise from the time series they are dealing with on one hand, and they test their typology on the data from two different national contexts (i.e. Belgium and Austria; see Maps 2 and 3 of Annex 2[18]).

For this report, we re-used the methodology of the previous authors to build an urban-rural typology based on data at the NUTS 2 level. Let us first mention that in the same time, we redid their analysis at NUTS 3 level to check the coherence with their work and to allow for a precise comparison between typologies at NUTS 3 and NUTS 2 levels. For the 1329 NUTS 3 used we obtain the same

[17] See http://www.espon.lu/online/documentation/projects/thematic/thematic_7.html.
[18] They used NUTS 5 as reference territorial units; the criteria for urban influence and the degree of human intervention are based on the means of the considered countries.

typology except for 9 territorial units[19]. This discrepancy seems to be due to slight differences in the shares of land cover.

The spatial repartition of the urban-rural typology based on population density, FUA ranking and land cover is presented at NUTS 3 level on the **figure 40** and at NUTS 2 level on the **figure 41**. As pointed out for the NUTS 3 level in project 1.1.2, the distribution remains uneven at NUTS 3 level. In average, the same global spatial pattern of zones corresponding to the urban-rural typology is found for NUTS 2 and NUTS 3. As can be seen, the distribution of territorial units with high/low urban influence (red/blue) is as uneven whatever the base unit taken into account. Moreover, the high human intervention zones are mainly along an axis that goes from southern England to Bulgaria through Germany whereas low and medium human intervention zones are more characteristic of southern and northern Europe.

But beyond these relative similarities observed in the global spatial structures from NUTS 3 and NUTS 2 typologies, important differences due the scale of the study can also be pointed. The cartographic changes due to the use of different territorial units have been described before in the theoretical part of this report and in the part related to univariate analysis. We would like to insist here on the differences in the typology based on the three criteria: population density, FUA ranking and land cover. As all of these three criteria are scale dependant, each of them can introduce different spatial modifications in the final typology.

[19] Dinant (BE351), Philippeville (BE353), Schwandorf (DE239), Oberhavel (DE40A), Potsdam-Mittelmark (DE40E), Storstrøms amt (DK006), La Coruña (ES111), Buzau (RO022), Sibiu (RO076).

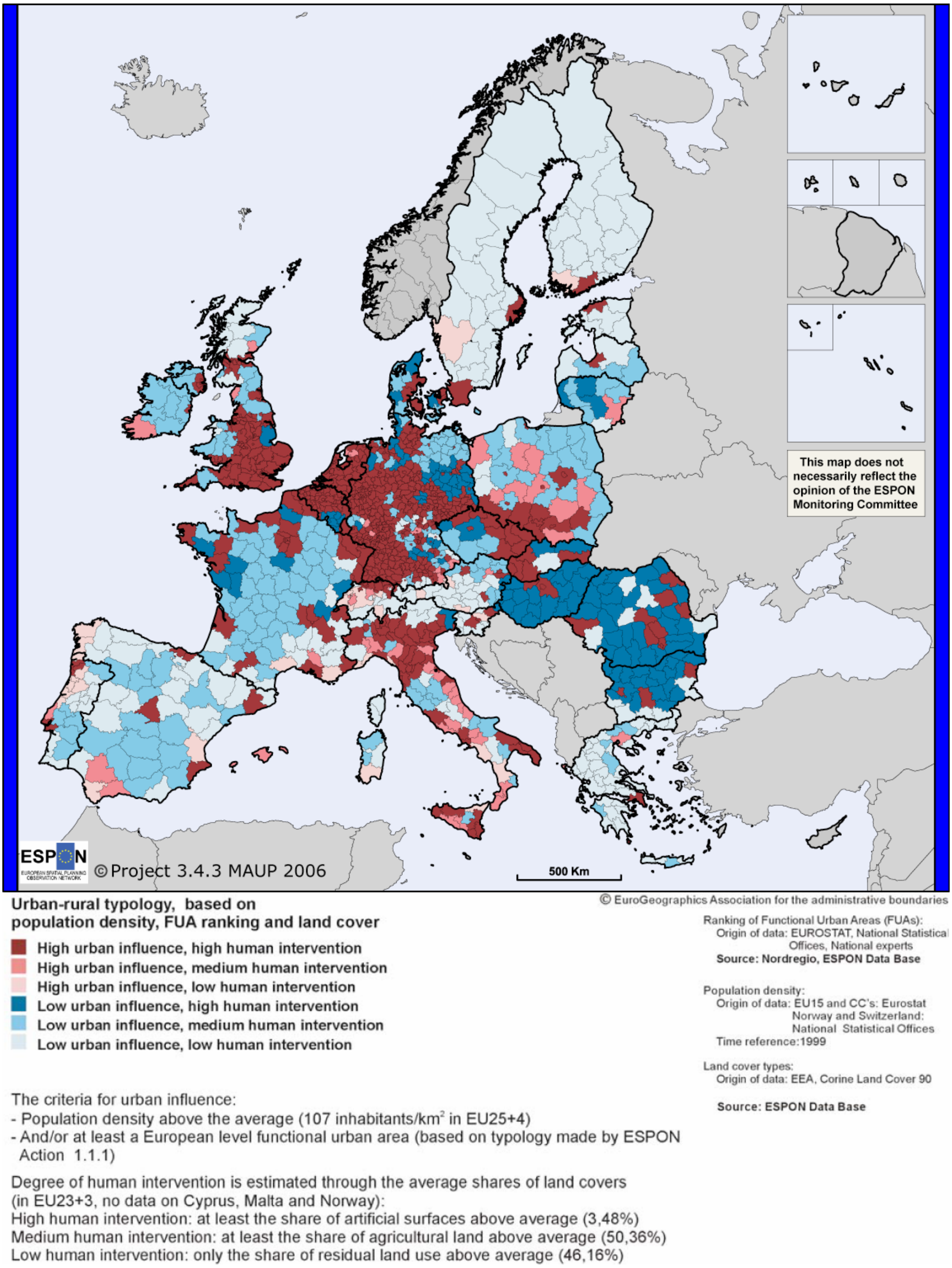


Figure 40 Urban-rural typology at NUTS 3 level

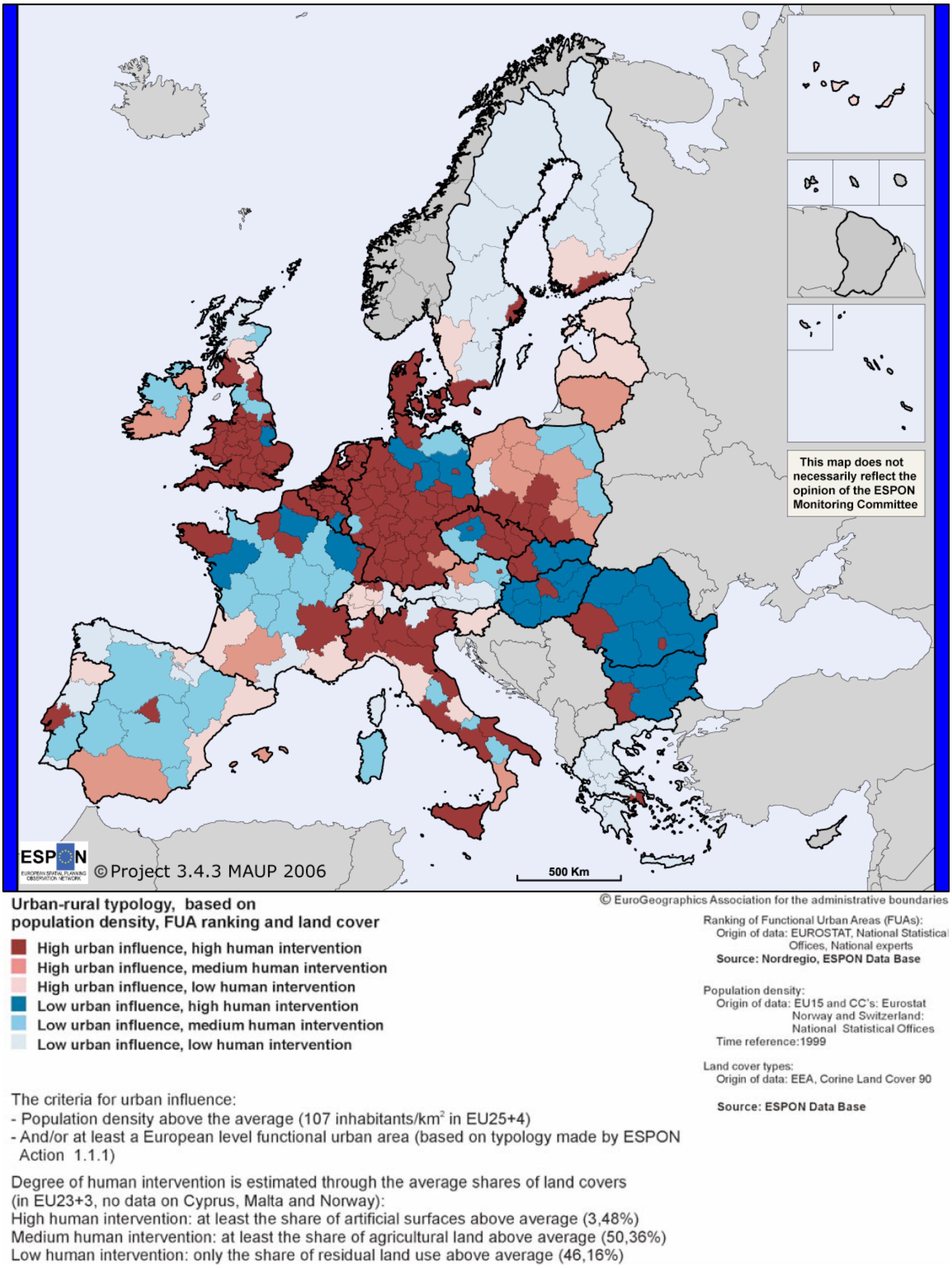


Figure 41 Urban-rural typology at NUTS 2 level

A typical and very frequent change can occur when one or several urban areas, characterised by a high population density and often by a high human intervention and defined individually at NUTS 3 level, are embedded in larger zones. For example, the south eastern part of Germany (eastern Bayern) shows a high variation in the urban-rural typology at NUTS 3 level while this is not the case at NUTS 2 level. These differences are due to an aggregation of the urban area at the NUTS 2 level while they remain individualised at NUTS 3 level. The effect of integration of isolated urban area (NUTS 3) in wider zones at NUTS 2 level is also clearly visible in Poland which in the cartographic rendering appears then as a continuous zone with a high urban influence at NUTS 2.

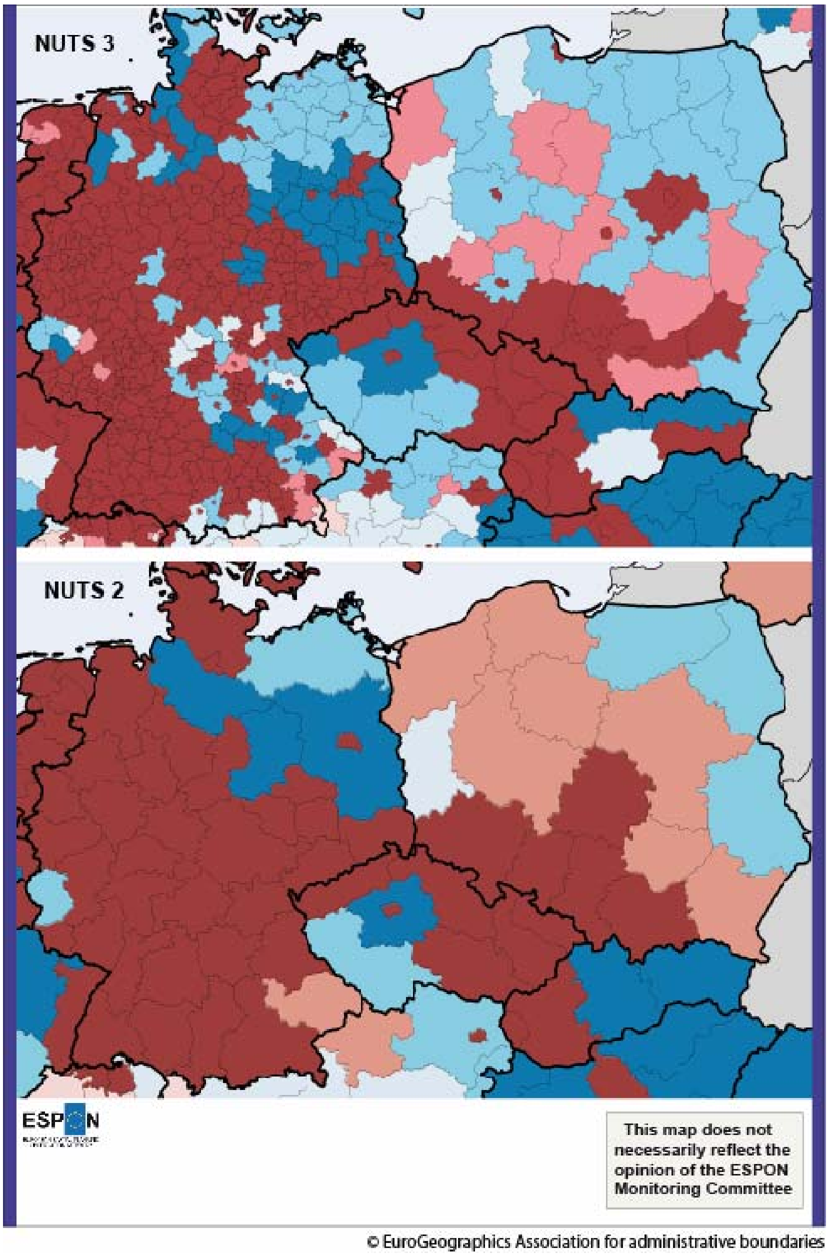


Figure 42 Zoom of the urban-rural typologies on Germany, Poland, Austria and Hungary

The criteria for urban influence are based on density population but also on the existence of a European level urban area[20]. Thus important differences between the typology at NUTS 2 and NUTS 3 levels can be expected. For example, in the south-western part of France (**Figure 43**), only the Gironde and Haute Garonne NUTS 3 are characterised by a high urban influence (and a high human intervention) due to the existence of a European level urban area (respectively Bordeaux and Toulouse) whereas neighbouring units are characterised by a low urban influence. In Ireland (**Figure 44**), the integration of the Dublin NUTS 3 unit, which is a European level urban area, in a wider zone at NUTS 2 changes the cartographic rendering and induces a division of the country into 2 zones according to the urban influence: a NUTS 2 zone with a high urban influence and another with a low urban influence (both being characterized by a medium human intervention). We could also quote the examples of Lituania, Estonia, Latvija or Norhern Irland which by switching from NUTS 3 to NUTS 2 show a much simpler typology due to the integration of European level urban area.

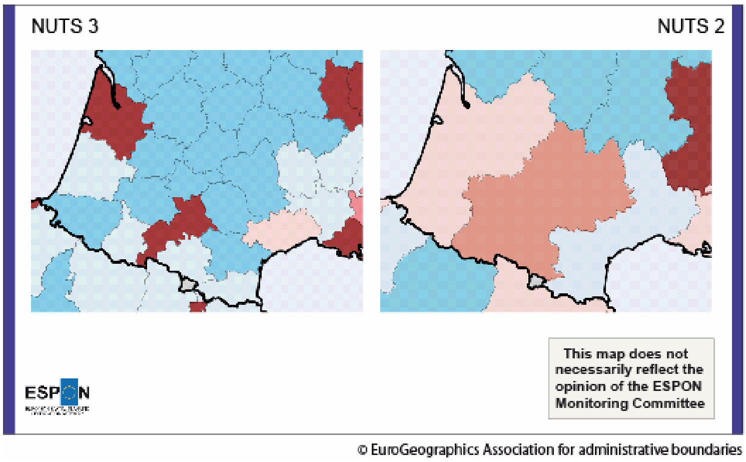


Figure 43 Zoom of the urban-rural typologies on the south-western part of France

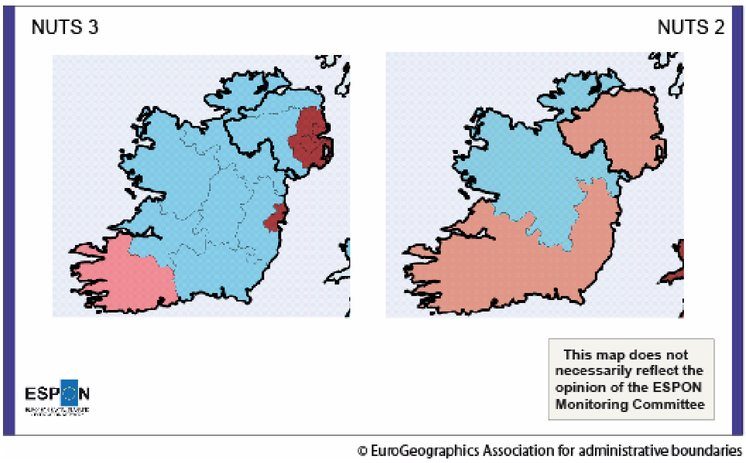


Figure 44 Zoom of the urban-rural typologies on Ireland

[20] based on typology made by ESPON Action 1.1.1

Beyond these differences on the cartographic rendering that has been already discussed, we have also evidence of the influence of territorial divisions on the spatial repartitions and the typologies often used in the ESPON project. After the discussion of this problem in ESPON meetings, the authors of project 1.1.2 decided to deepen this point and proposed a typology at a finer level for Belgium and Austria (based on NUTS 5). They demonstrated that the results are different from the one obtained at NUTS3 (cf. annex 3) but considered, as we have done in the first part, that these contradictory results are not a problem but rather a progress in the analysis. They insisted on the flexibility of the method and on the comparisons it allows between different scales.

Beside their synthetic interest, in particular at the cartographic level, the typologies are often used in the ESPON projects, in a second time, to compare the obtained classes to classical socio-economic indicators (GDP, population change and so on). Thus, in their Final Report, the authors show that 4/5 of the wealth (from GDP) concerned a bit more than 1/4 of Europe where the urban influence is high. These results were based on the typology built at NUTS 3. How are these conclusions modified when the level is changed from NUTS 3 to NUTS 2? More generally, since we have seen that the spatial distributions were not exactly the same, how are the statistical comparisons with the socio-economic indicators affected?

Table 12[21] shows several indicators, in absolute and relative values, associated with NUTS 2 and NUTS 3 according to the typology:

- number of territorial units
- area
- population
- GDP

The proportion of units and overall their area vary significantly from NUTS 2 level to NUTS 3 level. For example, for the low human intervention (types 4, 5 and 6), the area of the units with high urban influence (type 6) decreases from 30.7% at the NUTS 3 level to 20.8% at the NUTS 2 level. The units with high human intervention gather 1/4 of the total area (EU25+4) at NUTS 3 and 2/5 at NUTS 2. This can be partly accounted for by the criteria for urban influence which are affected by the presence of a European level functional urban area, as illustrated by several examples previously.

[21] See *Table 3.6. Urban–rural typology in relation to core indicators*, in the Final Report 1.1.2 (fr-1.1.2_maps_chap3_revised_31-03-05.pdf, p. 60)

Table 12 Urban–rural typology in relation to several indicators

NUTSn regions

	Nuts 3 Number	Nuts 3 as % from EU25+4	Nuts 2 Number	Nuts 2 as % from EU25+4
Type 1	691	52,0%	130	46,4%
2	58	4,4%	16	5,7%
3	34	2,6%	22	7,9%
4	125	9,4%	28	10,0%
5	184	13,8%	30	10,7%
6	201	15,1%	37	13,2%
n.a.	36	2,7%	17	6,1%
Total	1 329	100,0%	280	100,0%

Area in km²

	Nuts 3 Total	Nuts 3 as % from EU25+4	Nuts 2 Total	Nuts 2 as % from EU25+4
Type 1	906 881	19,3%	1 070 885	22,8%
2	219 444	4,7%	445 664	9,5%
3	127 231	2,7%	460 217	9,8%
4	508 597	10,8%	566 394	12,1%
5	1 049 959	22,4%	740 891	15,8%
6	1 440 576	30,7%	975 898	20,8%
n.a.	442 103	9,4%	434 842	9,3%
Total	4 694 790	100,0%	4 694 790	100,0%

Population in 1999

	Nuts 3 Total	Nuts 3 as % from EU25+4	Nuts 2 Total	Nuts 2 as % from EU25+4
Type 1	299 173	60,4%	284 426	57,5%
2	27 192	5,5%	41 154	8,3%
3	17 744	3,6%	47 059	9,5%
4	40 976	8,3%	49 214	9,9%
5	57 913	11,7%	36 042	7,3%
6	42 021	8,5%	28 843	5,8%
n.a.	9 925	2,0%	8 206	1,7%
Total	494 945	100,0%	494 946	100,0%

GDPpps in 1999

	Nuts 3 Total	Nuts 3 as % from EU25+4	Nuts 2 Total	Nuts 2 as % from EU25+4
Type 1	6 453 790	70,2%	6 136 414	66,8%
2	370 691	4,0%	525 665	5,7%
3	312 803	3,4%	876 917	9,5%
4	391 755	4,3%	450 045	4,9%
5	818 486	8,9%	564 942	6,1%
6	661 896	7,2%	484 163	5,3%
n.a.	182 581	2,0%	153 857	1,7%
Total	9 192 003	100,0%	9 192 003	100,0%

However, the population and GDP variables are much less sensitive to the NUTS level switching. Especially, **figure 45** shows that the proportion of GDPpps per capita in 1999 remains almost the same at NUTS 3 and NUTS 2 levels.

This experiment indicates that ESPON results are generally not completely modified when changing scale from NUTS 3 to NUTS 2 and vice versa. But they prove that one should be very cautious and always mention the NUTS level which has been used for the elaboration of statistical results.

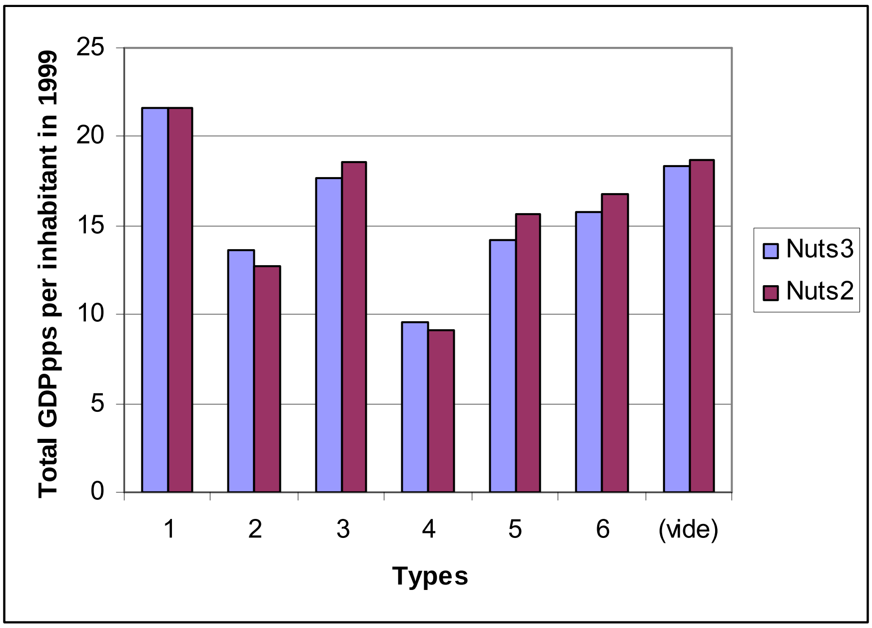


Figure 45 GDPpps per inhabitant according to the urban–rural typology

1.3 MAUP and the use of multivariate analysis

To go deeper into the MAUP question, we have completed the previous analysis by a multivariate analysis. The aim was to see how the territorial divisions can or cannot affect the results of a multiple linear regression. To do so, we used the classical ESPON dataset:

- GDP pps per inhabitant (2000)
- density of population (2000; in log[22])
- unemployment rate (2000)
- potential accessibility multimodal (2001; ESPON space = 100; see Project ESPON 1.2.1)
- Forest and non-wooded semi-natural areas per inhabitant (EEA Corine Land Cover 1986-1996)
- and the variation population between 1995 and 2000.

More precisely, we tried to account for the population variation by the other criteria. Are the NUTS which register population decreases characterised by a higher GDPpps per inhabitant or a lower unemployment rate and so on? Are the phenomenon or the phenomena which account for the population variation the same according to the NUTS level considered?

1.3.1 Global regression models

Table 13 shows for NUTS 0, 2 and 3 levels the variables that play a significant role in the change of the population variation, their position in the multiple regression, the sign of the relationship (positive or negative) and the r-squared that defines the quality of the final models. Moreover, we performed multiple regressions at NUTS 3 level for each country (NUTS 0).

If we consider the results for the whole Europe, differences are observed at NUTS 0, 2 and 3 levels and especially in the quality of the models obtained. At NUTS 0 level, only the GDPpps/Inh. variable and secondarily forest and non-wooded semi-natural areas /Inh. accounts for 55% of the change in the population variation: the higher the GDPpps/Inh. of a given country, the higher the increase of its population between 1995 and 2000. However, the two other models at NUTS 2 and 3 levels are of rather poor quality (respectively 18 and 19%).

Whereas at NUTS 3 level, on the whole Europe, the population variation between 1995 and 2000 is accounted for at only 19% by the unemployment rate, then by the population density (independently of the previous variable), by forest and non-wooded semi-natural areas /Inh. and by the potential accessibility multimodal, the built models are very different according to the countries. This

[22] To avoid dealing with a strongly asymmetric distribution, the logarithm of population density data was chosen in order to improve the models

demonstrates the underlying high variability of the phenomenon in Europe. Firstly, the models are often better, even if for some countries no model can be built: the quality vary from 10% for France to 83% for Sweden.

Table 13 Results of multiple linear regression analysis

	GDPpps /Inh.	Log Density	Unemploy ment Rate	Potential accessibility multimodal	Forest and semi-natural area /Inh.	R-squared	Number
NUTS 0	+ (1)				- (2)	55%	26
NUTS 2		+ (2)	- (1)	- (4)	- (3)	18%	264
NUTS 3		- (3)	- (1)	+ (4)	- (2)	19%	1295
Austria		- (2)		+ (1)		25%	35
Belgium	+ (3)	- (1)		+ (2)		52%	43
Bulgaria		+				38%	28
Czech Rep.	- (1)			+ (2)		82%	14
Denmark			- (2)		- (1)	53%	15
Finland			- (2)	+ (1)		73%	20
France			+ (1)	+ (2)		10%	96
Germany		- (2)	- (1)	+ (3)	- (4)	43%	441
Greece	- (3)		- (1)		- (2)	46%	47
Italy	+ (1)		- (2)		- (3)	31%	103
Latvia	-					63%	5
Lithuania	-					29%	10
Poland		- (1)	- (3)	+ (2)		47%	44
Slovenia	+					35%	12
Spain		+ (1)		+ (2)		27%	50
Sweden		+ (1)	- (3)		+ (2)	83%	21
Un.Kingdom	+ (3)	- (5)	- (1)	+ (4)	- (2)	46%	133

Moreover, the built models show differences in the selected variables, in their rank but also in the sign of their contribution. For example, an increase of the population in a NUTS 3 can be accounted for firstly by a low density, then by a high accessibility (independently of the density) and by a high GDP (independently of the density and the accessibility) for Belgium, whereas by a high density, by a high *natural* area /Inh. and by a low unemployment rate for Sweden. Furthermore, the NUTS 3 with an increased population are characterised by a high population density for Bulgaria, and by a low GDP for Latvia or Lithuania. We could define in this manner different examples. The aim was here to show the differences observed in the multiple regressions according to the selected territorial division.

This result shows that the relationships we can extract from a dataset depend both on the scale and the space on which the analyses are performed.

1.3.2 Local regression models with the Geographically Weighted Regression

In these previous global analyses performed on the whole ESPON space, we invoke a strong hypothesis: we assume a spatial stationarity of the relationship which means that we neglect the local variations in the relation between Y and X. Indeed, "the resulting statistics or parameter estimates are assumed to be constant across space although this might be a very questionable assumption to make in many circumstances" (Brunsdon *et al.*, 1996). Yet, the first results obtained when the countries are considered individually suggest the relationships vary in space.

One method to go beyond the spatial stationarity hypothesis is to use the geographically weighted regression (GWR) to appraise local variation in the parameter estimates of the independent variables (Fotheringham *et al.*, 1999). The main idea behind this approach is to extend the classical regression technique by spatially weighting the different factors which are involved in the least square minimization used to compute the regression models. Indeed closer units will have a larger weight than distant ones (practically the weighting function include a spatial range or bandwidth which must determined before the analysis). As a result, instead of obtaining a global regression model the application of the GWR provides a set of localised regression models that is different sets of regression parameters corresponding to different locations in studied space. Finally, one can appreciate the spatial variations in the models by mapping the different regression parameters over the considered space[23].

In the context of project 3.4.3 we investigated the spatial stability of the regression models accounting for the evolution of the population (1995-2000) obtained previously using the GWR method. We now described briefly the main results of this study.

Let's note that a preliminary study on the whole dataset allowed us to determine the optimal range for the GWR analysis (Gaussian weighting function) which varies between 190 km and 320 km. To allow for an unbiased comparison, we decided to fix this range to 250 km.

1.3.2.1 Relationship between the evolution of the population (1995-2000) and the unemployment rate

As a first example, we consider here the most significant descriptor (for the NUTS3 level) which explains the evolution of the population (1995-2000): the unemployment rate (r=-0.32). The relationship found is negative and the proportion of the variance explained by this descriptor in a global bivariate regression model is only 12%. The higher the unemployment rate for a given NUTS3, the stronger its tendency towards a decrease of the population.

[23] For more technical details see Brunsdon *et al.*, 1996 and Fotheringham *et al.*, 1999.

	Evolution of population (1995-2000)	
	Nuts 3	Nuts 2
Unemployment rate	-0.32	-0.25
GDP/Inh	0.13	0.27
Accessibility	0.22	0.15
Density (in log)		0.14
Forest and semi-natural area /Inh	-0.14	-0.27

Table 1 Simple linear relationships between the evolution of the population and the retained variables.

(all the correlation coefficients are significant at the threshold 2%)

The GWR methods allows for an improvement of 28% of the explanation model. Figure 46 shows the spatial variation of the Student parameter *t*[24] of the GWR for the whole ESPON space at the NUTS3 level. The negative t-values, corresponding to a locally negative relationship between the evolution of the population an the unemployment rate, are shown in green; the color intensity represents the intensity of this relationship. Conversely, locally positive relationships between these two variables are shown in red gradations. The white zones correspond to non significant relationships.

On this map, we find again as expected the results of the global regression on the whole ESPON space. Indeed, the local relationships are mainly negative on the whole territory. More precisely, we can observe a pattern center-periphery with a more negative relationship in the center of the ESPON space (as well as in Greece) which decreases gradually in intensity towards the periphery of this zone centered on Germany up to becoming non significant (Iberian Peninsula, southern France ; eastern Poland ; northern Scandinavia). Finally, for some zones (south west of France and its border with Spain; la Lithuania), the population tends to increase, between 1995 and 2000, in the NUTS3 for which the unemployment rate was high.

[24] As for the whole set of maps produced using the GWR method, we chose to show the *t*-values : the summary data allows us to keep the information on the significancy, on the sign of the relationship and on its intensity.

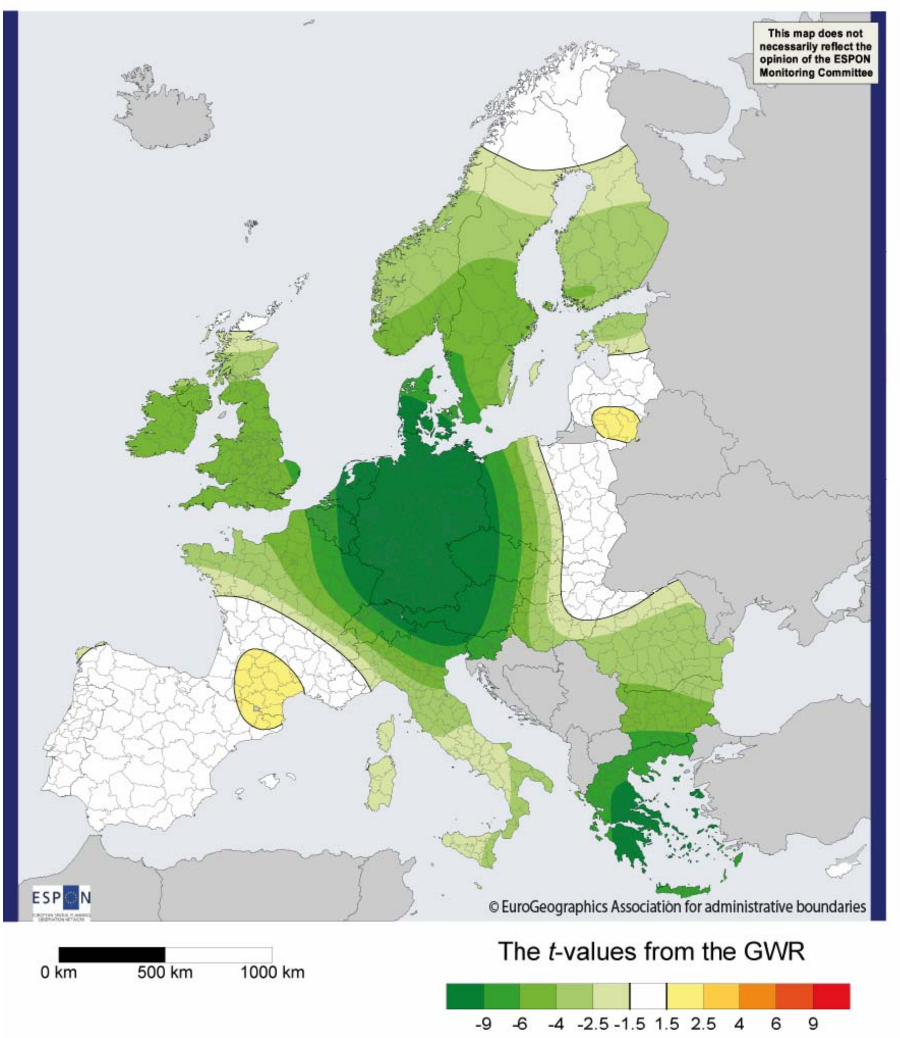


Figure 46 GWR parameter's *t*-values variation for the unemployment rate (NUTS 3, bandwidth 250 km)

This result shows that the relationship between the evolution of the population (1995-2000) and the unemployment rate computed on the whole set of NUTS3 is mainly dominated by Germany and Greece. They are consistent with the multiple regression analyses done previously for each country (see Table 13). Indeed, the three countries for which the unemployment rate was the first variable negatively correlated were Germany, Greece and the United Kingdom. The results of the GWR are thus not surprising, even though we can assume that the strongly negative relationship is probably enhanced by an internal MAUP effect induced by the fine gridding of the German NUTS3.

Keeping those two variables and staying at the NUTS3 level, we tried to vary the bandwidth, in order to see is other schemes at different scales could be identified. Here, we only show the map (Figure 47) of the results of a GWR done with a bandwidth of 500 km (r^2=19%)[25]. When the bandwidth is increased the GWR results tend to the results of the global regression model.

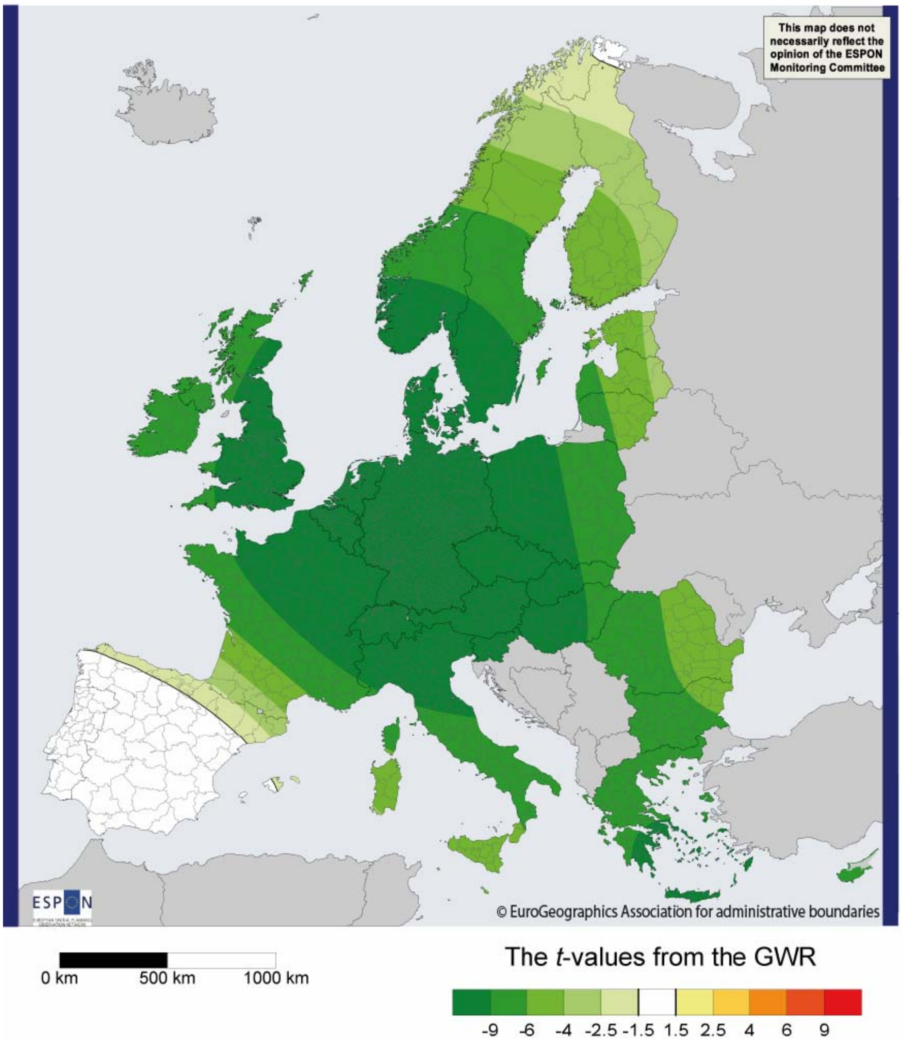


Figure 47 GWR parameter's *t*-values variation for the unemployment rate (NUTS 3, bandwidth 500 km)

[25] The bandwidth smaller than 250 km do not give supplementary information (the zones with a strong local relationship, either positive or negative are more confined in space but the patterns remain the same). Moreover, beyond 500 km, it is more difficult to see differences in the spatial variation of the relationship between the evolution of the population and the unemployment rate. The maps are no longer different and thus less interesting.

At the NUTS2 level, the unemployment rate is also the variable which best explains the evolution of the population. Again, a simple negative relationship between these two variables is found though weaker (r2 = 12%). We performed a GWR analysis in order to explain the local variation of the population by the unemployment rate at NUTS2 level and compare with the results obtained for the NUTS3 level. The spatial patterns of this GWR (Figure 48) are relatively similar to the previous ones.

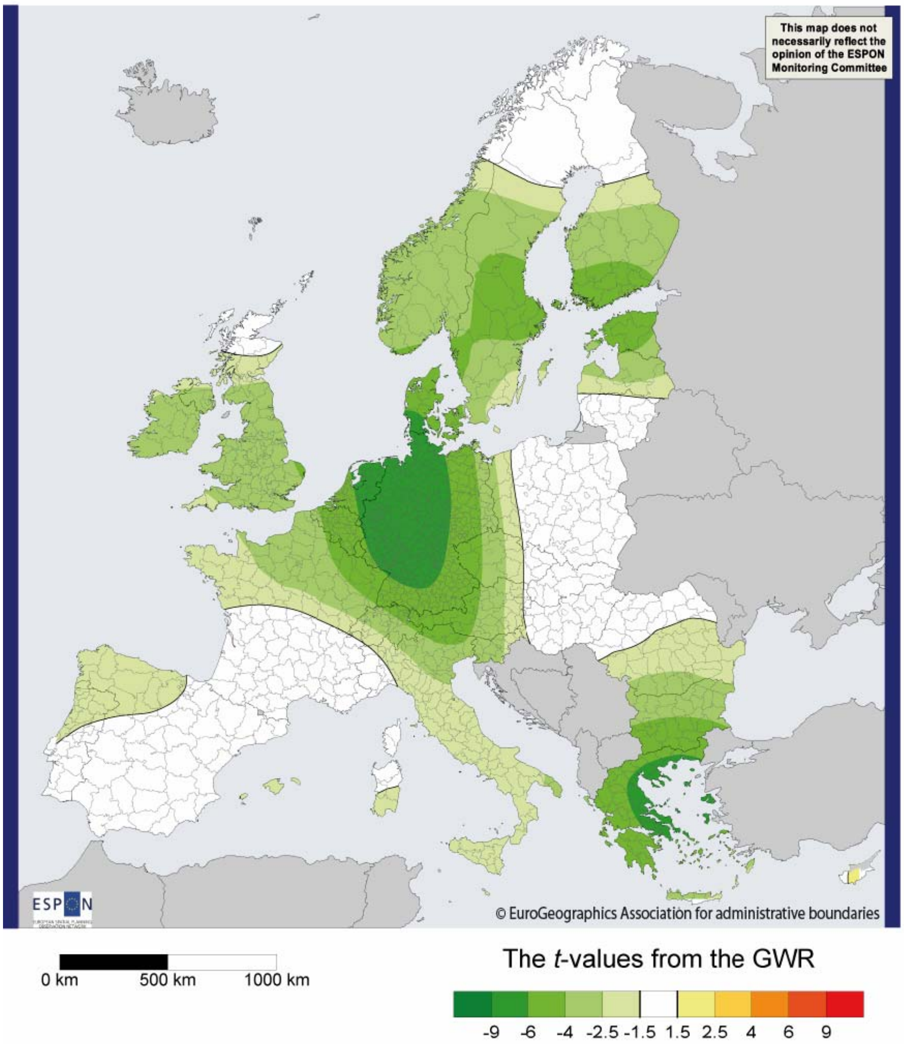


Figure 48 GWR parameter's *t*-values variation for the unemployment rate (NUTS 2, bandwidth 250 km)

1.3.2.2 Relationship between the evolution of the population (1995-2000) and population density

In the context of this report and before going to the details of a multiple GWR, we wanted to come back on an interesting results linked to regressions between the evolution of the population (1995-2000) and the population density (in log scale). Whereas at NUTS2 level a weak positive relationship (r=0.2) is found between these two variables, no relationship is found at NUTS3 level. In order to investigated deeper this point, we performed two GWRs (dependent variable: the evolution of the population; independent: population density in log; bandwidth: 250 km), one from NUTS2 data, the other with NUTS3 data.

Figure 49 and 50 show the t-values of this GWR. On the first one, concerning the level NUTS2, we see that the positive relationship globally observe (on the whole space) is found around Baltic Sea and in the south of Mediterranean countries of the ESPON space, in other words in peripheries. However, two isolated zones show an opposite (negative) relationship: Ireland and around Warsaw.

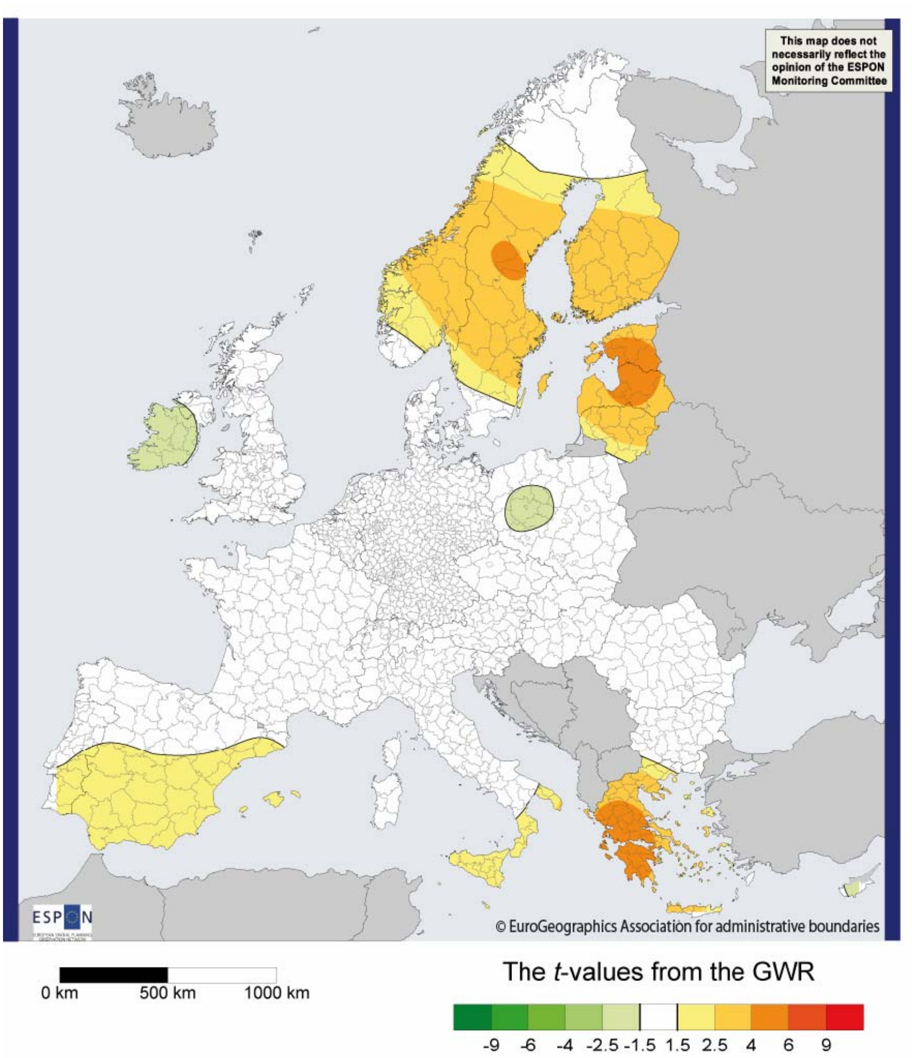


Figure 49 GWR parameter's *t*-values variation for the population density (NUTS 2, bandwidth 250 km)

If we now consider the results at the NUTS3 level where the relationship was not significant, Figure 50 shows a clear division of the space as a function of the t-value of the GWR: the center of the ESPON Space shows local negative significant relationships and the border of this territory shows local positive significant relationship. The combination of these two evolution schemes for the population as a function of the population density cancels out the relationship on the whole ESPON space.

This example is particularly striking and allows to clearly evidence the influence of the spatial non stationarity between variables.

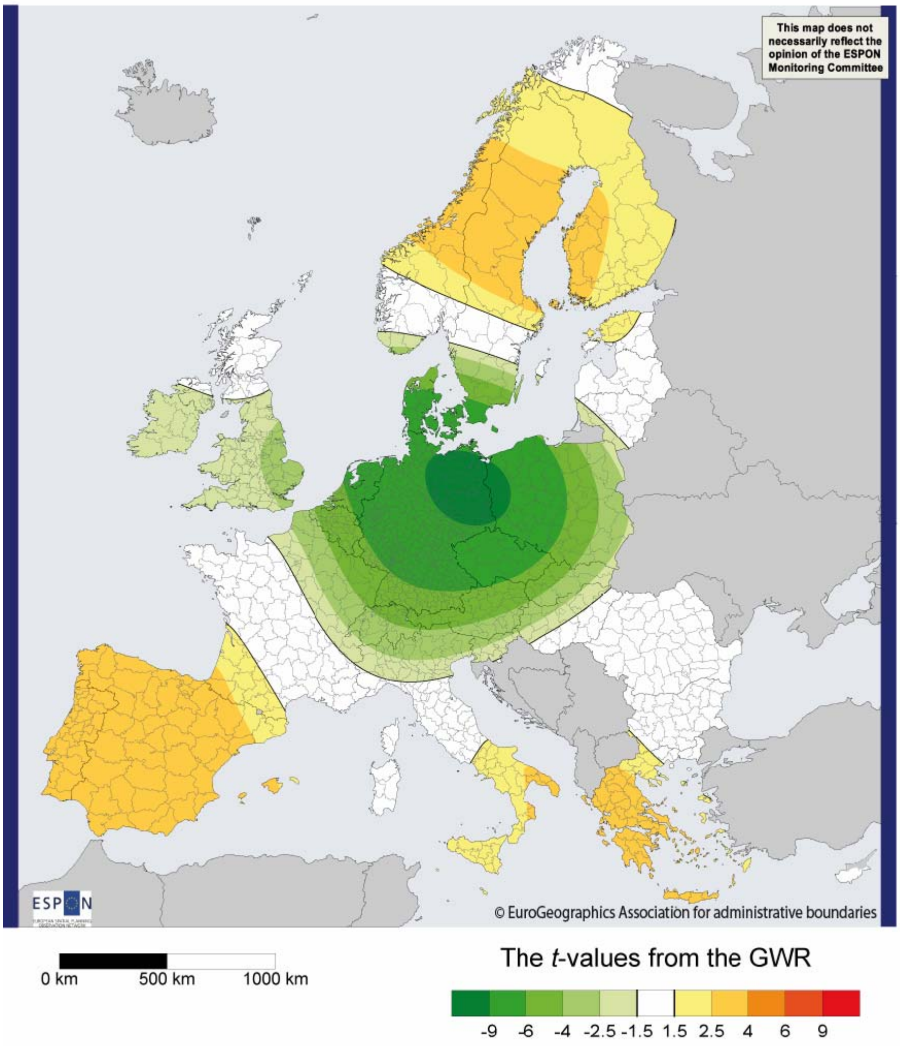


Figure 50 GWR parameter's *t*-values variation for the population density (NUTS 3, bandwidth 250 km)

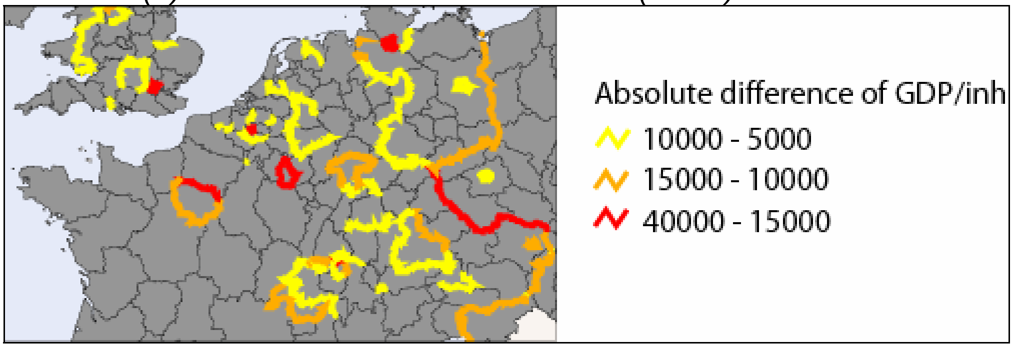
1.4 MAUP and the spatial analysis approaches

Last but not least, the MAUP has direct consequence on the results of advanced tools of spatial analysis and can completely change the cartographic and statistic outputs. A good example of this has been provided in the final report of ESPON project 3.1 in the part "dictionary of tools" where it was clearly demonstrated that all methods which are based on spatial contiguity (maps of discontinuities, local deviations, spatial autocorrelation, measure of spillover effects, …) are completely dependant from the choice of basic territorial units.

The **Figure 51** presents for example two maps of local economic heterogeneity (differences of GDP/inh. between contiguous regions) established at NUTS 2 and NUTS 3 levels.

- *At NUTS 2 level* (**51.a**), the attention of the reader is attracted (1) by spatial structures of upper level which are mainly related to international borders: the exceptional advantage of Luxembourg, the former political division of Europe, the difference with non-EU member countries like Switzerland and (2) by major metropolitan area, which are surrounded by circular discontinuities (Paris, München, Frankfurt, London, …).
- *At NUTS 3 level* (**51.b**) the picture is much more confused because all urban units located in Germany, Austria and Benelux are now able to produce differences with the surrounding peri-urban or rural areas. What the reader really perceives is local scale differences which are apparently present in certain states and not in other ones. But this perception is in fact false and equivalent urban-rural oppositions of GDP/inh would be observed in France, Spain or Italy if those states have used smaller territorial divisions at NUTS 3 levels.

(a) Discontinuities of GDP/inh. 1999 (euros) at NUTS 2



(b) Discontinuities of GDP/inh. 1999 (euros) at NUTS 3

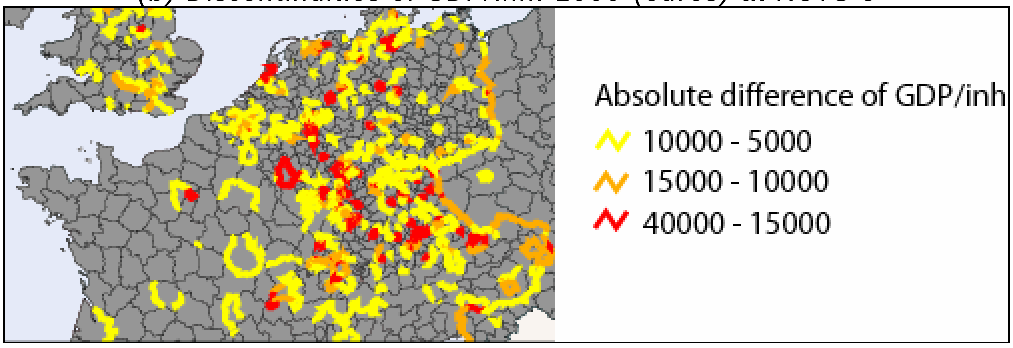


Figure 51 Impact of the choice of spatial units on the cartography of territorial discontinuities

(Source: ESPON 3.1, Final Report, Dictionary of tools)

=> The problem is not to decide which scale of analysis is the better one (both are interesting) but to avoid a *confusion of scale* on the same map.

2 Survey on maps perception and analysis of maps vision

Maps has been recognised since the beginning of ESPON as a major concern and strong effort has always been made in order to improve their quality and harmonisation by ESPON Coordination Unit and by TPG in charge of integration of results (ESPON 3.1 and ESPON 3.2). The different guidance papers produced by ESPON has defined very precise rules for realisation of maps according to specific templates. Moreover, the external diffusion of ESPON and its promotion has been always strongly related to the promotion of maps (like the one published in the 3rd Cohesion Report).

This focus on cartographic results is probably normal, as ESPON is an applied research program on *spatial* planning and *territorial* cohesion. But we can ask if this focus has not been sometimes exaggerated as major results has also been produced in forms of statistical tables, graphics, definition and of course texts about concepts and policy recommendations. We do believe that some discussion should be engaged by ESPON community on this point as we have sometime the feeling that the promotion and diffusion of reports is more correlated with the importance of cartographic production than with the real quality of outputs.

Whatever the future of this debate, we decided in the framework of project MAUP to proceed to a in depth investigation on the practice of maps by ESPON community. With the support of ESPON Coordination units, we decided firstly to launch a survey on the practice of maps which was realised during the Salzburg meeting in Spring 2006. And we tried also to complete this survey by some experiments on the perception of maps by observers using a sophisticated method of measure of path followed by the eye of observer. The questions that we want to analyse with this double analysis are:

- *What is the practice of maps by ESPON members?*
- *Which maps are preferred? why?*
- *How many maps can be used for the description of the same phenomena?*
- *What is really perceived by the eye of observer looking at maps?*
- *Which recommendations can be deduced for ESPON II?*

2.1 A survey on the cartographic preferences of the ESPON community

During the ESPON meeting held in Salzburg in March 2006, the ESPON Project 3.4.3 (supported by the ESPON coordination unit) realised a survey in order to analyse which type of maps or combination of maps was considered as the most relevant by the ESPON community and if differences could be observed between different categories, especially between so-called “researchers” and “policy-makers” (Annex 4). Due to the limited time available (15 minutes), the survey focuses on one very classical indicator (GDP per capita) and proposed to realise a benchmarking between six possible cartographic representations of the target phenomena (Figure 52)

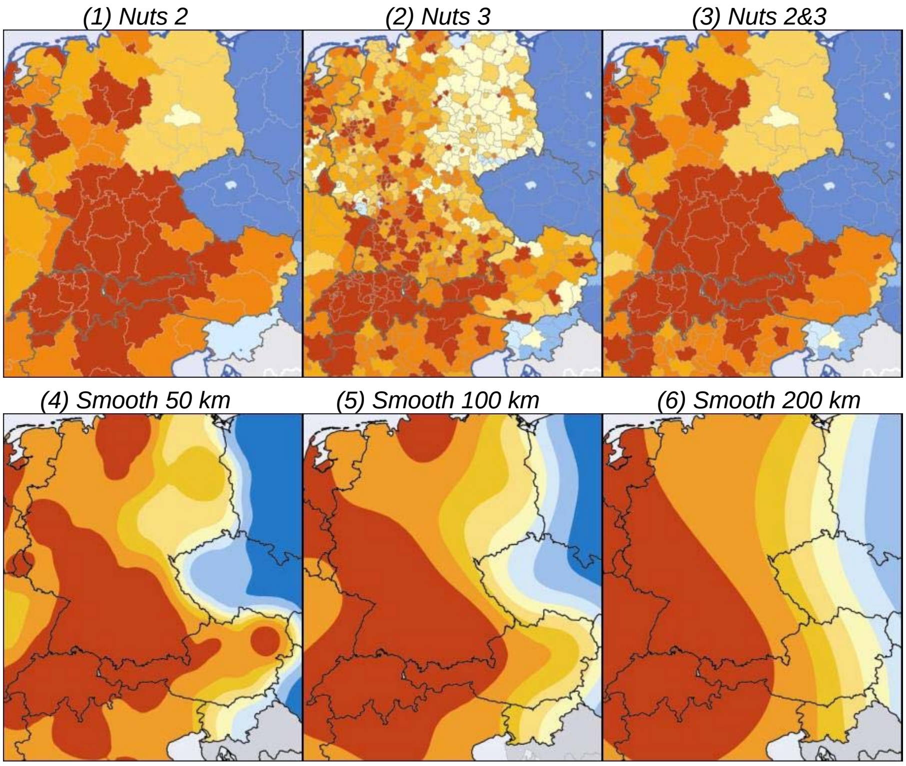


Figure 52 Sample of the six maps used for Salzburg’s Survey

- **The maps 1 and 2** which are based on Nuts 2 and Nuts 3 delimitation define the classical cartographic solution used in ESPON.
- **The map 3** which is based on a mixture of Nuts 2 and Nuts 3 proposes a solution which is generally recognise as most interesting from scientific point of view (homogeneity of area of territorial unit) but does not follow the official hierarchy proposed by Eurostat.
- **The maps 4, 5 and 6** are based on a gaussian smoothing method which eliminates the regional borders and focus the interpretation on the spatial distribution of the phenomena at different degree of generalisation.

2.1.1 A sample of 105 answers

The 105 answers obtained in Salzburg define a relatively good sample of the ESPON community:

1. Age and Gender: The over representation of men (75%) as compared to women (25%) is not surprising but reflects a disequilibrium inside the ESPON community. The age rank from 19 to 69 with a mean value of 45 for men and 43 for women.

2. Nationalities: 30 different nationalities are represented in the survey, from which 14 nationalities with more than 3 answers: Austria (10), Germany (10), Finland (10), Sweden (7), France (6), Netherlands (6), Spain (5), Hungary (5), Belgium (4), Italy (4), Portugal (4), U.K. (3), Greece (3) and Norway (3). The sample is not perfectly representative at countries level. Austria is logically over-represented as the meeting took place in Salzburg. Nordic countries are strongly present in ESPON. If we consider the distribution according to EU memberships, we observe that the new member states represents 17% of the answers which fits nicely with their share of the population of the ESPON area (15%). The old member states represents 71% of the answer and the rest of the answer is due to countries non member from EU but member from ESPON (Switzerland, Norway) or present at the meeting as host (one answer from Russia).

3. Level of education: the majority of the answers are produced by people with a level of education equivalent to master degree (58%) but one third of people declared a level of education equivalent to Ph'D (33%). Only 4% of people declare a lower level of education and 5% did not answered. In terms of education, the ESPON community is a "dream team" of people with globally very high level of education. It means of course that the appreciation of maps by this community is not necessary the same that the one of other actors (especially at local level).

4. Main professional activity: The borders between scientific and political activity is of course not always clear. But most participants to the survey (except 8) agree to choose a main field of professional activity. The sample present a good equilibrium with 51% of "Researchers or Teachers", 41% of "Administrators and Policy makers" and 8% of "others" which are for example private consultant or people sharing equally their activity between research and political decision.

2.1.2 The practice of maps in the ESPON community

Before to analyse the cartographic preferences of the ESPON community, it is important to evaluate the importance of maps in the professional activity of people and the degree of autonomy that they have in the elaboration of this type of tools.

The Figure 53 indicates clearly that maps are a major concern for the member of the ESPON community and that this intensity of the practice of maps is common to researchers and policymakers. More than 80% of people are using maps in their professional activity at less once a week and 50% are using maps several time during the same week. Scientists and policymakers are using maps with the same frequency in their daily activity but they are not exactly in the same situation as scientists are more likely to have a direct control on the production of the maps that they need.

The Figure 54 shows that 2/3 of the scientists are producing the maps they need in their own team or service when it is the case of only 1/3 of policy makers. Moreover, 18% of the scientists has a full autonomy and declare to produce themselves the maps their need when it is the case for less than 5% of people who declared to be policy makers. Policymakers have therefore less control on the amount of map production and it is only *a posteriori* that they can exert a political evaluation. The systematic quotation "*This map does not necessary reflect the opinion of the ESPON Monitoring Comitee*" is at the same time (1) a recognition by policy makers of the power of map in terms of communication and (2) a will to control on a tool which is mainly in the hand of scientists.

The figure 55 reveals another clear difference between scientists and policy makers concerning the potential use of maps. The idea that maps can be used as simple illustration is shared equally by scientists and policy-makers (40 to 45%) but the other types of use are clearly different. On the one hand, more than 80% of researchers consider maps as a research tool when this opinion is shared by less than 40% of policy-makers (40%). On the other hand, more than 50% of policy-makers are using maps as a decision tool when it is the case of only 5% of researchers.

The fact that both scientists and policy makers are using very frequently maps does not mean that they have the same practice and the same expectations. Scientists are producing frequently directly the maps that they need in a research perspective. Policy makers are less able to control the production of the maps they need for their activity of decision and research. A coordination procedure is therefore necessary in ESPON in order to insure that the maps produced by scientists in a research perspective can be also useful for policy makers in an operational perspective…

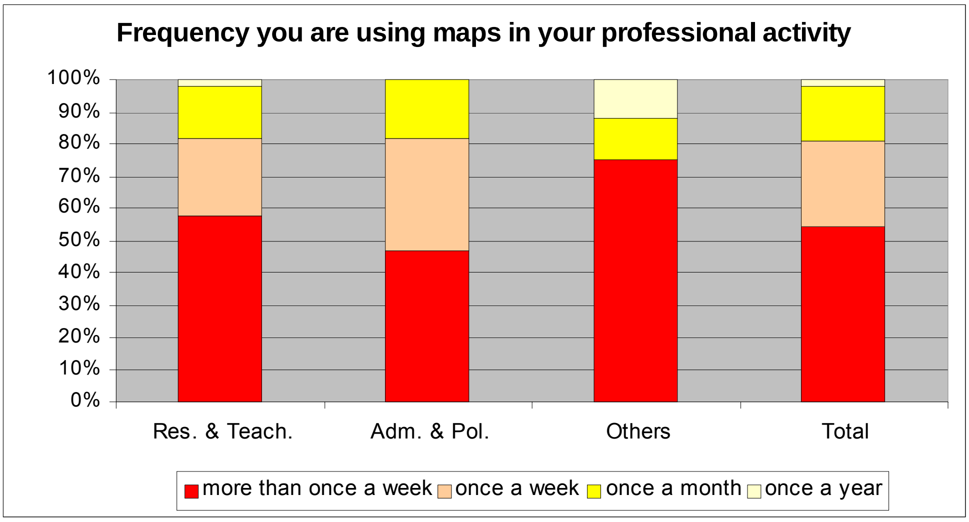


Figure 53   Frequency of the use of Maps in ESPON community

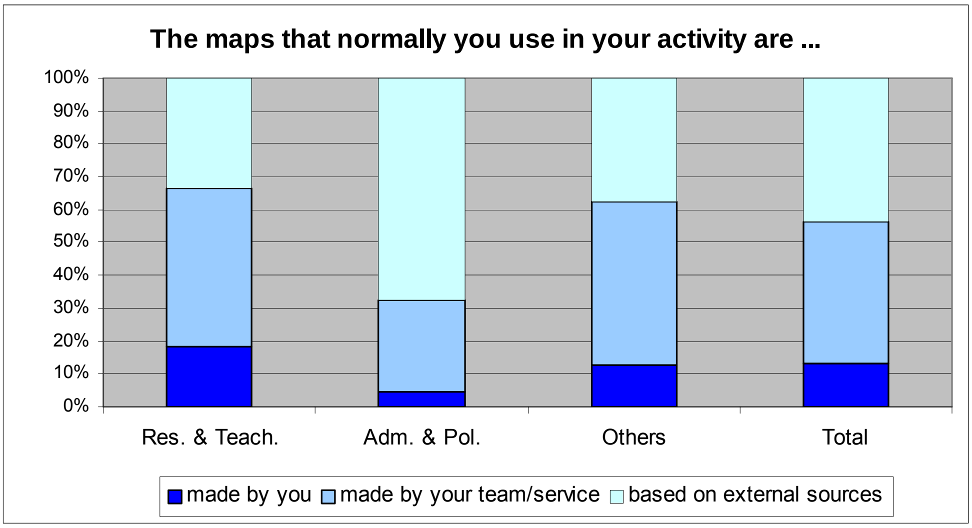


Figure 54   Autonomy in the production of maps in ESPON community

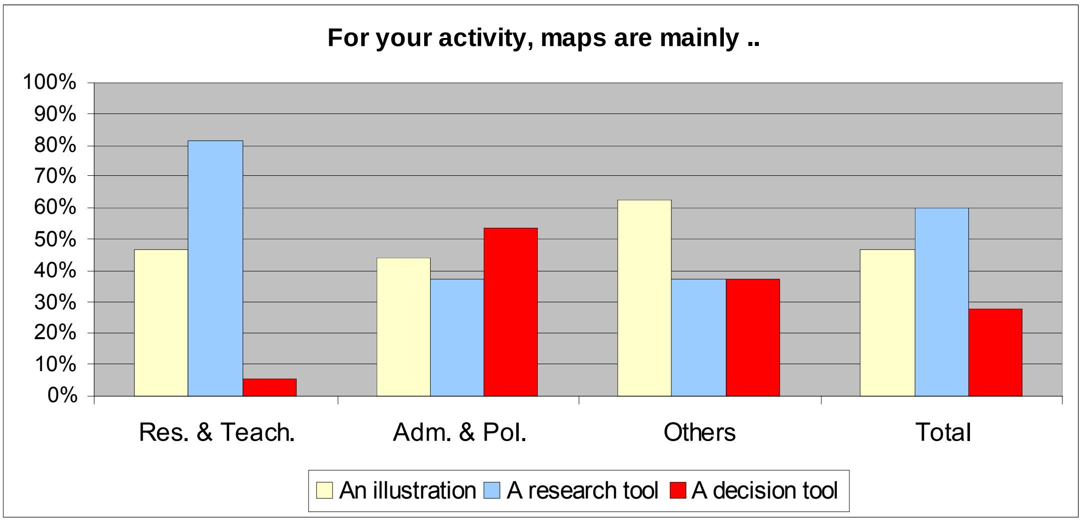


Figure 55   Function of maps in professional activity of the ESPON community

2.1.3 What is your favourite map? The winner is…

Even if the author of the survey was personally convinced that it is not possible to define a "best map", they decided to introduce this question "*What is your favourite map*" in order to be able to compare the map preferences when people are choosing only one map or when they are able to combine several maps.

As demonstrated by Figure 56, most people (except 7) agreed to answer to the question and propose as favourite maps a classical cartography at local level NUTS 3 (36%) or an alternative solution of mixture of NUTS 2 and NUTS 3 (38%) which keep the local territorial dimension but limits the heterogeneity. The smoothed maps which propose a too high level of generalisation are clearly rejected (span 100 and 200 km) but the map with the most local span of smoothing (50 km) is chosen as favourite by 19% of people and obtain the 3rd rank. What is finally the most surprising result is the very low score of the map in NUTS 2 division which was chosen by only 6% of people and appears only in 4th position. The choice of the favourite maps is not related to professional activity. In each case we have a mixture of researchers and policymakers in more or less equal proportion to their size in the global sample.

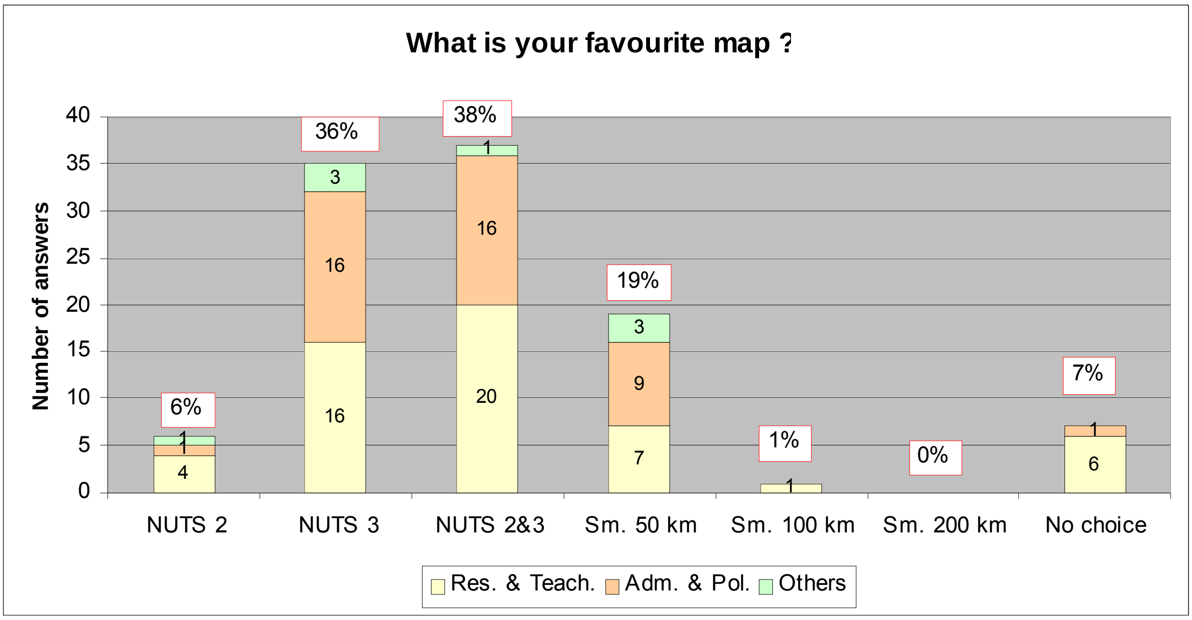


Figure 56 Favourite map of the ESPON community in case of single choice

The fact that scientists and policy makers are producing the same choice of favourite maps is a very important result of the survey which was not expected.

The fact that NUTS 2 maps has been chosen as favourite maps by a minority of people (6%) is a also very tricking result as ESPON I has not been able to produce many results at NUTS 3 and has been obliged, for practical reason, to limit the synthesis at NUTS 2 level (see. Projects 2.4.2, 3.1, 3.2, 3.3, …). A reflection on database collection and harmonisation appears crucial for ESPON II.

The elaboration of complete database at NUTS2 & 3 level appears as a minimum requirement for the future.

2.1.4 A general interest for map combinations

The fact that people agreed to propose a favourite map did not mean that they were reluctant to the introduction of several maps of the same phenomena in a report. As demonstrated by Figure 57, the majority of the ESPON community is in favour of map combinations, without differences between scientists and policy makers. This is a very important discovery with many consequences for the question of the MAUP

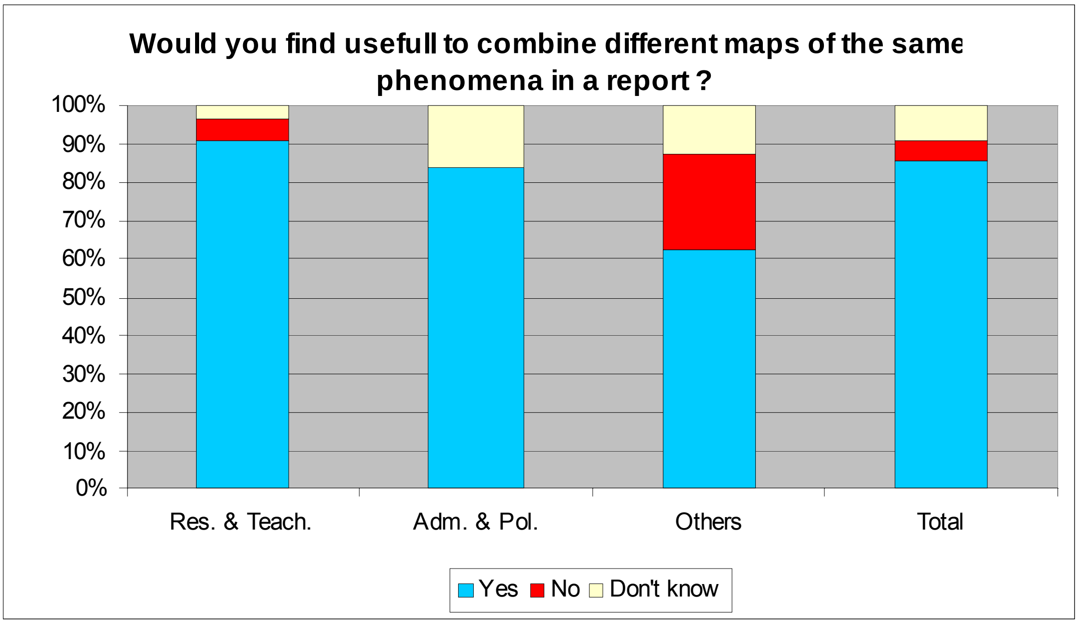


Figure 57 Usefulness of maps combination according to ESPON community

People propose generally to combine two maps, sometime three. The combinations which are proposed reveal two objectives

- It is interesting to observe the phenomena at different scales of territorial aggregation (e.g. NUTS2 combined with NUTS 3) or different scales of spatial smoothing (e.g. smoothed at 50 km combined with smoothed at 200 km). One of these scales should be local and keep the maximum of information when the other provides a more global picture.
- It is interesting to combine a regional map (based on NUTS division) and a spatial map (based on smoothing methods) because the first one is useful for the concrete political actions (e.g. allocation of funds) but the second is more interesting for the elaboration of global strategies (e.g. territorial visions or scenarios).

The most frequent solution is therefore to combine two maps, one of them being a regional map of local level (NUTS 3 or NUTS2&3) and the other one a smoothed map with medium level of generalisation (50 to 100 km). With this solution, the two objectives are fulfilled.

2.1.5 A conceptual evolution of ESPON?

The fact to open the door for combination of maps produces an important change in the appreciation of the most interesting maps (Figure 58).

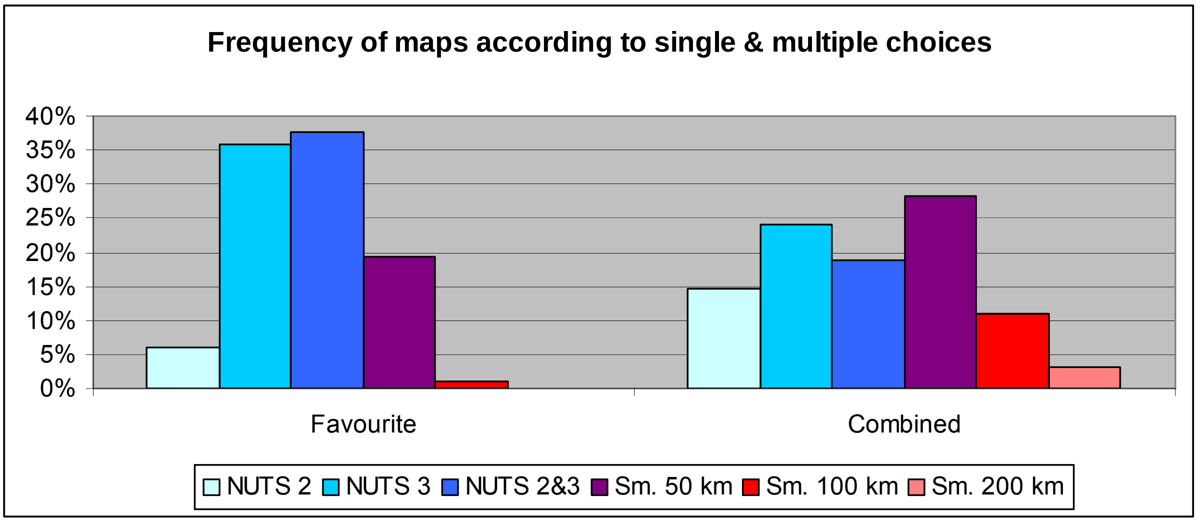


Figure 58 Favourite maps of ESPON community in case of multiple choices

Two major changes can be pointed when we compare the favourite maps in the framework of multiple choices as compare to previous situation of single choice:

- The hierarchy of maps is modified and the map which is the most often used in combination is the smoothed 50 km which was only in 3rd rank in case of single choice. It means that ESPON community like this type of cartographic representation but only when it is combined with a more classical representation based on territorial division.
- The dispersion of choices is much more important when combination of maps is possible, which is not only a pure statistical effect. Indeed, some maps which where very few chosen isolated are now frequently used in combination. It is particularly obvious for the maps which present a higher degree of territorial aggregation (NUTS2) or spatial generalisation (smoothed 100 and 200 km).

What appears very clearly with the results of the survey is the fact that **ESPON community do no more believe that it is possible to define a "best map" for the representation of a phenomena**. It is something relatively new if one compares the actual situation with the period of the SPESP (1998) where the representative of the Commission had clearly declared that interactive mapping with multiple choices was excluded because it was a bad solution from political point of view. The development of new cartographic tools making possible the easy and quick realisation of various maps of the same phenomena is one possible explanation of this evolution of mentalities. But the technical aspect is not the major fact and we can rather observe **a conceptual evolution of ESPON which has fully integrated a multi-level approach, both at scientific and at political levels**.

The qualitative appreciation of each type of maps which is presented in Table 14 indicates that the ESPON community has a relative clear picture of the advantages or inconvenient of each type of cartographic solution.

Table 14 Quality of each type of map

Quality	Nuts 2	Nuts 3	Nuts 2&3	Sm. 50km	Sm. 100 km	Sm. 200 km	Mean
Easy readable	94%	69%	65%	82%	72%	59%	**73%**
Useful for my daily working activities	63%	73%	62%	59%	31%	19%	**51%**
Suitable for communicate a message to a wide audience	70%	57%	60%	74%	53%	36%	**59%**
Innovative as it looks different from the maps normally used in my daily working activity	5%	9%	31%	57%	48%	41%	**32%**
Suitable for policy documents/presentations	74%	69%	64%	69%	51%	30%	**60%**
More appropriate to be included in research reports and journals	40%	56%	47%	41%	32%	24%	**40%**
Mean	**58%**	**55%**	**55%**	**64%**	**48%**	**35%**	**52%**

- **The maps established at NUTS2 level** are for example considered as the most easily readable (94%) but only 63% consider these maps as useful for their daily activity even if they are suitable for policy documents or presentation (74%) or for communication of messages to a wide audience (70%). These maps are not innovative (5%) but practical.
- **The maps established at NUTS 3 level** are considered as less easy to read (69%) than NUTS 2 because of the small size of units but they are the more appreciated for daily working activities (73%) even if they are not so practical when the problem is to communicate results to a wide audience (57%) or to elaborate a political document (69%). They are considered as not innovative (9%) but practical.
- **The maps established at NUTS 2&3 level** are considered as more innovative than the previous ones (31%) but they are globally less appreciated for daily activity and for communication of scientific or political results, probably because they are unusual and do not use the official NUTS level.
- **The maps established with local span of smoothing (50 km)** are certainly one of the most appreciated solutions as they obtain good or

excellent scores on the majority of criteria. They are considered as easy to read (82%), suitable for communication to a wide audience (74%) or for policy documents (69%) and they are considered as the most innovative (57%). But as they remove the limits of territorial unit, they are not considered always as useful for daily working activities (59%)

- **The maps established with medium or large span of smoothing (100 and 200 km)** are generally less appreciated by the ESPON community, even if it is recognised that they are easy to read (72% and 59%) and relatively innovative (48% and 41%) as compared to maps established within NUTS delimitation. It is clear that the span of smoothing is very important and that, when it is too large (200 km) the message delivered by the map is too simple and the reader has the feeling to have lost the local dimension.

2.2 What is really perceived on maps? Toward an objective evaluation of eye perception

The survey realised in Salzburg helped to precise the subjective preferences of the members of the ESPON community and provide valuable inputs for the elaboration of recommendations for ESPON II. But we can really ask if this approach is sufficient because the subjective perception of people can be biased by many factors. What is at stake is to evaluate if the message delivered by maps is really perceived in a correct way by the reader and, more generally, if different people looking at the same maps are really depicting the same message, the same information.

The resource of the project ESPON 3.4.3 was clearly not sufficient to launch an in depth analysis on this subject, but we have decided to introduce at less some hints on what could be such an in depth evaluation of the perception of maps based on an objective methodology elaborated by K. Serrhini (University of Compiègne) and P. Mathis (CESA). The basic idea of this approach is to examine the **path** follow by the eye of the observer when he discover and explore a new map. The eye of the observer is indeed attracted by some specific elements of the maps like the legend, the title, the sources and is more generally attracted by certain spatial configurations which are recognised as more interesting than others (maximum values, minimum values, discontinuities…). He comparison of the path followed by different people give us the opportunity to discover regularities or specificities in the ways that people are following when they look at maps.

From technical point of view, the method is based on a medical engine called **oculographe** which is normally used in the therapy of eye's trouble but is also used for psychological experiments on the perception of pictures. The application of this **oculographe** to research on the perception of maps has been initiated by the Ph'D of K. Serrhini (Serrhini, 2000) which has revealed interesting results.

Using the photo oculographe or gaze follower allows to analyse the ocular moves (visual strategies) of people looking at various maps (slides). Indeed, it is thanks to the ocular moves that we can follow with our eyes a moving target, have a look at a map or have a feeling of the space inside which we evolve. The specialists divide the ocular moves in three categories: the jerks, the trackings and the fixings. For example, the rough perception of a given object is done by a sequence of fast moves (jerks), while the details of the object are only caught during periods in which the eye is relatively immobile (fixings).

2.2.1 Experimental protocol

Various GDP/inh maps (12 in total) were presented to volunteers. These maps correspond to three series of slides:

1) The first series, which corresponds to the maps of the survey realised in Salzburg (Annex 4) can be itself subdivided in two subseries:

- Subseries 1: 3 maps showing GDP according to different subdivisions of the territory of the Europe member states (Nuts2; Nuts3; Nuts 2-3);

- Subseries 2: 3 maps showing GDP (same data as the previous subseries) according to different smoothing degrees (50, 100 and 200 km).

In this first series, GDP is represented by a color gradation from dark blue to red through yellow and orange. These maps include a title, a caption (9 color gradations), a graphical scale plus the ESPON logo.

2) The second series is composed of 3 maps which are actually zooms on central Europe of the maps of the subseries 1.

3) The third series is finally composed of 3 maps which are zooms on central Europe of the maps of the subseries 2.

The whole set of slides were presented to 6 volunteers during a short time (10 seconds). Three volunteers were hospital employees (without a thorough knowledge of cartography and its techniques) and the remaining three had had an initiation to cartography.

The choice of a short exposition period can be justified by the will of testing the identification of elements, symbols… which attract the gaze during the first instants of an image reading.

2.2.2 Analysis of the experimental results

Three types of analysis are possible:

- A statistical analysis of the different categories of ocular moves
- A spatial analysis of these ocular moves: what are the elements that most attract the gaze?
- A temporal analysis of the ocular moves: what are the visual strategies used by the different volunteers?

2.2.2.1 Statistical analysis

Figure 59 shows that, except for maps 3 and 6 (GDP2000_Nuts3 and GDP2000_Smooth200km), the average of fixing moves (during the reading of the details) of initiated volunteers is higher by at least 2 units than that of the non initiated volunteers. Let's recall that the recording only lasts 10 seconds and that a 1 unit difference in fixing moves is not likely to be significant.

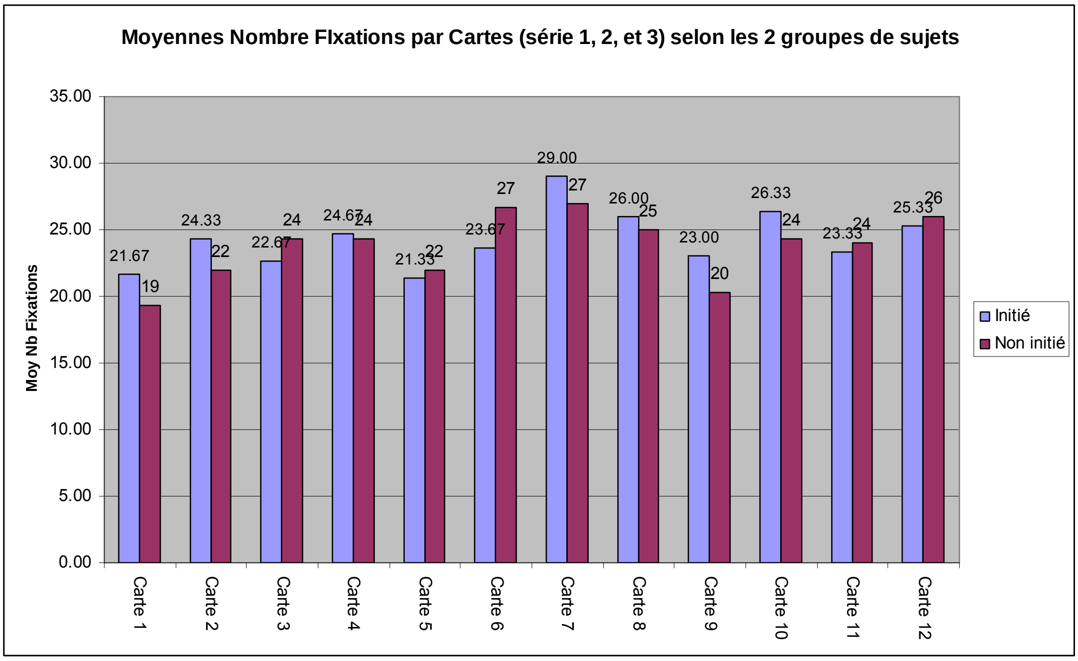


Figure 59 Average of fixing moves per map (12 in total) and per types of volunteers

Figure 60 shows that, except for maps 5 and 6 (GDP2000_Smooth100km and GDP2000_Smooth200km), the average duration of fixing moves is higher for the non initiated volunteers than for the initiated ones. For instance, for maps 1 and 2 (GDP2000_Nuts2 and GDP2000_Nuts2_3) the average duration of fixing moves of the non initiated volunteers are clearly higher than that of the initiated (the difference is about 114 msec for map 2).

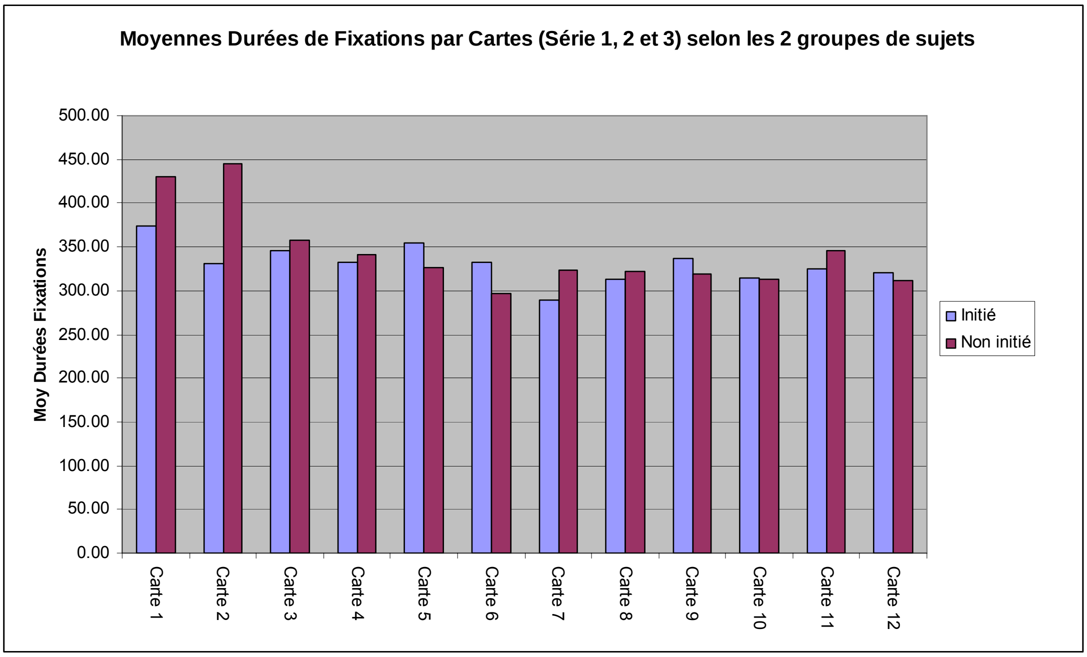


Figure 60 Average of fixing moves durations per maps (12 in total) and per types of volunteers

In summary, the two previous figures (Figure 59 and Figure 60) suggest that:

- Firstly, the average number of fixing moves corresponding to the observation of 12 maps is relatively larger for the initiated candidates than for the non initiated ones.
- Secondly, the average duration of fixing moves corresponding to the observation of 12 maps is relatively larger for the non initiated candidates than for the initiated ones.

The fact that the average number of fixing moves is larger (among initiated) for a fixed exposure time (10s) implies that the average duration of fixing moves is necessarily smaller (among the initiated). This seems to be true according to the previous data.

The initiated candidates explore a larger number of zones in a map than the non initiated. The latter seem to spend more time to fixed locations Thus, reading experience as well as professional experience, culture… of the initiated people are many factors which can account for the way they read an image (visual strategies).

2.2.2.2 Spatial analysis

In this section, we analyze the records of the ocular moves corresponding to the exploration of the following map. The spatial analysis of the ocular moves gives us the following informations:

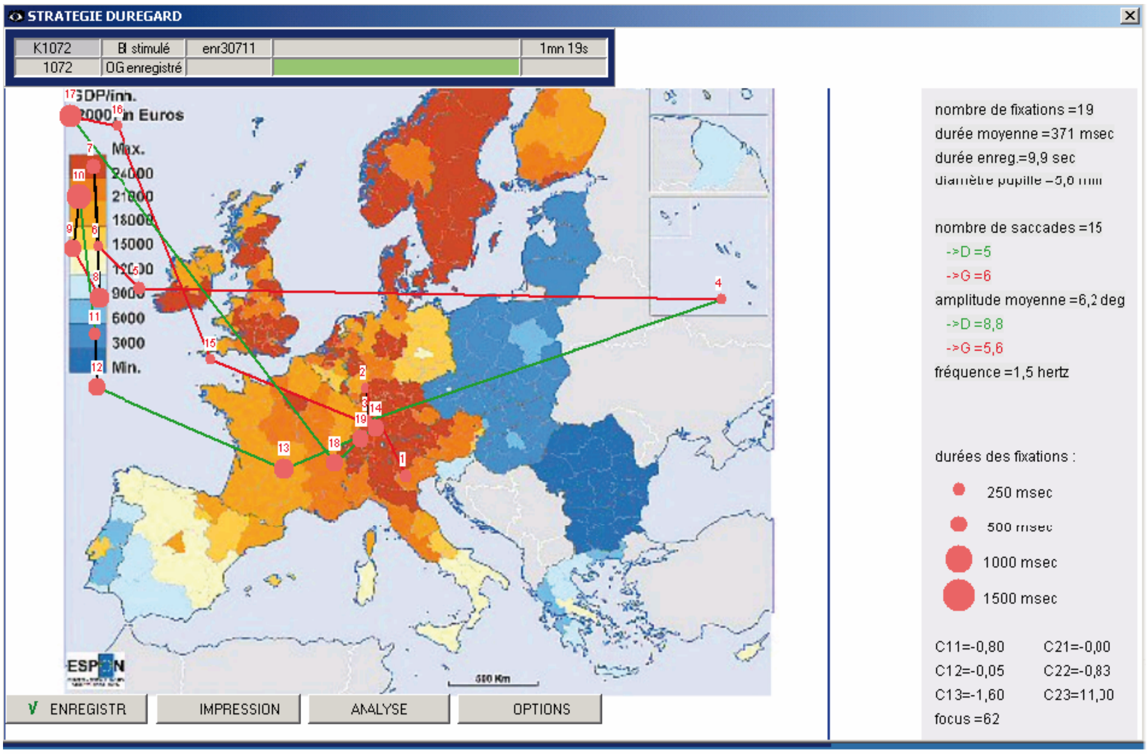
a) Differentiated readings of the title and the caption (Figure 61)

In front of the maps of the first series, the three volunteers who were initiated to cartography have a systematic reading of the title and the caption (located at the top left corner). This reading is different from the first map to the last one of this series.

Among the non initiated volunteers, one out of the three volunteers does not pay attention to the title nor to the caption of the 6 maps of the first series (no ocular move). For the two other volunteers, we observe no systematic interest in the title and in the caption. They have clear less ocular moves (and thus less time) than the initiated volunteers.

The photo-oculograph device allows for finer analyses than the determination of the time (in msec) spent in a given zone of the slide through the use of the vector analysis not performed here.

Here again, the initiated volunteers seem to have acquired characteristic visual strategies (compared to the non initiated volunteers).



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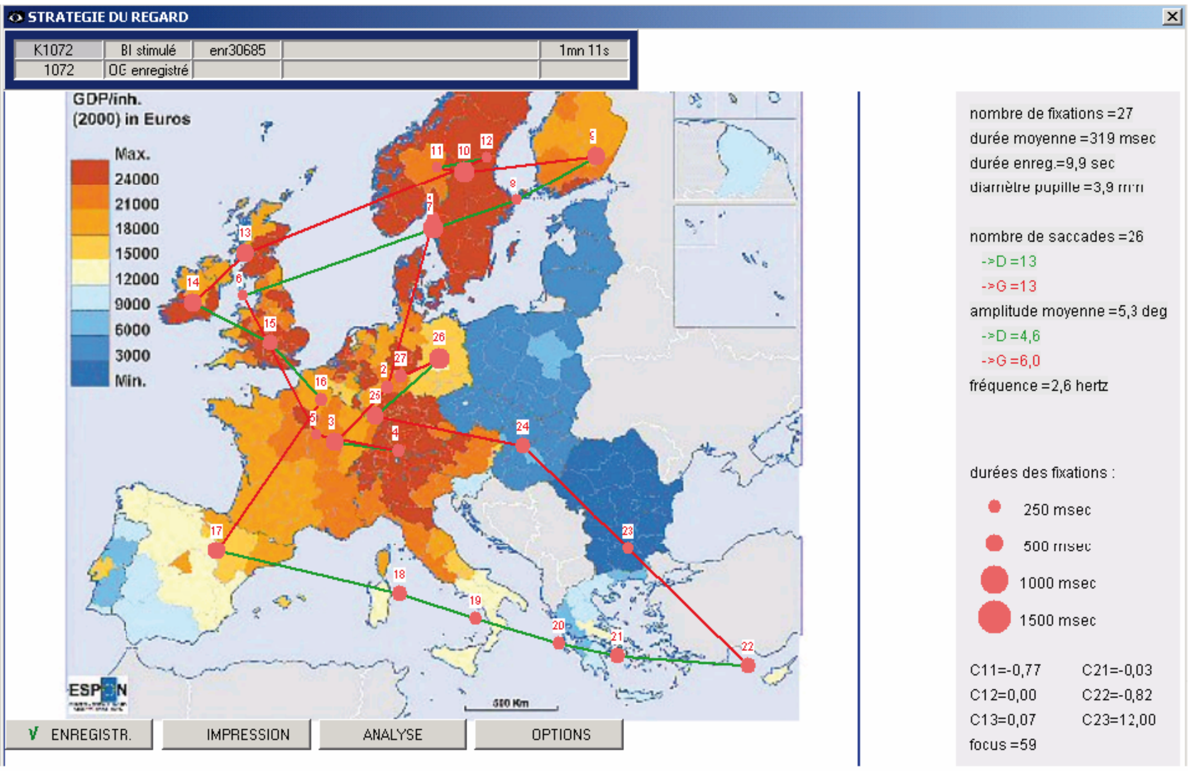
Map1: GDP 2000 Nuts 2 – Volunteer A: initiated



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Map 1: DGP 2000 Nuts 2 – Volunteer B: non initiated

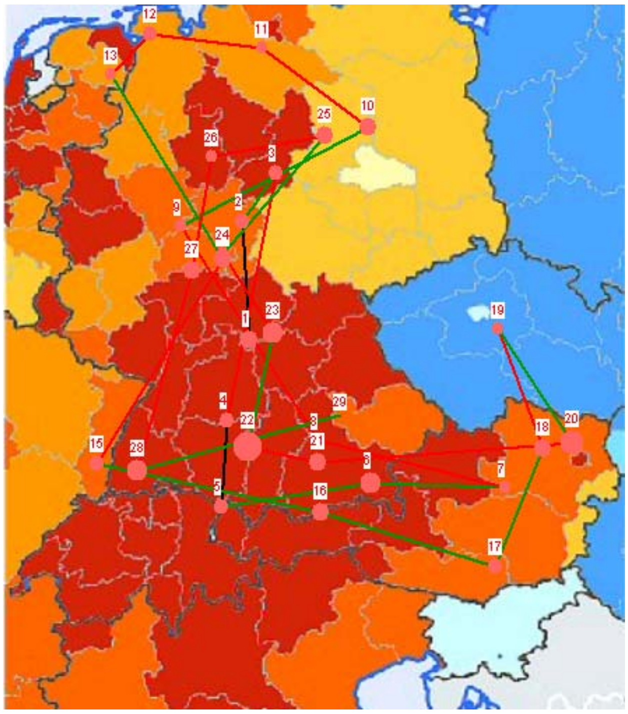
Figure 61 Different readings of the title and the caption

But what about the knowledge processes regarding the information included in the maps?

The Experimental Graphical Semiology method itself is unable to give an answer to this question. It is necessary to couple this approach with specialized approaches of knowledge data extraction (opinion poll).

b) Some similarities in the ocular moves

Firstly, the spatial analysis of the ocular moves shows that the exploration of a map starts for the two types of volunteers from a zone located at the center of the map (Figure 62).



Map 7: Zoom GDP 2000 Nuts 2

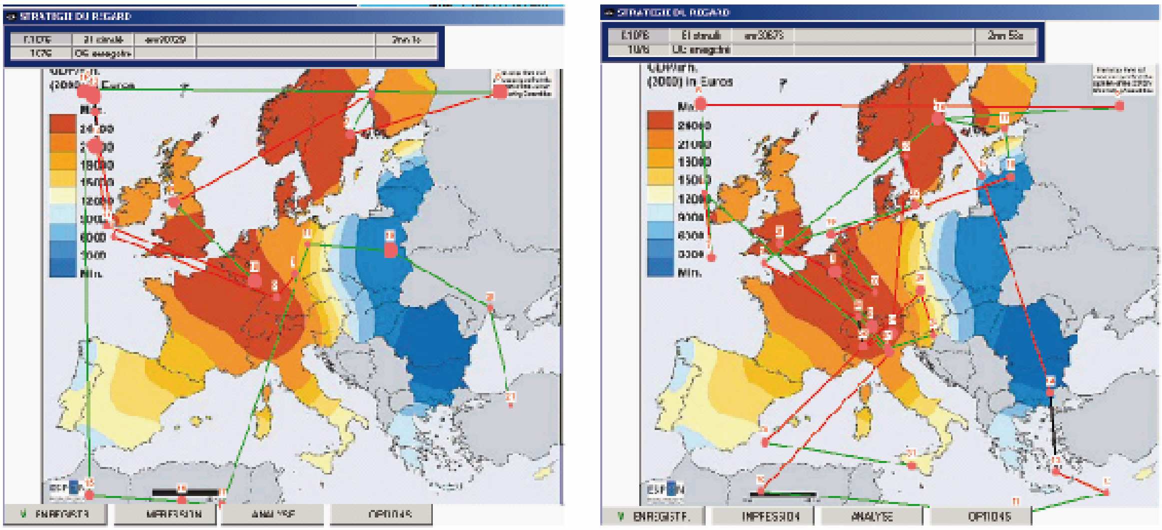
Volunteer C: initiated

Figure 62 The center of the map as the start of the exploration

Moreover, we observe the use of similar visual strategies by some volunteers. The set of written elements in the map 5 (GDP 2000 Smooth 200 km; Figure 63) induces for the two volunteers D and E (non initiated volunteers) the same type of ocular moves revealing similar visual strategies.

This last result suggests that some non initiated volunteers are focusing on the observation of inaccessible elements such as text elements in a map (experience of text reading).

In the case of map 5 above and for the two volunteers D and E (Figure 63), we observe a reading of the title and of the caption (top left corner), of the text located at the top right corner "this map does not necessarily …" (for the maps of the subseries 2), of the ESPON logo (bottom left corner) and of the caption (bottom middle). This scanning forces the volunteer to travel through the center of the map by ocular moves and stops. This travel allows him to reach the different text elements of the map.



Map 5 : GDP2000 Smooth 200 km
Volunteer D: non initiated

Map 5 : GDP2000 Smooth 200 km
Volunteer E: non initiated

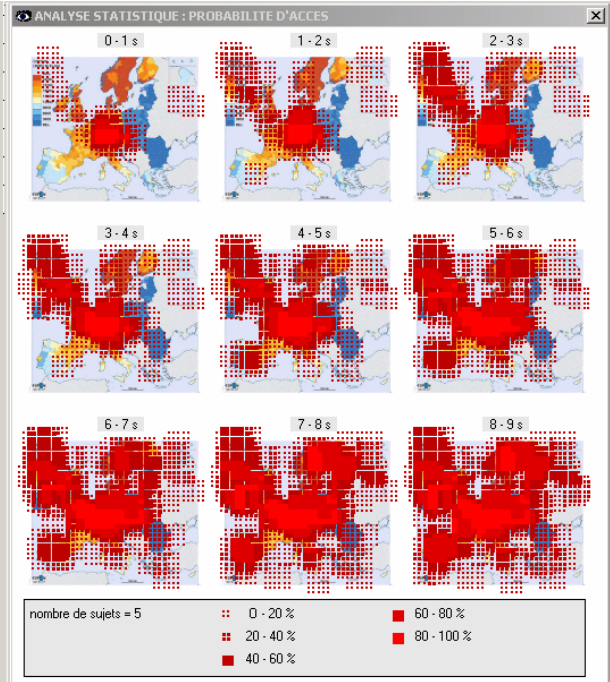
Figure 63 Visual strategies by two non initiated volunteers during the exploration of a map

2.2.2.3 Temporal analysis of the visual strategies

This analysis allows for a study among a group of volunteers who have observed the same map some global trends such as the probability of access to the different elements of the map or the average access time to these elements.

The Map 2 was cut in 9 temporal slices, each having the same duration. Figure 64 shows the percentage of the volunteers of the studied group (limited to 5 persons in the present document) who looked at a given element of the map.

Thus, the perception starts at the center of the map (dark red spot in the center corresponding to 80-100% of the volunteers). Then, after 4 seconds, the record shows an important red zone (60%) which spreads out from the center to the top left corner (location of the caption) of the image. Finally, after 8 seconds, we observe the development of two important new red spots (60-80%) corresponding on one hand to Norway and Suede (Northern Europe) and on the other hand to the ESPON logo.



Map 2 : GDP2000 Smooth 200 km
Volunteer C: initiated

Figure 64 Access probability

In summary, the zones of map 2 which were the most looked at are:

- The center which is characterized both by the presence of identifiable elements (France, Belgium, Germany, Switzerland) and by attractive colors (orange and red).
- The top left corner which shows the title and caption of the map (experience in text reading)
- The top middle region with very attractive colors corresponding to Scandinavian countries.
- The bottom left corner corresponding to the reading of the ESPON logo.

Conclusion

The analyses of the situation of ESPON Program as regard to the question asked at the beginning of this part (pp. 86-87)   are rather clear:

2. *ESPON is concerned by the MAUP from both statistical and cartographical point of view.* The selected examples which has been presented of research developed in the ESPON program has revealed that in many cases, different conclusion could have be obtained by ESPON TPG is they have used different territorial division than the actual NUTS 2 and NUTS 3 units.

3. *The NUTS 3 level is much more sensitive to MAUP than NUTS 2.* It is true that heterogeneity of area or population of spatial units are observed at both level, but most NUTS2 units (with some exceptions like Brussels, Prag, London, …) are mixed geographical object which combines urban, periurban and rural territories and which present therefore a global coherence. In the case of NUTS 3 units, the situation is more critical as different geographical objects are sometime mixed in the same territorial units and sometime isolated in separated units. This creates important difficulties for the examination of spatial organisation and can induce false perception of reality.

4. *The divergence of results according to different territorial divisions is not a problem but a factor of progress for ESPON.* When the divergences of results are correctly analysed, they provide added value to the knowledge on spatial organisation and introduce progress for spatial planners. The problem is not to select one good level of analysis (impossible task) but to define different targets of analysis. For example, the dissociation of urban / periurban / rural area which is realised by NUTS 3 level in some countries (Belgium, Netherlands, Germany, Austria) provide very interesting information on local differences as compared to regional differences between aggregates of upper level. What is questionable with NUTS 3 is not the gain of information at local level but the fact that this new dimension is introduce only for some countries and displayed on the same map than other spatial units where this local analysis is not available.

5. The community of ESPON researcher and policy makers is ready to adopt new innovative practices of mapping and spatial analysis. The authors of the research apologize on the fact that they was not convince from this point at the beginning of the researcher. They had expected that only researchers and a minority of policy makers would be ready to adopt non-standard territorial division (like mixture of NUTS 2 and NUTS 3),

borderless cartography (smoothing methods) and combination of different maps for joint approach of the same phenomena. This pessimistic point of view was related to previous experiments of the SPESP where such proposals had been clearly refused by the managing authority and where a more normative approach was decided. As decision tool, maps should be one and only one for each phenomenon and they should fit with official delimitation as it is the legal framework for the development of structural funds policies. This crucial modification is probably the sign that ESPON is actually more interested in ambitious strategic planification (revision of ESDP) as in the simple adaptation of existing political tools.

6. *New cartographic and statistical tools are cause and consequence of new political practices in European Spatial Planning*. What is therefore at stake with the MAUP is not the solution of a technical problem but the development of new methods which are based on recent scientific **and** political innovations. When regional policy of EU was limited to a simple problem of transfer of funds to lagging regions, NUTS 2 and NUTS 3 division provide a sufficient framework for diagnosis. With the development of new topics like "polycentrism", "cross-border cooperation", "territorial cohesion", "multiscalar analysis" or "TIA", it is necessary to propose new tools related to new vision of European territory. Analysis based only on NUTS 2 and NUTS 3 units are clearly the past and we have to invent the future …

Part 3: Progress for ESPON II with revised ESPON maps

Introduction

With this final part of the report, we develop a set of proposals which do not intend to solve the question of MAUP (as explained before, it is a false problem) but to suggest progress for ESPON II. We limit our analysis to the question of cartography which is the most important request addressed to the TPG MAUP, but the reader has to keep in mind that statistical problem are also of huge importance.

Our first proposal of improvement is the elaboration of a new hierarchy of NUTS division elaborated by C. Vandermotten and P. Medina from IGEAT. The simple mixture of NUTS 2 and NUTS 3 units discussed in previous part is indeed not sufficient to solve the question of optimal territorial divisions for ESPON II. We propose therefore more accurate methods of aggregation based either on equal population or functional areas. At the same time, we use pragmatic rules in order to propose a really operational solution.

Then we develop a set of proposals of alternative methods of cartography based on cartograms, gridding and smoothing methods which are relatively easy to apply (test has been made on ESPON database) and which present specific advantages for some fields of investigation. In each case, we discuss precisely the methodology and the political consequences of the use of these alternative methods of cartography.

We discuss finally the more general question of dynamic mapping with the problem of combination of different maps, interactivity and animation. What is at stake is to determine how to make the most fruitful the combination of different maps and how to help the user to determine the most efficient solution in specific situations

In order to make easier the comparison between different solutions or alternative methods, we have tried to use systematically the same variable (GDP/inhabitant in 2000 in euro or pps). But we have also introduced some external examples when needed.

1 Proposal for a new European statistical division

1.1 Critical approach to current divisions

The NUTS division used for the statistical description of Europe, especially at the most frequently used NUTS 3 and NUTS 2 levels, corresponds essentially to the administrative division framework (with some restrictions for UK or countries where the intermediate administrative framework is weak and where there is a decoupling between the latter and the NUTS division, like Portugal). This brings about a considerable size diversity in the division of the 1277 NUTS 3 units dividing the continental 25+4 Europe. The population in those units varies from 15,000 inhabitants (the Swiss Canton of Appenzell I.R.) to 5,151,000 (the Madrid Community). At the level of the 272 NUTS 2 units (273 if we include the Brandebourg subdivision), the range goes from 26,000 (the Aaland Islands in Finland) to 11,002,000 (Ile-de-France) inhabitants. If we consider the GDP produced in those NUTS 3 units, the ratio between the unit with the highest total GDP and the unit with the lowest one is 1 to 506. In such conditions, it is hard to use such a division as a basis for structural analyses. But the main source of interpretation difficulty does not so much reside in the difference in units size as in the fact that, according to the different cases, metropolitan realities are more or less correctly reflected by a single NUTS 3 administrative unit (this is the case for the Madrid Community) or, inversely, split into several units, some of which roughly corresponding to the central part, the others to parts or whole of periurban areas (such as the Ile-de-France departments or, still worse, the London Mega divisions). Consequently, the simple calculation of GDP/head, though one of the most commonly used indicators, is just senseless in many cases: in Belgium for example, the Brussels-Capital Region (NUTS 1, 2 and 3) can be presented as one of the wealthiest in Europe (ranking twentieth at NUTS 3 level as regards its GDP/head), whereas its available income per inhabitant is in fact today one of the lowest of the three Belgian Regions, since almost 6/10 of the workers who contribute to the creation of its GDP reside in the other two Regions of the country. The political impact of such situations, especially in a federal country like Belgium where there is no financial cross-subsidization between the Regions' budgets, is easy to imagine.

A solution that is sometimes applied to partly answer such a situation is the use of a mix, according to countries, of NUTS 2 and NUTS3 units: at the level of the economic structures, it is for example more relevant to compare a German Regierungsbezirke (NUTS 2) to a French department (NUTS 3) than the latter to one of the 441 German Kreise. Nevertheless, this mixed solution is far from solving the basic question of a good assessment of the situation prevailing in metropolitan regions and functional urban areas of the largest cities (FUAs), in which, as the case may be, metropolitan realities are either arbitrarily divided out among centre and periphery inside common FUAs, or inversely, dissolved in too huge entities.

We propose here two alternative division methods which allow solving, at least in part, some of the above-mentioned problems. A more global solution would imply a radical re-division of the statistical frameworks by reconstructing them from NUTS 5 units but, in addition to the political and statistical problems of such a revolution, it would be quite inconvenient to provide data within frameworks that could be geographically and economically relevant but would in no way correspond to the institutional frameworks in which States operate and in which they apply and check the impact of their policies. Consequently, the two solutions proposed hereafter have set themselves two basic rules:

- using only a process of NUTS 3 units aggregation. This level is thus not being questioned as basic frame of reference for States' provision of figures to EUROSTAT[26];
- keeping national divisions as superior framework, whose borders are consequently not broken, as far as those national frameworks remain those in which major political trends are defined and in which structures and dynamisms develop.

Meanwhile, in the second proposal, we will see that the division proposed allows, if need be, a reconstruction of transnational entities when strong cross-border complementarities exist (such as in large cross-border urban areas).

[26] We have however made a small exception in one of the two methodologies in which we propose a subdivision of some heterogeneous or densely populated French departments on the basis of NUTS 4 (sub-prefectures) and 2 Swedish NUTS 3 units on the basis of counties.

1.2 First methodology: Similar population volume units

As seen above, in the 25+4 Europe, without taking account of the isolated territories of Spain (Canaries), France (DOM) and Portugal (the Azores and Madeira), the NUTS units population is quite variable and reaches on the average:

- 422,000 inhabitants for the NUTS 3 units (with a standard deviation of 190,000 and extreme values from 15,000 and 5,151,000);
- 1,722,000 inhabitants for NUTS 2 units (with a standard deviation of 1,041,000 and extreme values of 26,000 and 11,002,000);
- more than 5 million inhabitants for NUTS 1 units (with extreme values of 26,000 and 22,444,000).

In this first proposal, we simply merge current contiguous NUTS 3 units to create new n1NUTS 3 units with the only aim to get as close as possible to units of about 500,000 to 600,000 inhabitants (Figure 65). Similarly, we try to approach as much as possible new n1NUTS 3 units of 2 million inhabitants (Figure 66) (we have also considered an intermediate level n1NUTS2 with areas of about 1,000,000 inhabitants, but the maps are not produced here).

In the aggregation process the following rules have been followed, in a decreasing order of constraint:

- national borders may not be crossed
- units have to be merged, starting from the regrouping of urban centres and their periurban areas
- with the exception of the cases where it is linked to the location of a central city and the external part of its FUA in different units (in such a case GDP/head levels are very different since an important part of the manpower of the peripheral unit(s) is active in the central unit), contiguous NUTS 3 units should be merged on the basis of the closest GDP/head levels, the latter indicator being considered here as a very rough and elementary approximation of the similarity of structures;
- if possible, depending on objectives of similar population volumes, there should be no crossing of the boundaries of infranational territorial entities with strong political identity (German Länder, autonomous Spanish Communities, etc.).

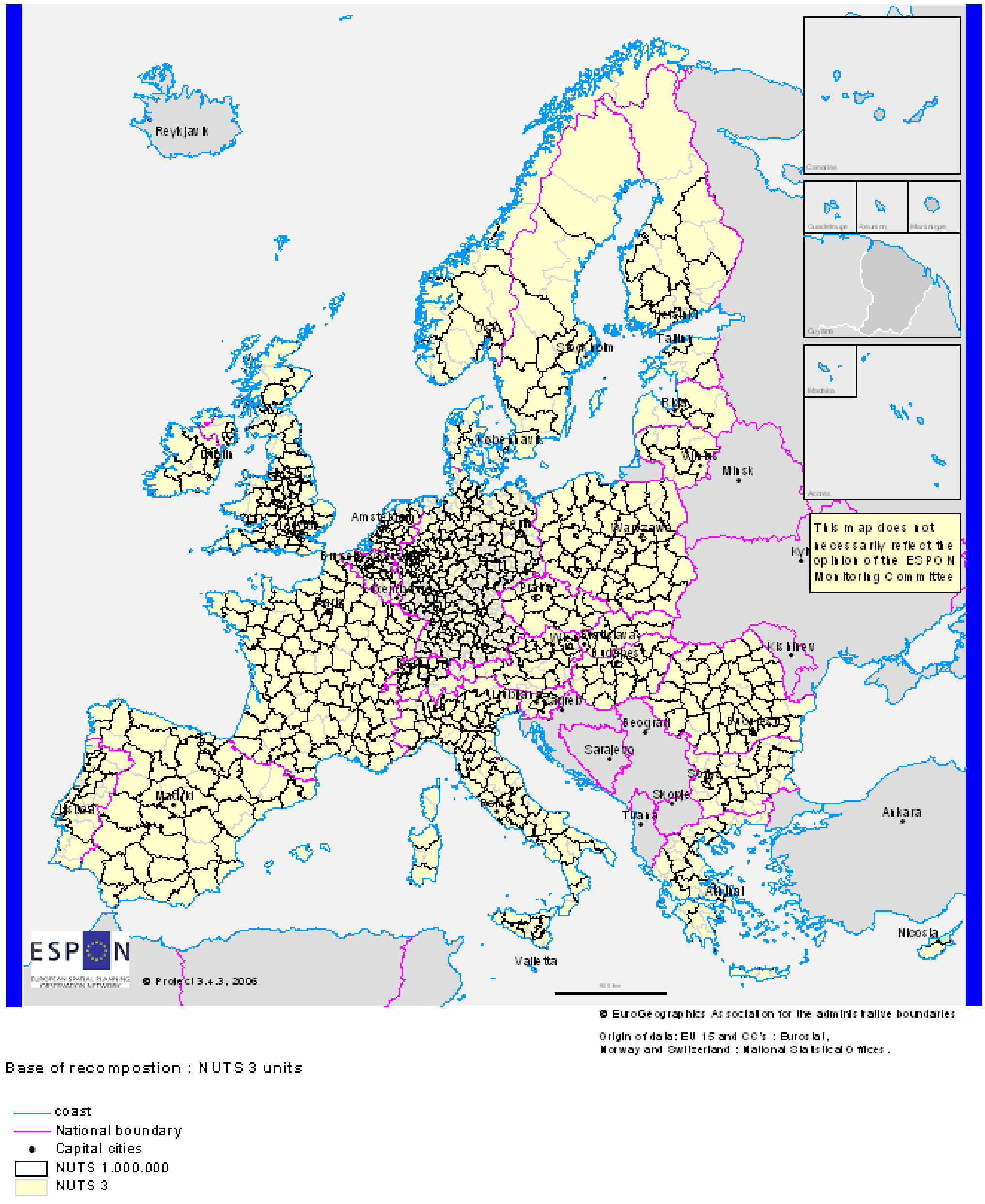


Figure 65 Recomposition of the NUTS division into units of same population (600.000 inhabitants)

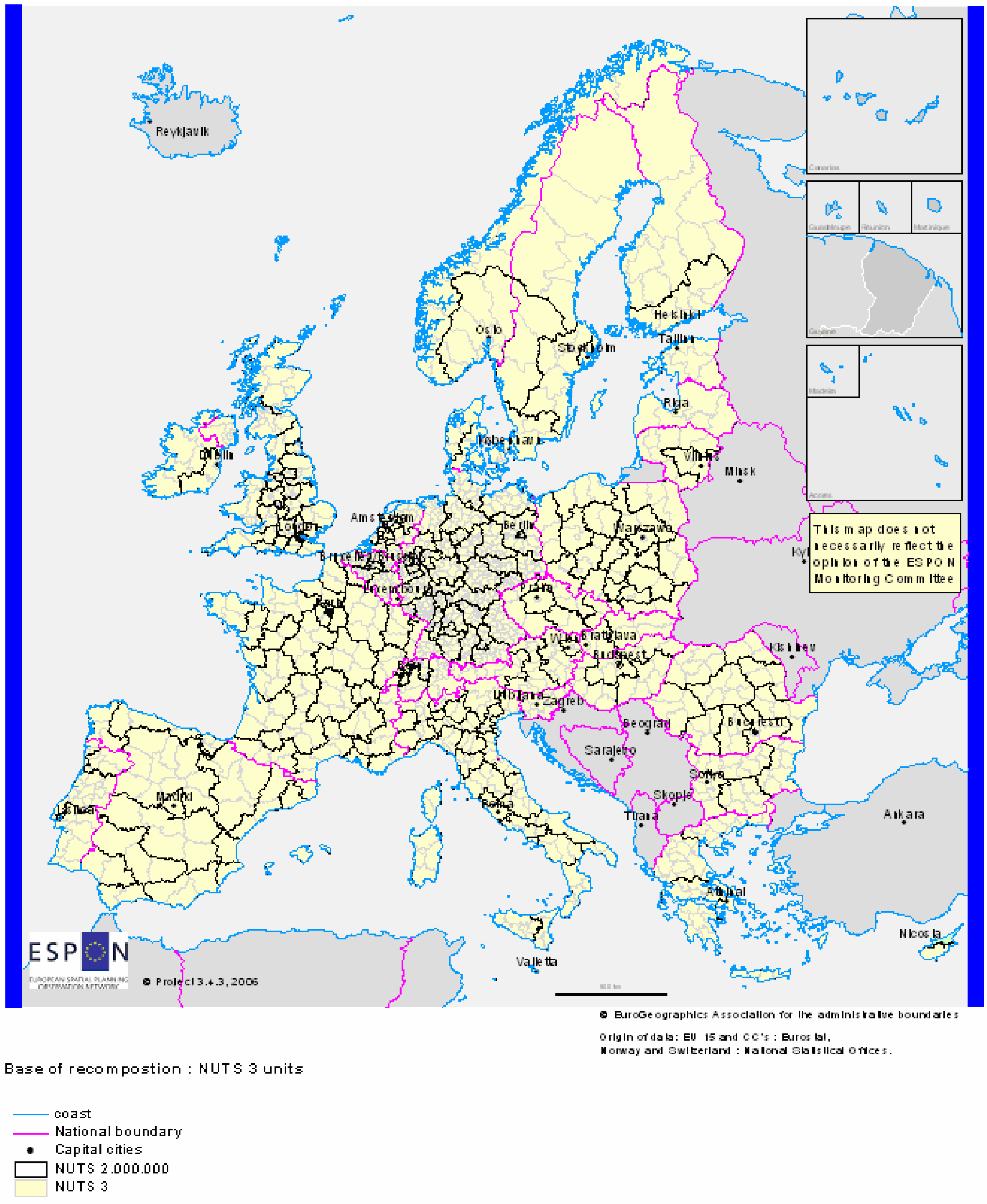


Figure 66 Recomposition of the NUTS division into units of same population (2.000.000 inhabitants)

A first series of maps compares the geography of population densities and GDP/head in n1NUTS 3 and n1NUTS 1 divisions with corresponding maps in classic NUTS 3 and NUTS 2 (see Annex 5).

The advantage of this method is obviously to be found in its simplicity, not to say simplism. Knowing that each unit mapped approximately groups the same population, it allows to relativize the impressions given by classic maps, where huge patches of colour may actually only relate to a little population. On the contrary, the major disadvantage of this methodology is that the quest for similar populations can lead to aggregating and amalgamating units whose economic or social structures are in fact quite different. Moreover, in the case of very large FUAS, one and the same FUA can be divided into several n1NUTS 3 units, if not in several n1NUTS 1 units in the case of FUAs such as in Paris or London. Neither was it possible to respect the rule set when the current NUTS 3 units already had more than 500,000 to 600,000, if not more than 2,000,000 inhabitants (for ex. Paris, Madrid, etc.).

1.3 Second methodology: Functional units

1.3.1 Bases of the methodology

While trying as much as possible to maintain a certain homogeneity in the population volume of the new units, and in particular to avoid new units inferior to 300,000 or 400,000 inhabitants at the basic level, the methodology proposed poses as fundamental factor the idea, also put forward in other studies of the ESPON programme, that FUAs are an essential basis of the territorial structuration. It is inside those entities that a good deal of the redistribution between GDP and income occurs. It is therefore a priority not to isolate parts of one FUA in two new different units. This labour pool may sometimes incorporate secondary FUAs of smaller size (like Mechelen in Belgium in comparison to Antwerp). This rule has been applied without difficulty in the case of large monocentric FUAs, even if it led to basic units of exceptional sizes but which account for a single functional reality (Greater London and Ile-de-France, with new basic units of more than 11 millions inhabitants; Madrid with more than 5 millions). In the case of polymegacities, where a coalescence of several FUAs can be observed, whose structures are not necessarily similar and which do not function as a single structural whole, we have tried to best adjust the basic units to the individual FUAs of each of the big cities making up the polymegacity, while giving a chance to grasp the latter's global reality at the higher aggregation level. This is how, in Belgium, one can identify new basic units as close as possible to the FUAs of Brussels, Antwerp, Ghent and Leuven and, at the same time, at a higher level, have a global view of the demographic and economic weight of the central metropolitan rhomb of the country. In the same way, one can identify proxys of Amsterdam's, Rotterdam's, Utrecht's... FUAs, and have at the same time a global view of the Delta metropolis; or identify the FUAs of Cologne, Dusseldof, Essen, Dortmund, etc. and the whole Rhine-Ruhr with its population more or less identical to that of the elementary area surrounding Paris or London.

Yet, only medium- or large-sized FUAs are likely to ensure territorial frameworks at the scale of regional metropolis logics, as underlined in ESPON1.1.1 report. Therefore, and in order not to build too small units, we have not tried to constitute new basic units for FUAs with less than 250,000 inhabitants and even for FUAs of that size, the statistical constraints of NUTS 3 division have sometimes led us to build basic units regrouping two or more FUAs on that scale. We have also isolated, in peripheral regions, entities with more or less homogeneous structures and with a population of more than 300,000 or 400,000 inhabitants which did not contain any FUA of 250,000 inhabitants. Such a situation accounts in itself for a specific structural reality.

Finally, we have infringed the rule not to retain basic units insufficiently populated in cases when small units subsequently enabled the researcher to constitute *ad-hoc* cross-border metropolitan units. For instance, we have preserved the individuality of the current NUTS 3 unit of Mouscron, with 52,000 inhabitants only, but which can be linked to the Lille metropolis. We have even formed a specific unit from the current two NUTS 4 units (sub-prefectures of Gex, in the Ain department, and Saint-Julien-en-Genevois in Upper Savoy), allowing a better comprehension of the cross-border urban reality around Geneva.

1.3.2 Operationalization

Starting from these considerations, we propose a statistical subdivision at two (instead of three) levels, which we will call n2NUTS 2 and n2NUTS 1.

The n2NUTS 2 are thus in theory constituted:

- from the current NUTS 3 units or by aggregation of these from the identification of the FUAs of at least 250,000 inhabitants, with the best possible adjustments;
- or from one or more current NUTS 3 units that do not belong to the above category, including one or more FUAs of a lesser size, forming together a territory of at least 400,000 inhabitants and possessing a sufficient structural homogeneity, at least in terms of level of GDP/head.

Exceptions to the rule thus concern either current not much populated NUTS 3 units linked by default to new neighbour units defined according to the above rules, although they are not polarized to them or do not share their structural characteristics, or current NUTS 3 units, possibly of small size, kept isolated because clearly polarized toward a foreign neighbour country, which will allow if necessary to combine them with the n2NUTS 3 or n2NUTS 2 of the neighbour country.

The following rules determine the constitution of n2NUTS 1:

- no n2NUTS 1 units of small size (less than 700,000 inhabitants if possible);
- a single n2NUTS 1 unit should group together n2NUTS2 units which make part of a same polymegacity;
- a single n2NUTS 1 unit should group together n2NUTS 2 units oriented toward a similar major regional metropolis (for ex. the large regional metropolises in France).

As a conclusion, we propose in this methodology a four-level classification: (n2)NUTS 5, the level of basic territorial entities (communes, etc.), the n2NUTS 2, n2NUTS 1 and n2NUTS 0 levels, respectively corresponding to the large FUAs or the interstitial and weakly urbanized peripheral areas, to the large megapolitan frames of the national spaces of the largest countries, and to the States.

1.3.3 Results

We have determined 633 n2NUTS 2 units for continental 25+4 Europe (Figure 67), instead of the current 1277 NUTS 3 units, that is to say about twice less units. Their average population grows from 422,000 to 705,000 inhabitants. The minimum size of the units gets higher in most countries. The dispersion of average values decreases between the different countries, reflecting a higher international homogeneity of the definitions. Meanwhile, inside each country, the dispersion grows because of the reunion of the central and peripheral areas of the large FUAs in single entities: therefore, in most countries, the size of the biggest units goes up, reaching populations of more than 11 million inhabitants in Great Britain and in France, more than 5 million in Spain, more than 3 million in Italy, Greece and Germany.

In terms of GDP/head of the new n2NUTS 2 units, the extremely high and aberrant values which expressed nothing else than the narrow delimitation of the central parts of the metropolitan areas disappear: in relation to the current NUTS 3 units, a strong decrease in maximum values and standard deviations are observed between values in most of the countries, and in particular in Germany, France, Norway, Great Britain, after the insertion of units such as Munich Kreisfreistadt, Hambourg, Paris, Hauts-de-Seine, Oslo or Inner London into larger metropolitan realities.

The methodology leads of course to the construction of certain units of very large size in terms of surface, in the northern weakly populated parts of the Nordic countries, which does not seem to pose a problem given their homogeneity and their very low population densities. A strong increase in the dispersion of the units' size can also be observed, compared to the current NUTS 3 division, for instance in the countries where the current division is spatially fairly homogeneous, although in reality spaces with very few population are opposed to a Capital-Region concentrating a large part of the population and activities, as in the Baltic Countries.

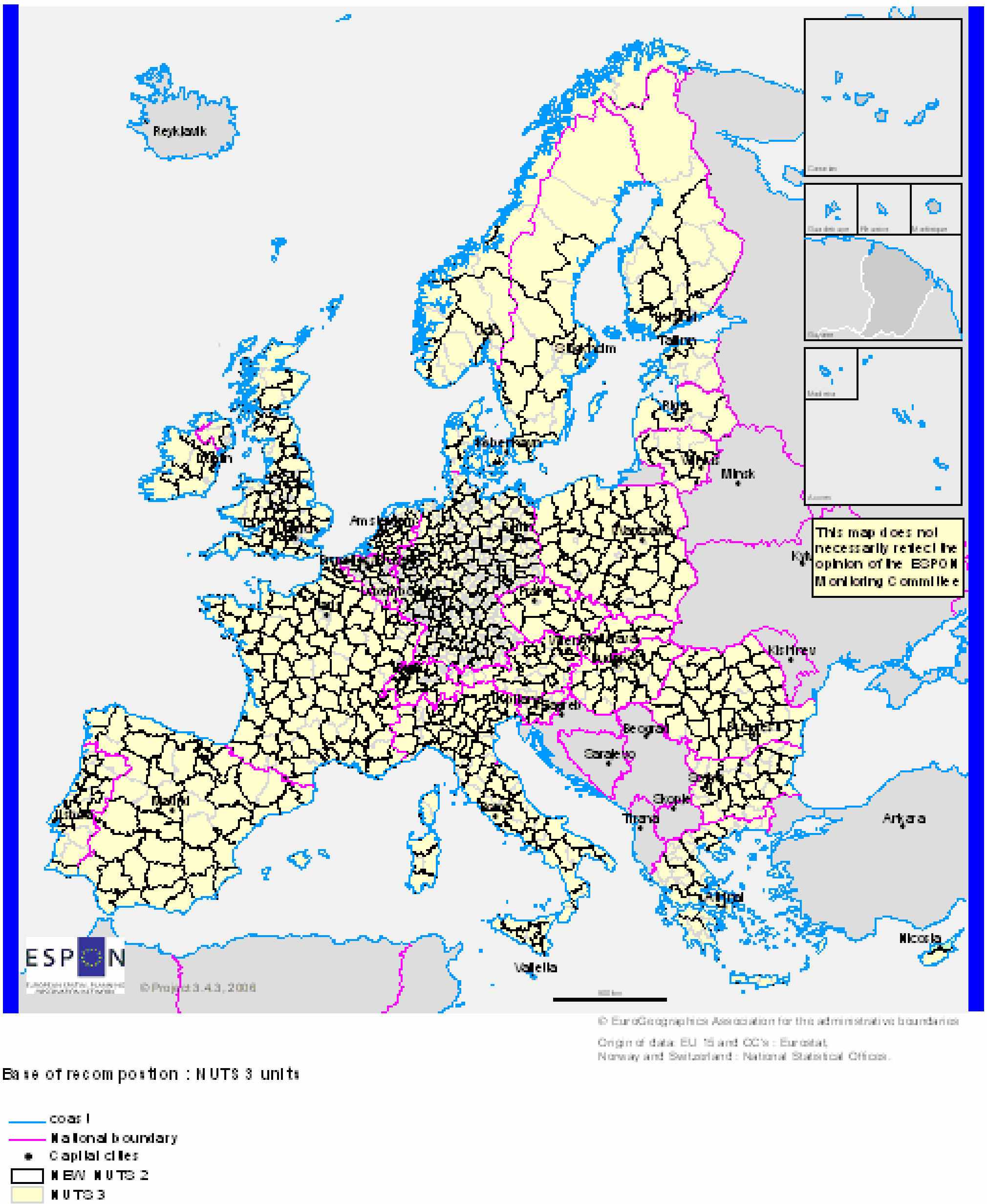


Figure 67 Recomposition of the NUTS division into functional units: new NUTS2

We have identified 277 new n2NUTS 1 units within the same space (Figure 68), that is to say almost the same number as the current NUTS 2 units (272). The most striking differences are due to the higher number of units in France, Italy and Poland, and the smaller number of units in small countries where current NUTS 2 units are modelled on historical administrative units of small surface, as in the Dutch provinces and in Belgium or in Austria's Länder. There is thus relatively less difference between the features of n2NUTS 1 units and those of the current NUTS 2 units than between n2NUTS 2 units and the current NUTS 3 units. However, the wish to highlight the existence of polymegacities leads to create some n2NUTS 1 units with much bigger population volumes than the current largest NUTS 2 units in Belgium (central metropolitan Rhomb or Flemish Diamond), in the Netherlands (Delta metropolis), in Germany (Rhine-Ruhr). The same is true when taking into account the functional reality of the large London metropolitan area.

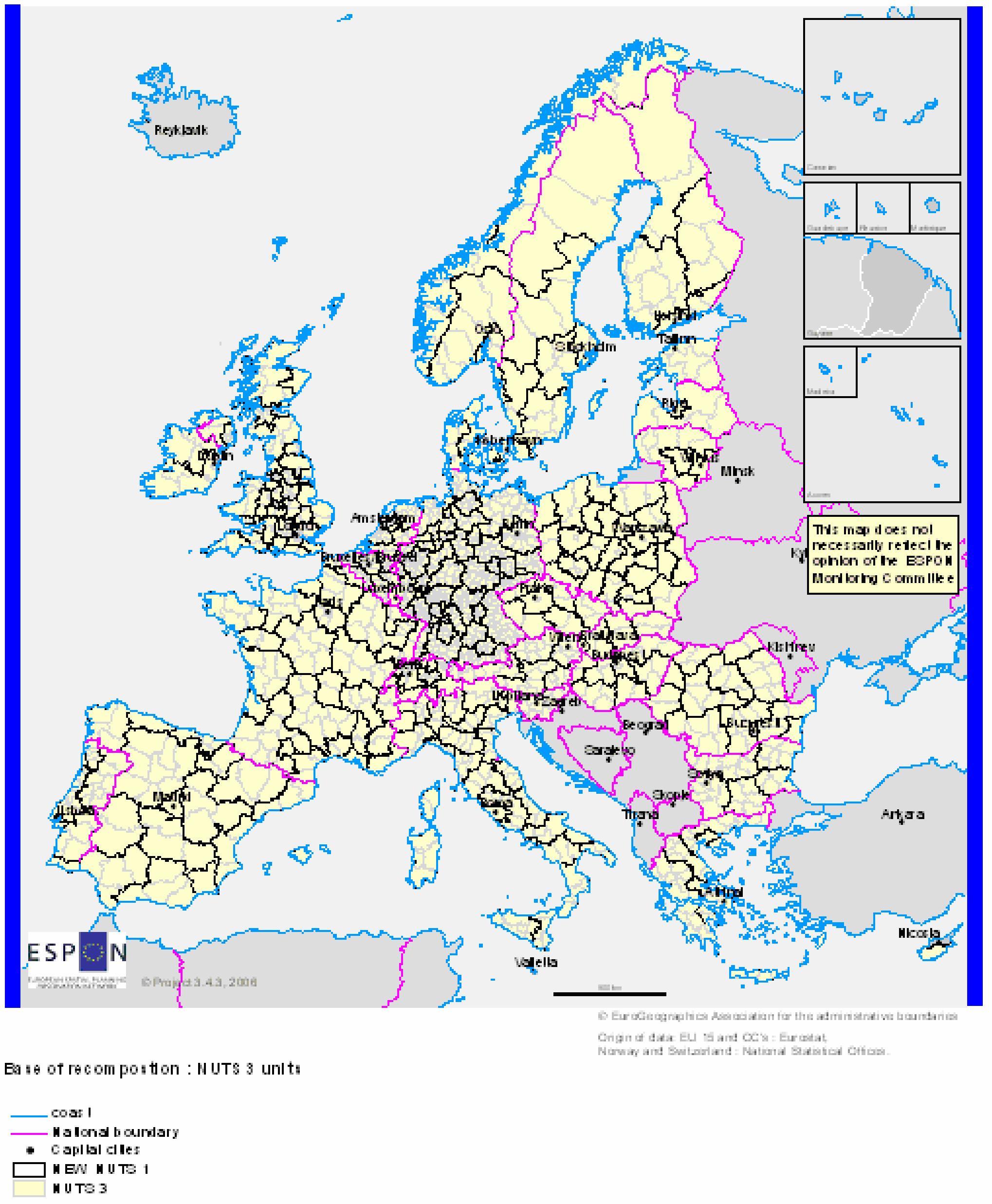


Figure 68 Recomposition of the NUTS division into functional units: new NUTS1

The Appendixes provide the list of the current NUTS 3 units linked to the n2NUTS 2 and n2NUTS 1 units, with a small comment country by country.

1.4 Conclusion

The present proposals, especially those developed in the second methodology, aim at providing a more adequate framework for a regional description of Europe, in particular better highlighting metropolitan realities which actually structure a European space integrated and inserted into the globalised economy. However, we insist we do not intend here to do away with the provision of basic statistical data at the most disaggregated possible level – NUTS 3 at least–, still less in some countries where the NUTS 3 level appears insufficiently fine as in some regions of France (for instance the NUTS 4 sub-prefectures or the labour pools corresponding to the Dutch NUTS 3, the COROP). Lastly, the proposed creation of such statistical units does not aim to take the place of administrative areas which have their own legitimacy and in which States apply structural policies.

2 Exploration of smoothing methods

2.1 Theoretical approach

2.1.1 Continuous representation

The aim of a continuous representation of socio-economical data on a geographical space is to provide a set of abstraction of the studied phenomena. This is particularly useful when data are heterogeneous in their values or in spatiality. The result is a 3D representation which is projected on a 2D representation where either level lines or gradient. One could define maxima and minima, attraction or repulsion basins, ... which explain global tendencies of the phenomena and produces information at a higher level than the level at which data were collected.

As input of the representation, we have a discrete information of socio-economical data, typically administrative units with

- spatial attributes (area units with particular points as centers or centroids, segments of lines representing frontiers, polygons,...)

- social attributes, considered as derived from a counting process issued from sampling

Then we model the spatial space as a geometric surface $\mathcal{G}$ (a portion of plan or sphere), on this surface is defined a topology (neighborhood) and a metric (distance). The aim of the continuous representation is to build an operator Φ that maps the geometric space in $\mathbb{R}$. Interpretation of tither an estimation of the real phenomena or a transformation of data.

The difficulty is to fix the constraints under which the function Φ is computed. These constraints are on the aim of representation, on the family of operator Φ that are considered and on the dependence of the metric of the geometric space. Typically, one wants to build a model putting in relation social data and geometric properties.

2.1.2 Direct representation of the phenomenon related to measurement points

In that case we suppose that the phenomenon is located in space in specific positions. Denote by M_i the set of points where the value of a_i had been observed. The operator Φ should satisfy a specific constraint like

$$\Phi\,(M_i) \;=\; a_i,$$

in each point where observation has been done. Then we should find the best operator satisfying this constraint. We call such an operator an interpolation or extrapolation of the phenomena. It could be done by classical techniques like Bezier ou Spline surfaces.

In the case when data are not known precisely, due to a white noise on measurements for example, the aim is to construct the operator in order to minimize some criteria on the distance between the observation points and the estimation by the operator. We call such an operator an approximation of the phenomena. The traditional tool to make such an approximation is the regression according to a model (linear or multilinear).

2.1.3 Direct representation of the phenomenon related to measurement areas

When the observations are related to areas, the problem is much difficult because we have to determine how the phenomena is spread on the area. Consider the observation areas as a partition of the geometric space (administrative units) $\mathcal{G} = \cup_i (A_i)$. The constraints on the operator Φ are now on the integration of the operator:

$$\Phi(A_i) = \int_{A_i} \Phi(M)dM, \quad \int_{\mathcal{G}} \Phi(M)dM = \sum_{A_i} \Phi(A_i).$$

The last equation is simply the fact that the whole mass of the phenomenon is preserved. Such a construction is called a mass preserving operator. Usual representation for that is a histogram with constant or variable length, depending on the analysis. If the operator is piecewise linear, we get the pycnophylactic method that have been previously studied in this report.

A particular application of this approach is density estimation. We suppose that the phenomenon has a density *f* that is the "amount" of phenomena in a point *M* is the "limit" of

$$f(x) \sim \frac{1}{|A|} \int_A f(x)dx$$

where *A* is arbitrary small. The difficulty is to find the adequate size of the sets *A* to estimate the density (granularity) such that the estimation error is sufficiently small. Several methods have been developed to solve this problem: sequences of histograms, smoothed histograms, filtering techniques based on continuity hypothesis, and more generally kernel method which produces several estimators depending on the parameters of the kernel.

2.1.4 Constraints on the family of operators

In all previous situations one have to specify the properties that the operator Φ should verify. Because we want a visualization at a large scale, the first property is usually the continuity.

$$||\Phi(M') - \Phi(M)|| \leqslant \alpha.\delta(M, M').$$

That is the phenomena does not contain barriers, discontinuities due to some characteristics of data.

A second hypothesis usually made is that the operator is differentiable. That says that the gradient function has a semantic and we could define in each point a specific direction corresponding to the force that results from the operator Φ.

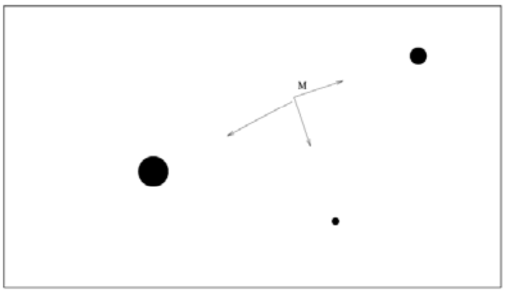
$$F = -grad\Phi.$$

This underlines that the system is produced by an evolution and the observed data are the result of movements induced by forces.

Of course, the operator could exhibit other structural properties: piecewise linear, polynomial, exponential, smoothed polynomial, ... All of these families fix the number of parameters of the operator to be estimated.

2.1.5 Spatial action

In fact the last comment gives another interpretation of continuous maps: it allows the representation of spatial actions inside the global system. Then the semantic of $\Phi(M)$ is an attraction potential of all entities to point *M*. If we put a virtual observer at point *M*, its natural movement will be in the direction given by $grad\Phi$.



Consider now the operator written in the following way:

$$\Phi(M) = \sum_{e \in \mathcal{E}} S(e).I(g(e), M),$$

where *E* represents the set of all units on which we get observations, *S*(*e*) the value of the social index under study, *I* an action function taking as arguments the geometry *g*(*e*) of the unit *e* and the point *M*.

• Additive effects of social observations and social effects are proportional to the observation

• Spatial action is concentrated in $I(g(e),M)$ and is only a coefficient on the social observation. In many cases, the spatial attribute of an entity is reduced to a point. It could be the administrative or economical center, centroid or gravity center of the entity area.

The usual properties of the action function are homogeneity and isotropy of space, that is

$$I(g(e), A) = f(\delta(g(e), M)).$$

The function only depends on the distance between points. In some papers, oriented actions could be implemented by a formula like

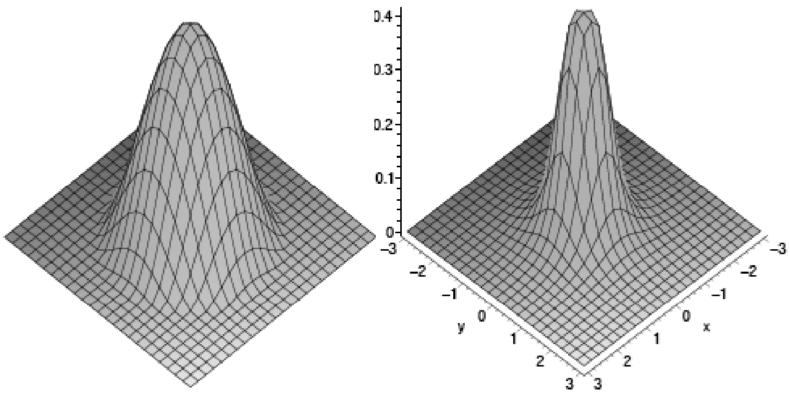
$$I(g(e), M) = h(\overrightarrow{g(e)M})) = i(\delta(g(e), M)).\vec{u}_{g(e),M}$$

2.1.6 Spatial action function

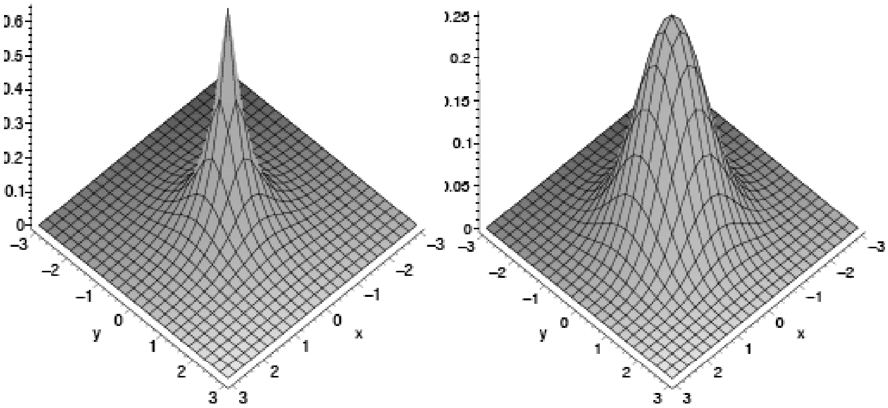
All the computation and interpretation of Φ is concentrated in the function I as a function of the distance $d = \delta(g(e), M)$. This function f is first defined by its shape that is to rely with system model.

2.1.6.1 Shape of the action function *f*

disk model ($d \leqslant R$)	1	uniform (discontinuous)
amortized disk ($d \leqslant R$)	$\left(1 - (\frac{d}{R})^2\right)^2$	no effect after R (polynomial)
gravity model (Pareto)	$\frac{\beta}{1+d^\alpha}$	long range dependencies
exponential model	$e^{-\lambda.d}$	rapid decreasing
gaussian model	e^{-d^2}	continuous local dependency



Smoothed disc and Pareto shape



Exponential and gaussian shape

2.1.6.2 Range of the interaction function

First of all, in order to compare several continuous maps, one should preserve an invariant for all functions. Considering the mass preserving condition (the total amount of the phenomena remains unchanged if we change the shape of the function). Consequently,

$$\int_{\mathbb{R}^2} f(\delta(O,M))dM = \int_0^{+\infty} 2\pi x f(x)dx = 1$$

It is interesting to note that the action function could be interpreted as a probability density function, that is *f*(*d*) is the probability of contribution of point *M* to a point *N* located at a distance *d* of *M*.

But to compare maps according to some shape it is necessary to fix the parameters of the shape. Define the range to be the mean action distance,

$$R_f = \int_{\mathbb{R}^2} \delta(O,M) f(\delta(O,M))dM = \int_0^{+\infty} 2\pi x^2 f(x)dx.$$

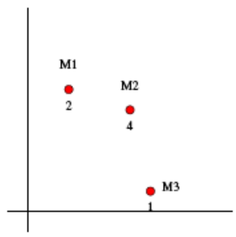
This expression is coherent with the additivity of the model but other expressions (median, quantiles,...) could be used as range of the shape.

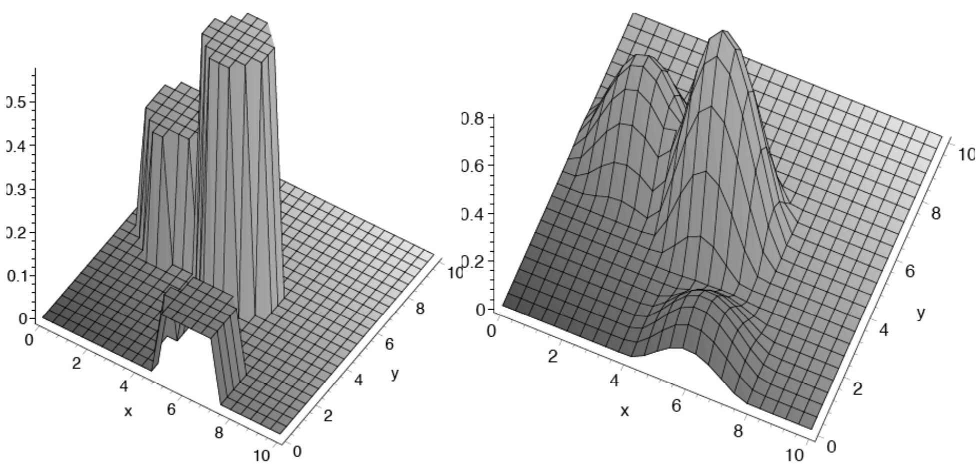
The usual shape and corresponding parameters are given in the following table:

Model	*Shape*	*Parameter*	*Range*
disk	$\frac{1}{\pi R^2}\mathbb{1}_{d\leqslant R}$	R	$\frac{2}{3}R$
amortized disk	$\frac{3}{\pi R^2}(1-(\frac{d}{R})^2)^2\mathbb{1}_{d\leqslant R}$	R	$\frac{16}{35}R$
exponential	$\frac{\alpha^2}{2\pi}e^{-\alpha d}$	α	$\frac{2}{\alpha}$
Gaussian	$\frac{\beta}{\pi}e^{-\beta x^2}$	β	$\frac{1}{2}\sqrt{\frac{\pi}{\beta}}$
Pareto(3)	$\frac{2\gamma}{\pi^2(1+\gamma^2 x^4)}$	γ	$\sqrt{\frac{2}{\gamma}}$

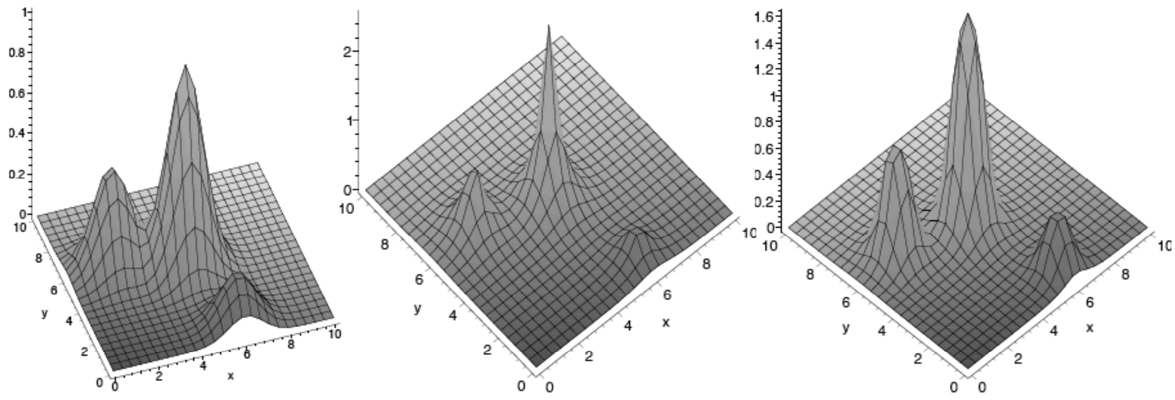
Consider the following example to illustrate the impact of the shape on the analysis, range is fixed to 1 for all shapes:

Points	Coord	Mass
M_1	(2,6)	2
M_2	(5,5)	4
M_3	(6,1)	1





Disc and amortized disc shape



Gaussian, Exponential and Pareto shape

According to these examples with the same range, the continuous maps exhibit different behaviors. The disc shape produce discontinuous maps, the exponential and Pareto case are not differentiable. Moreover, some surfaces show isolated areas and others produce a global mass "centered" around the gravity center.

The conclusion of this argument is that the semantic of the action function is of fundamental importance. Work should be done for modelling the action itself and then choose the adequate shape and range.

2.2 Practical problems for the use of smoothing method in ESPON

We have seen in previous section (§2.1) that the choice of a good method of smoothing is related (1) to the properties of the information under investigation and (2) to the assumption made by the observer of the phenomena, in particular on the form and scale of interactions which are supposed to have created the present distribution or which can modify it in the future. It means, in concrete terms, that the **choice of the smoothing method is not a technical detail but a crucial choice** which can not be based on trivial consideration of availability *("I use the smoothing module available in my GIS")* or subjective feeling *("I choose this smoothing method as the result looks nice")*.

The problem that we have to discuss in this section is therefore to define the best choice of smoothing method to be used in future research of the ESPON II program, taking into account the particular nature of data available (generally areal data, based on NUTS2 and NUTS3 divisions with a certain level of uncertainty) and the particular questions that are asked by ESPON policy makers (general preference for local territorial differenciation but interest for multi scale approach).

2.2.1 Consequences of the fact that ESPON database is based on counting data elaborated in modifiable areal units

In the majority of cases, ESPON data are collected on the base of areal division and are based on counting: counting of surfaces (amount of area with a specific land use), counting of people (amount of population in a given social category), counting of production (amount of GDP realised in a specific branch), counting of services (amount of bed of hospitals), counting of specific plants (amount of Seveso installations) and counting of events defined on a period of time (amount of birth or death). The index which are derived from this data are therefore combinations of raw-count variables which can not be measured directly but are necessarily related to a particular territorial division. It is important to precise this point by some examples:

⇨ *The altitude or the temperature* are phenomena which can be (theoretically) measured for every point of a given surface, providing we have the good instrument. In practical terms, the measure is never realised in all points but on a sample which can be regular (a grid of altitude) or not (a sample of meteorological station) and can be more or less accurate in space (altitude measured on a network of point of different level of resolution like 100 m, 1 km, 10 km) and time (measured of temperature elaborated each second, each hour, each day, …). In every case, these phenomena are measurable on each point and, even if the measure can be more or less precise, we can consider that one and only one value is possible in each point of the surface. We can therefore apply statistical methods of spatial interpolation like triangulation, kriging, local average, etc.

⇨ *The Unemployment rate or the GDP/inh* are completely different phenomena as they can never be measurer for a single point but are always related to a surface. Indeed, as they are based on counting, they need to be elaborated for a particular spatial subset (a NUTS unit, a square grid, etc.) which introduce a specific information. Of course, we can define centres of spatial units and consider that the value of GDP/inh or the value of Unemployment Rate is measured for this point but it is a dangerous illusion. What is really measure is the mean value of GDP/inh or unemployment in the neighbourhood of the point defined by the particular territorial unit that has been chosen. The same point (X,Y) can therefore be associated to different values of GDP/inh or Unemployment when territorial units are modified and it is impossible to consider that any exact value is available.

The fact that 99% of indicators and variables produced or used in ESPON are based on NUTS2 and NUTS3 division means that the methods of interpolation related to point measurement are not relevant and should not be used for the realisation of smoothed maps in ESPON (*Grasland, Mathian, Vincent, 2001*). It is clearly a bad news as the majority of smoothing methods easily available in GIS or spatial analysis packages are precisely methods adapted to interpolation of exact values of phenomena which are known on a sample of point: triangulation, nearest neighbour, Kriging, Shepard's method, … The methods of continuous representation which are adapted to ESPON data are more difficult to apply as they are generally not available in standard GIS or standard statistical packages of spatial analysis. Basically, we can define two groups of methods adapted to the specific case of counting data elaborated on a territorial grid.

1. **The picnophylatic method** elaborated by W. Tobler (1979) and further developed by Rase (1998) which has been presented previously (see Part1, §3.3). This method has not been used in ESPON because actual software version available is not able to support a sufficient number of territorial units.
2. **The neighbourhood potential method** elaborated by C. Grasland (*1991*) and further developed by the Hypercarte research group (*Grasland, Mathian & Vincent, 2001)* and has been applied several times to ESPON data (*see. Dictionary of tools in Final Report of ESPON projects 3.1*). In this case, software version has been developed for application to wide datasets (e.g. Smoothing of CLC realised by the EEA in the framework of the CORILIS project) but the different softwares which are actually able to

perform this method are not integrated in standard GIS or statistical packages.

2.2.2 Classical interpolation are non relevant solutions

Taking into account the difficulty to use this new methods specifically adapted to areal units, we can really ask if it is really interesting to do so and if the standard softwares of interpolation between point pattern are not sufficient? As an example, the team which was coordinator of the project 3.1 where this new methods was elaborated has decided in a more recent work of project 2.4.2 to use the classical method of point pattern elaboration for the measure of variation of GDP/inh between (Figure 69). Is it really a problem? Apparently not as this map was further selected by ESPON CU for a publication dedicated to promotion and diffusion of ESPON results (*ESPON 2005*).

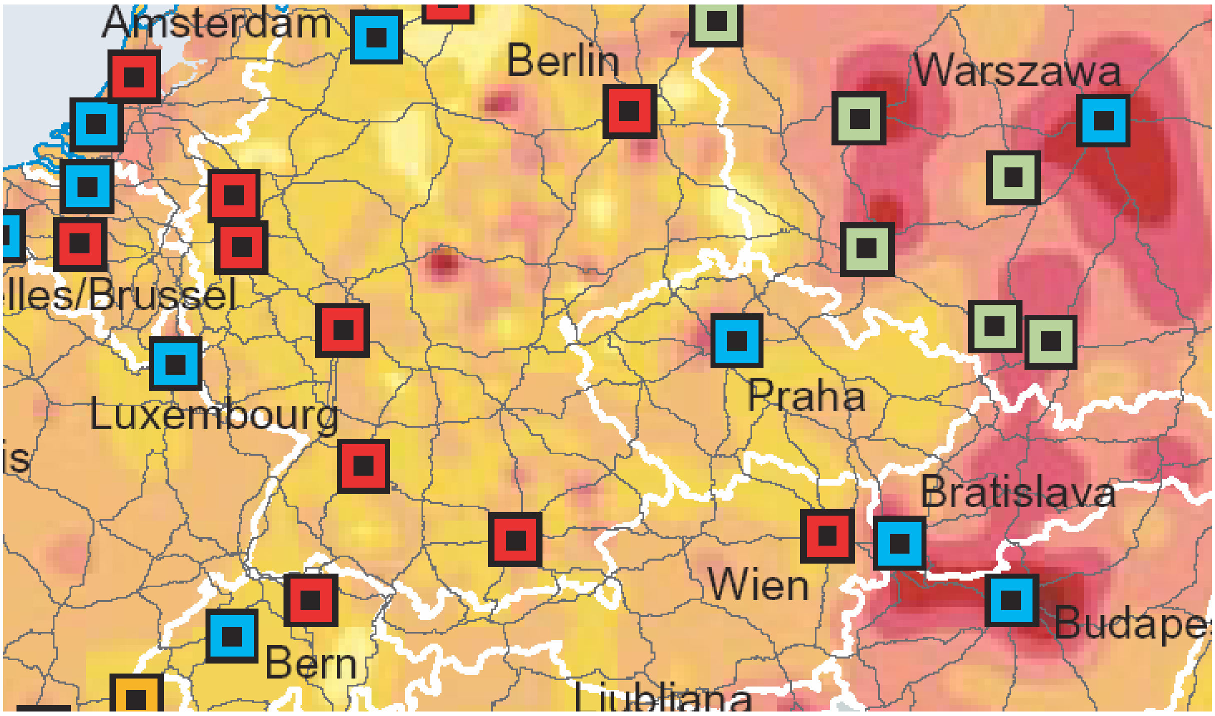


Figure 69 Example of an inappropriate method of smoothing

Source: *In Search for Territorial Potential*, ESPON Synthesis Report II, Spring 2005, p. 21, http://www.espon.eu

At first glance, this map is not shocking and looks rather nice. But a more detailed analysis reveals that it presents a strong heterogeneity in the distribution of growth rate of GDP/inh and that this heterogeneity take place only in the north-western of Europe (Belgium, Germany, Austria, Netherlands) and is less frequently observed in southern and eastern countries. Is it the reality?

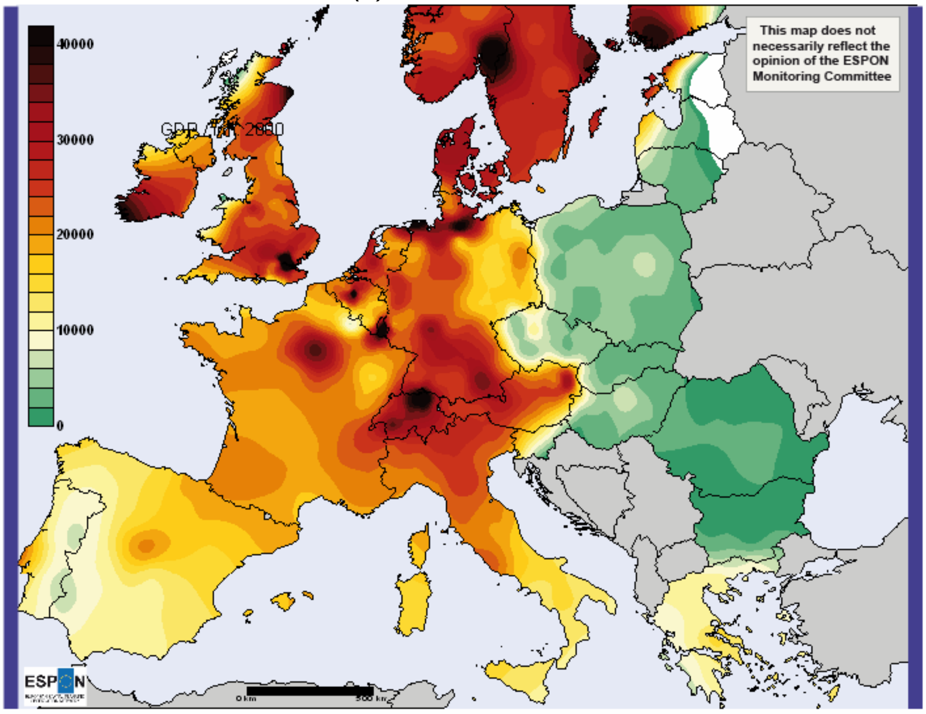
The answer is "no" because what is in fact revealed by the map is not the spatial heterogeneity of growth rate of GDP/inh but the spatial heterogeneity of NUTS3 units which has been used for the interpolation of growth rate by a non appropriate method. This map is dangerous because its apparent message (heterogeneity of growth rate in NW Europe) is a simple bias and the real trivial message (heterogeneity is growing with the number of territorial units) is no more visible. The limits of NUTS division has been removed by the smoothing technique but there effect is always present in the spatial distribution

This example reveals that **the application of non relevant methods of smoothing is very dangerous and should be avoided in the ESPON program** because it can induce false interpretation to researchers and policy makers. In this particular example, it would have been much better to use the classical areal representation of growth rate in NUTS units because the map would have been more or less the same but the reader would not have been induced to the **false conclusion** that "*there exists a higher <u>spatial</u> heterogeneity of economic growth rate in NW*". The reader which is normally aware of the scale problems induced by NUTS units would have simply drawn the **right conclusion** which is that "*heterogeneity of economic growth rate <u>of territorial units</u> is higher in NW Europe is higher than economic growth rate <u>of territorial units</u> of southern and eastern Europe*".

To illustrate the danger of non-adapted methods for political decision, we have computed the distribution of GDP/inh 2000 with a standard smoothing technique, available in many GIS, the Shepard's method. The same method has been applied in two different situations of level of aggregation, with data at NUTS 2 and NUTS 3 levels (Figure 70). If we consider that the major aim of smoothing method is to remove the problems induced by territorial division, we should expect that both maps will display approximately the same spatial distribution. But this minimum requirement is clearly not fulfilled. After application of the Shepard's interpolation method, the map derived from NUTS 3 information (Figure 70b) is always characterised by a strong heterogeneity in Germany and Benelux when the map derived from NUTS 2 information (Figure 70a) appears more regular with less peak of high GDP.

This problem is not specific to Shepard's method and the same differences would be observed with any other method of interpolation (kriging, triangulation, inverse distance to power...) because interpolation method are not adapted to smoothing of indicators derived from counting inside surfaces (*Grasland, Mathian, Vincent, 2001*). With classical interpolation methods, the results remains dependant from initial NUTS divisions and are simply a more or less fuzzy version of what can be observed in classical choroplethes maps. They are therefore dangerous as they give a false impression of solving the problem when they are only introducing confusion.

(a) initial data at Nuts 2



(b) initial data at Nuts 3

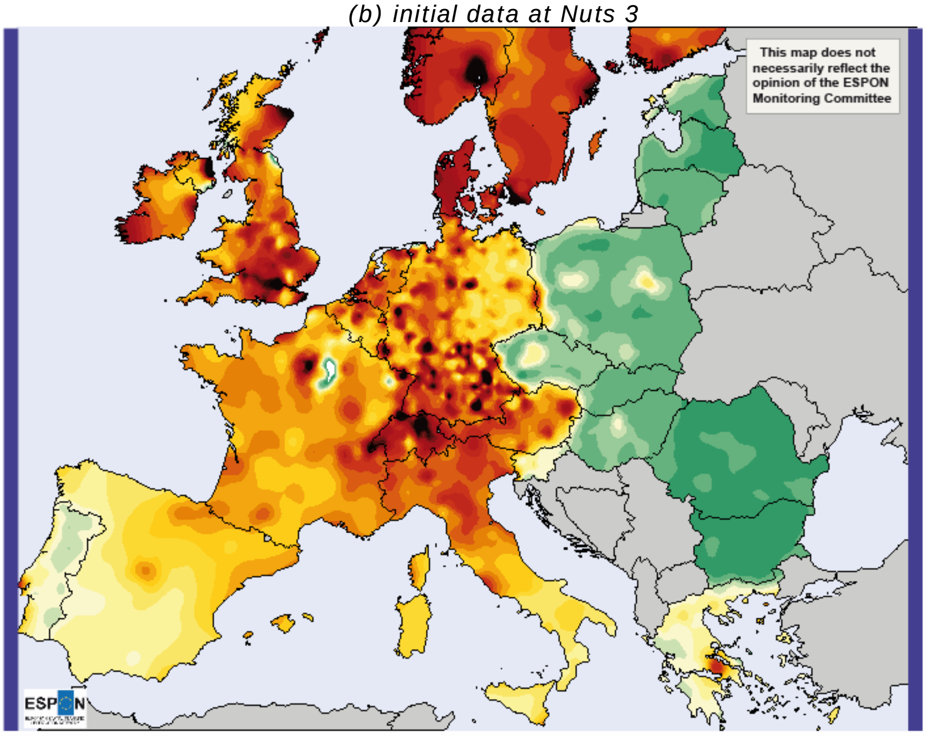


Figure 70 Comparison of Shepard's interpolation method applied to Nuts2 and Nuts3 data

2.2.3 Smoothing methods based on potential are relevant solutions if the span of neighbourhood is sufficiently large

Having criticised the classical methods of interpolation, we have now to verify if the smoothing methods based on gaussian neighbourhood potential are more relevant when we use the same criteria of comparison between results derived from NUTS 2 and NUTS 3 initial information.

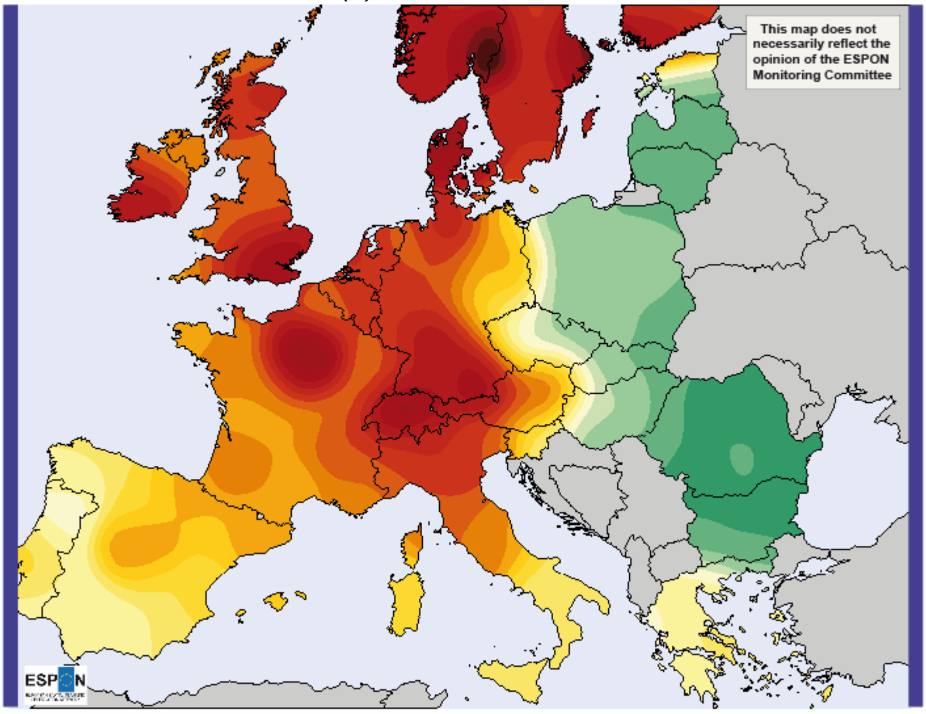
The Figure 71 which presents smoothed map realised with a Gaussian smoothing method based on a span of 100 km demonstrate that the condition of stability is now fulfilled as the spatial patterns are more or less equivalent, despite the fact that initial information was more aggregated in one case (Figure 71a) than in the other (Figure 71b). Only some minor differences can be pointed and the policymaker which use this map has now a guarantee that the spatial pattern is independent from the initial scale of aggregation of information. The map would have been the same if we have used as initial information the distribution of GDP and Population at NUTS 4 or even NUTS 5 levels.

This result is not obtain by chance but is the consequence of the fact that the properties of the smoothing method are convenient to the specific nature of the information under investigation (counting variables distributed on a surface). What is "smoothed" is not the distribution of the ratio variable GDP/inh but the distribution of the counting variables GDP and population. The weight of spatial units is directly taken into account and what is really measured is theoretically independent from initial territorial division as it is the amount of GDP in a neighbourhood of 100 km divided by the amount of population in the same neighbourhood.

The uncertainty on the result is simply related to the fact that we ignore the exact location of population and GDP inside each basic territorial unit, but this uncertainty is limited by the size of territorial units. When NUTS 2 units has a radius of 100 km, the precise location of GDP and population can be different from the representative point which has been chosen as center, but this uncertainty is never greater than 50 km and errors can be subject to consolidation as the potential is a weighted sum of several spatial units. If the span of neighbourhood is sufficiently greater, as compared to the size of territorial units, we can obtain the statistical guarantee that the resulting map is at 99% equivalent to the exact map that would have been produced with exact information on the location of population and GDP inside territorial units.

In other words, the only problem that we have to solve with this techniic is the definition of the minimum span of neighbourhood which provide the guarantee that the resulting map is correct at 99%.

(a) initial data at Nuts 2



(b) initial data at Nuts 3

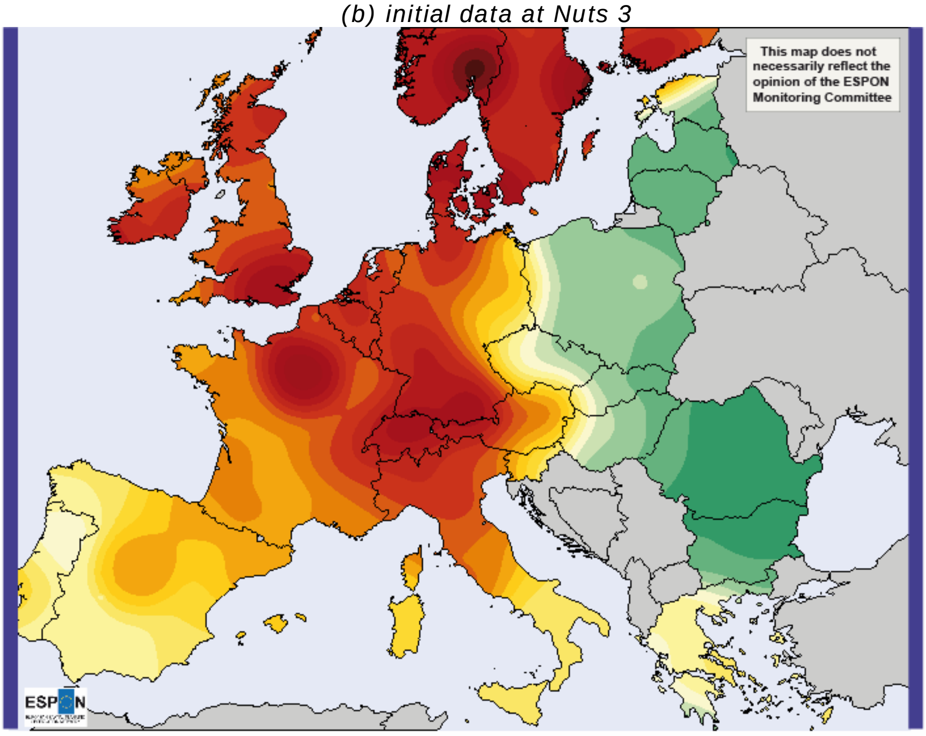


Figure 71 Comparison of gaussian smoothing method applied to Nuts2 and Nuts3 data

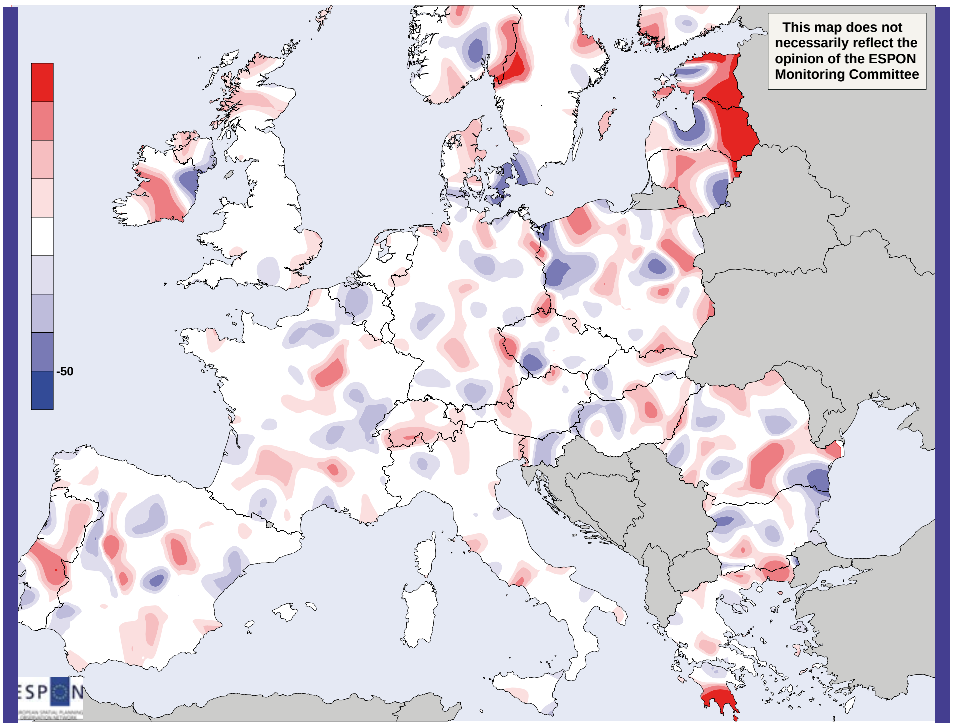
The determination of the minimum span of smoothing is easy to determine in the case of NUTS 2 information as we can use the NUTS 3 information as reference. Indeed, as NUTS 3 information is more precise, we can consider that the minimum span of smoothing to be used at NUTS 2 level is the one which offer convergence with the results obtained at NUTS 3 level. The correlations between spatial distributions obtained with spans of 50, 100 and 200 km are presented in Table 15 and the differences between maps are provided on Figure 72.

Table 15 Correlation between smoothed values of GDP/inh 2000 obtained from NUTS2 and NUTS3 information

Scale	R-Pearson	R-Spearman
50 km	0.979	0.982
100 km	0.994	0.990
200 km	0.999	0.997

- A span of 50 km of gaussian smoothing is probably not sufficient when applied to a distribution of NUTS2 units. The correlation is relatively high (0.98) but the observation of resulting maps shows very visible differences and the precise analysis of residuals (Figure 72a) indicate that the mistakes are regularly greater than 5% on the majority of the ESPON space. It means that we can not have confidence in the description of spatial forms which would be realised with such a map.
- A span of 100 km of gaussian neighbourhood seems to be more relevant because the correlation is much better (+0.994) and the differences between resulting maps are now very difficult to identify by visual inspection (Figure 72). The precise analysis of residuals (Figure 72b) indicates that it is only in the border areas of the ESPON space (Greece, Portugal, Estonia, Lettonia) that important relative differences can be observed. And also in the case of very wide NUTS2 units like Denmark or Ireland which modify substantially the aggregated distribution of the phenomena as compared to NUTS 3 level.
- A span of 200 km of gaussian neighbourhood would provide a perfect correspondence between results of smoothing starting from NUTS2 and NUTS3 (+0.999) but the interest of the results would be very limited because most internal difference of European territory are removed and only trivial results remains visible.

(a) Difference between maps for gaussian smoothing 50 km



(b) Difference between maps for gaussian smoothing 50 km

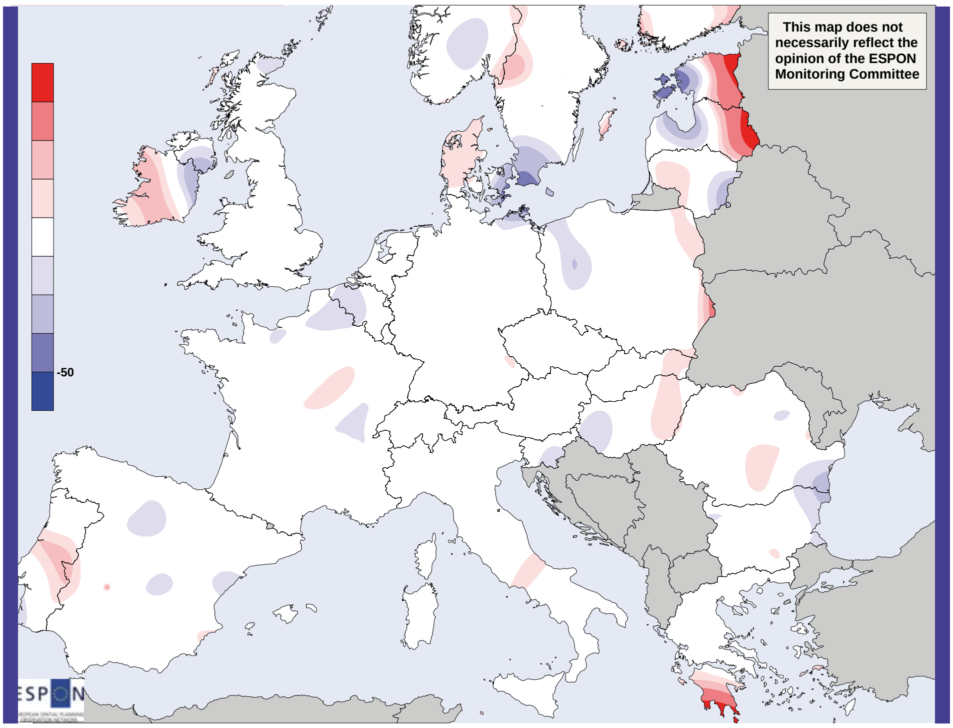


Figure 72   Determination of minimum span of smoothing for NUTS 2 information

We can therefore conclude from these preliminary experiments that a span of 100 km defines a correct value of gaussian smoothing when applied to NUTS 2 information. It is not possible to realise the same experiment for the definition of minimum span of smoothing when data are available at NUTS 3 level, because to do so we would need a complete coverage of Europe at NUTS 4 or NUTS 5 level. But experiments realised on limited part of the European territory (France, Belgium) suggests that a span of 50 km is generally correct for NUTS 3 information, except in northern part of Scandinavia.

3 Polygon-related cartograms and representation of size effects

According to W. Tobler (2004) we propose to use the term "**cartogram**" for cartographic representation of a phenomena where the area of territorial units is transformed in order to be made proportional to a given value describing a count (population, GNP, Birth). This help to avoid confusion induced by the general term "Anamorphose" which can described any type of cartographic transformation, including cartogram but also "lences" or time distance distorsion. To be completely precise we will use the expression "**polygon-related cartogram**" suggested by W.D. Rase (2006) for the case of transformation of territorial units which defines a complete partition of a given territory (states of the World, Länder of Germany, …).

3.1 Cartography of ratio and visualisation of denominator

Before to analyse in detail the properties of polygon-related cartogram, it is interesting to discuss a more general problem which is the cartographic representation of a ratio R=N/D defined by the division of one count variable called numerator (N) by another count variable called denominator (D).

According to the rules of graphic semiology which has been defined in the seminal work of J. Bertin (1974), the correct representation of count variable is based on the visual parameter "size" (e.g. disks with area proportional to population) and the correct representation of ratio variables – and more generally quantitative variables which do not fulfil the property of additivity i.e. where the sum is nonsense – is the choropleth map which use the visual parameter "value" which is in practice an increasing proportion of intensity[27].

As the majority of index and variables produced in ESPON are ratio (division of two count variables) or synthetic parameters of intensity which do not fulfil the property of additivity, the great majority of map is based on the choropleth method which is the filling of the area of territorial units with a colour or a pattern which describe the state of the population living in territorial unit. The

[27] This classical rules are apparently no well known by all members of ESPON and many maps produced by TPG did not fulfil the condition of a sound representation. The most frequent mistake is the use of "colour" instead of "value" for the cartographic representation of quantitative indexes. Colour can be combined with value for esthetic reasons but the message of maps is false and confusing if colours are not ranked in order of intensity (with eventually double progression of value around a mean value). Another mistake is the choropleth (areal) representation of variables which are in fact count variables and should be correctly represented with size symbols. The best example is the map of variation of the share of European GDP produced by ESPON project 1.1.3 which was based on a *difference* of share and should has been map with circle proportional to the size of difference and colours indicated if the difference is positive or negative. The area representation which was used was not correct : it would have been possible only if the statistical parameter was a *rate* of increase of the share but not a difference.

problem with this type of representation is that the visual perception of the global map is proportional to the area of units and not to their economic or demographic size. The experiments made on visual perception by the CESA with the Oculographe (see Part2, §2.2) underlines that the eye of the user of a map is primarily attracted by large surfaces with homogeneous pattern of colour and is not able to perceive easily small units or complicated patterns where colours are mixed. In practical terms, it means that when a user look at a map of GDP/inh. he will be more influenced by the large area of high level of GDP/inh. of Scandinavia than by the high level of GDP/inh. of metropolitan region of north western Europe like Paris, London, Brussels. What is striking is the fact that, when we consider the real economic or demographic size (i.e. GDP or Population) the conclusion is completely different and, for example, the GDP or the population of the region of Ile de France is greater than the one of the whole Sweden. The problem with any ratio of the form R=N/D is therefore related to the fact that, for a correct evaluation of R, it is necessary at the same time to have an idea of the volume of D which is subject to this intensity.

- If the phenomena under investigation is a population density they are no problems because the size of the denominator (D) is visible through the area of territorial units[28]. Moreover, all phenomena where the denominator is proportional to the area of units can be represents efficiently in usual cartographic template. For example, the share of natural area in the global land cover of regions or the accessibility of a territorial units (if we consider that a sufficient number of nodes has been used inside each territorial units to obtain a mean value of accessibility available on all the surface).
- If the phenomena of interest is a social or economic one, the situation is completely different and the use of classical choropleth representation induce a false perception of the size effects. A simple and efficient solution to remove the problem is the combination of a size variable (proportional to D[29]) and a value variable (proportional to Z).

As an example, we have established two maps of GDP/inh. in 2000 at NUTS 2 and NUTS 3 level where the denominator (Population) is introduced as size variable (Figures 73 and 74).

[28] With eventually some minor mistakes according to the choice of map projection.
[29] It is possible but less logical to use proportionality to the numerator (N).

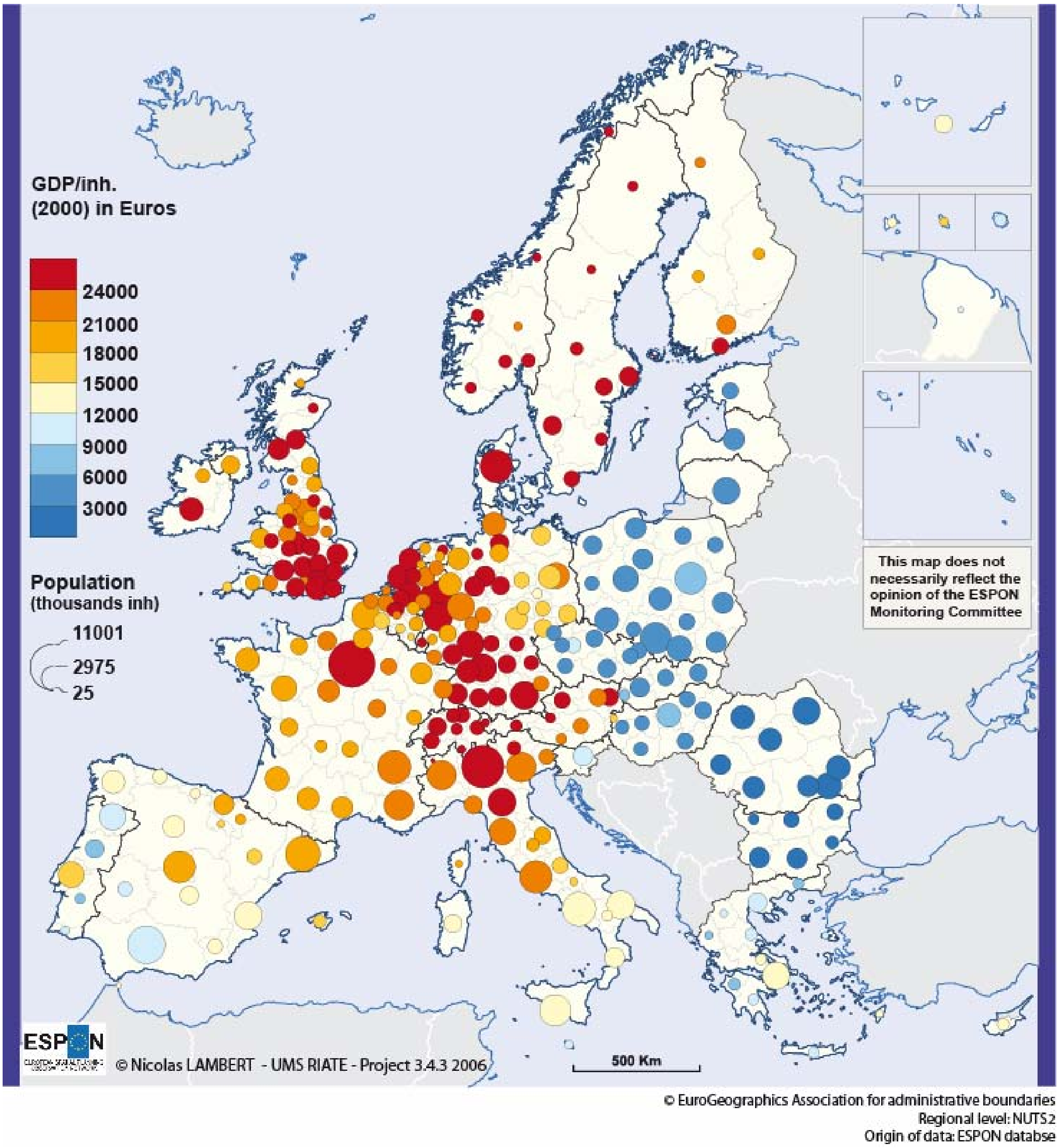


Figure 73 GDP/inh combined with population at NUTS 2 level in 2000

As compared to a classical map presenting only GDP/inh., the figure give to the policy makers a much more accurate vision of economic unequalities in ESPON 29 because he/she can combine two complementary informations (GDP/inh. and population) and eventually three if we consider that he can deduce population density from the more or less important coverage of areal units by circles proportional to population. This map answer to the question "*Where are* *<u>people</u>* *located in region with high/low GDP per capita*" when the classical map answered only to the question "*Where are* *<u>surfaces</u>* *located in region with high/low GDP per capita*". It is not a minor difference!

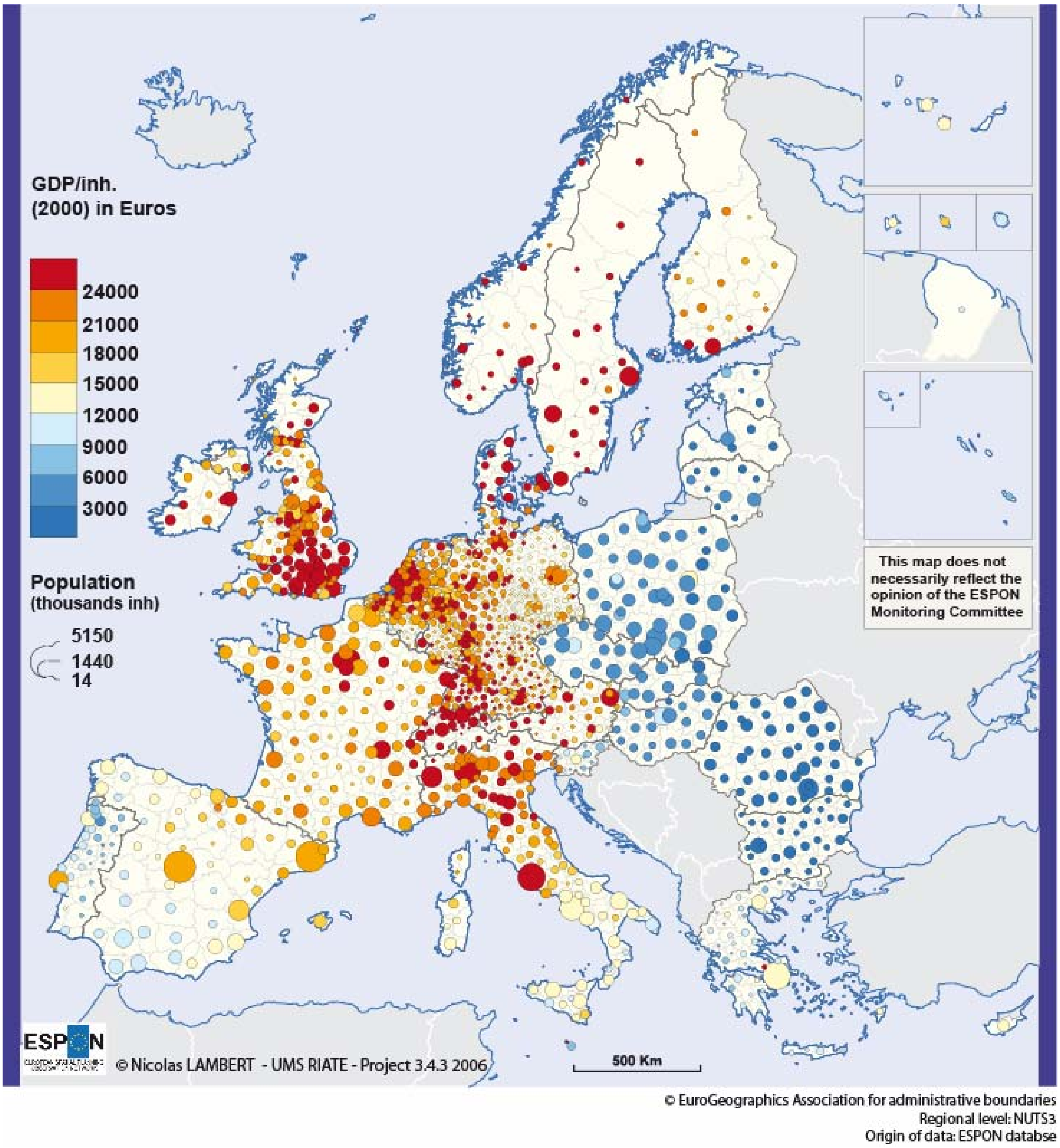


Figure 74 GDP/inh 2000 with circles proportional to population (NUTS3)

The application of the same solution at NUTS3 level provide of course a very different picture as the one obtained at NUTS2. The first obvious difference is the fact that the map is very difficult to analyse in Germany where the size of circle is generally too small to examine in detail the colour located inside. A classical choropleth areal map with only GDP/inh. seems therefore better for the user which prefer to analyse a global surface. But the fact to introduce population provide a more correct view, including in Germany where the relative high level of GDP/inh. is more visible here than in classical maps where there surface is too small to be visible.

3.2 Cartograms as solution to the MAUP?

We have seen in previous section that the combination of a ratio with its denominator on the same is an important progress for the realisation of maps in the framework of ESPON. Nevertheless this method has some limitations and can not be generalised in all situations. The combination is especially useful for representations at NUTS 2 level where the maps are not too complex and the spatial units sufficiently large and homogeneous. But it seems to be less relevant at NUTS 3 level where the high heterogeneity of size of spatial units make impossible the addition of further information like size.

Moreover, and it is true at NUTS 2 or NUTS 3 level, the introduction of circle proportional to the size of spatial units has an important default which is to make more difficult the analysis of spatial heterogeneity and territorial discontinuities along borders. As the territorial units are not "filled" by a colour, the differences or similarities between neighbouring regions are more difficult to evaluate in spatial terms. The reader's eye is obliged to produce a greater effort when it has to define cluster of regions which are similar or when it has to delineate lines of maximum differences between homogeneous areas.

The cartogram are therefore a particularly interesting solution as they solve the spatial continuity of the phenomena (as classical maps) but make also possible the visualisation of size effects (as maps based on circle proportional to denominator). Historically, the first cartogram elaborated in 19th century was very abstract representations where the spatial units were transformed into square or rectangles proportional to the target variable (Tobler, 2004). The regions was grouped in approximatively the same position as they are on the maps but the topology was not strictly maintained and the shape of unit was not kept which obliged to put the name of spatial units on each rectangular representation. Such method was therefore limited to representation of a small number of territorial units.

With technical progress induced by computer science, new algorithm for the building of cartogram has been elaborated with strict condition of conservation of topology (contiguity between spatial units) and optimisation in the global conservation of shape (despite enlargement or reduction of units). More details on this are available in Tobler (1961, 2004) or Tikunov (1988). The technique of cartogram which has been limited to a small circle of specialists until the year 2000 has now spread widely and is easy to use by any research team having at less a specialist from GIS. As an example, the anamorphosis proportional to population of NUTS 2 and NUTS 3 units can be realised in less than 30 minutes on a good PC computer with an additional script of Arc View. The computation could be of course easier with a generalised map of borders between region like the one elaborated by MCRIT and RIATE

The map of GDP/inh. in 2000 with area proportional to population at NUTS 2 level (Figure 75) provide a clear and comprehensive view of the distribution of GDP between inhabitants of ESPON 29. The reader can immediately identified the most important regions in demographic terms (size of the area) and the regions where the level of GDP/inh. is high or low (colour value of the area). The region of "*Inner London*" which was hardly visible on a classical map is now very easy to observe, as the other metropolitan regions of small superficy but high population (Hamburg, Brussels, Wien, Athens, …). On the contrary, the wide region with very few population like northern Scandinavia, Scotland or rural regions of Spain are dramatically shrinking. A spectacular example is given by Greece where the map reveals that Athens and Thessaloniki region concentrate more than half of the population of the country.

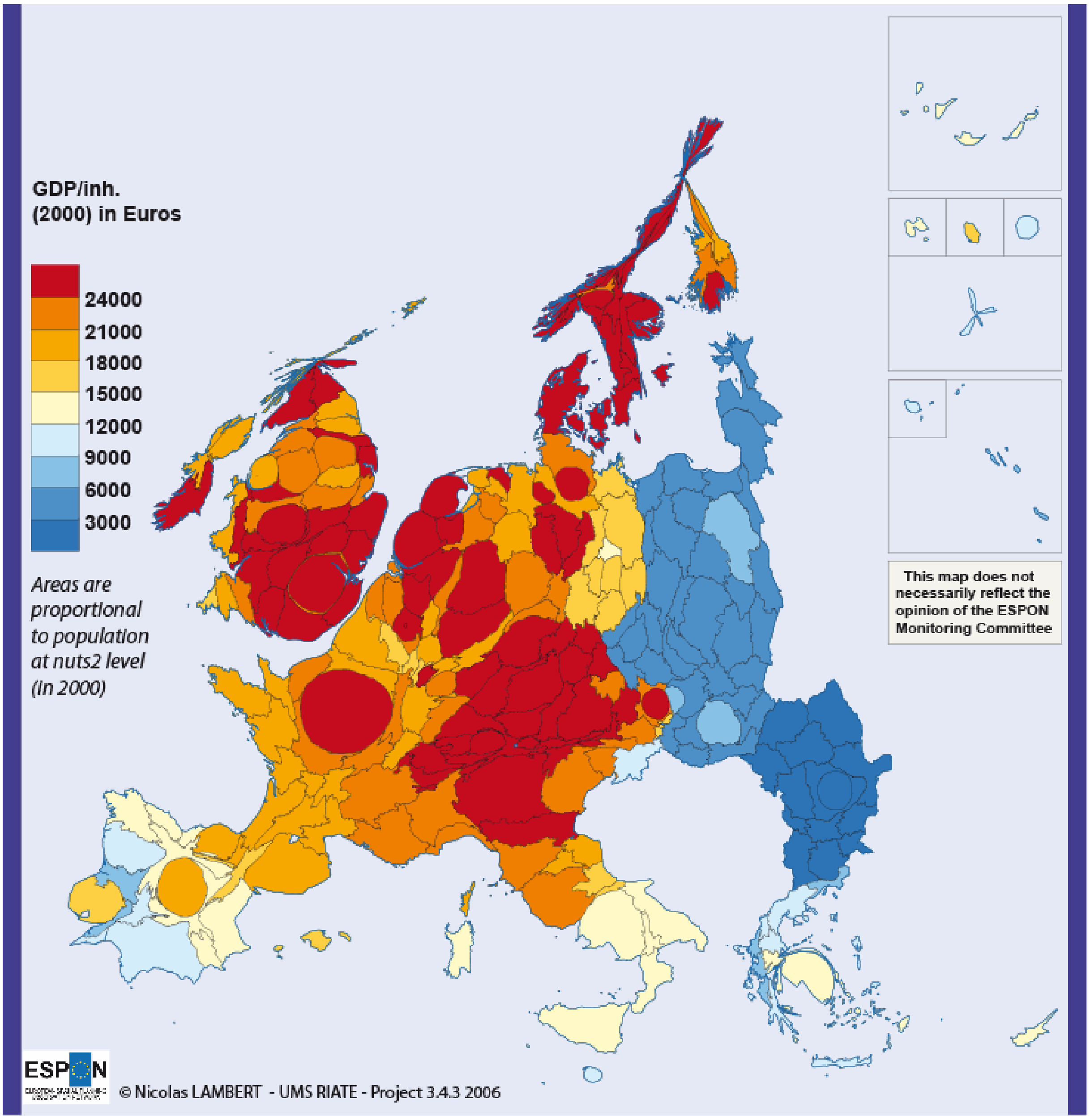


Figure 75 GDP/inh 2000 with cartogram proportional to population (NUTS2)

The same transformation at NUTS 3 level produce a map (Figure 76) which is globally very similar to the one established at NUTS 2. What happen is that the most populated area at NUTS 3 level are the most likely to define the value of GDP/inh. for aggregated unit at NUTS 2 level. As this most populated area are cities of very small area, they are very few visible on classical maps at NUTS 3 level, which explains why the colours of the maps are sudainly modified at NUTS 2 level. With cartogram, the city are yet very visible on the map at NUTS3 level and the change is therefore less dramatic at NUTS 2. In other words, the effect of MAUP is strongly reduced on cartogram where surface is proportional to the denominator of the ratio of interest.

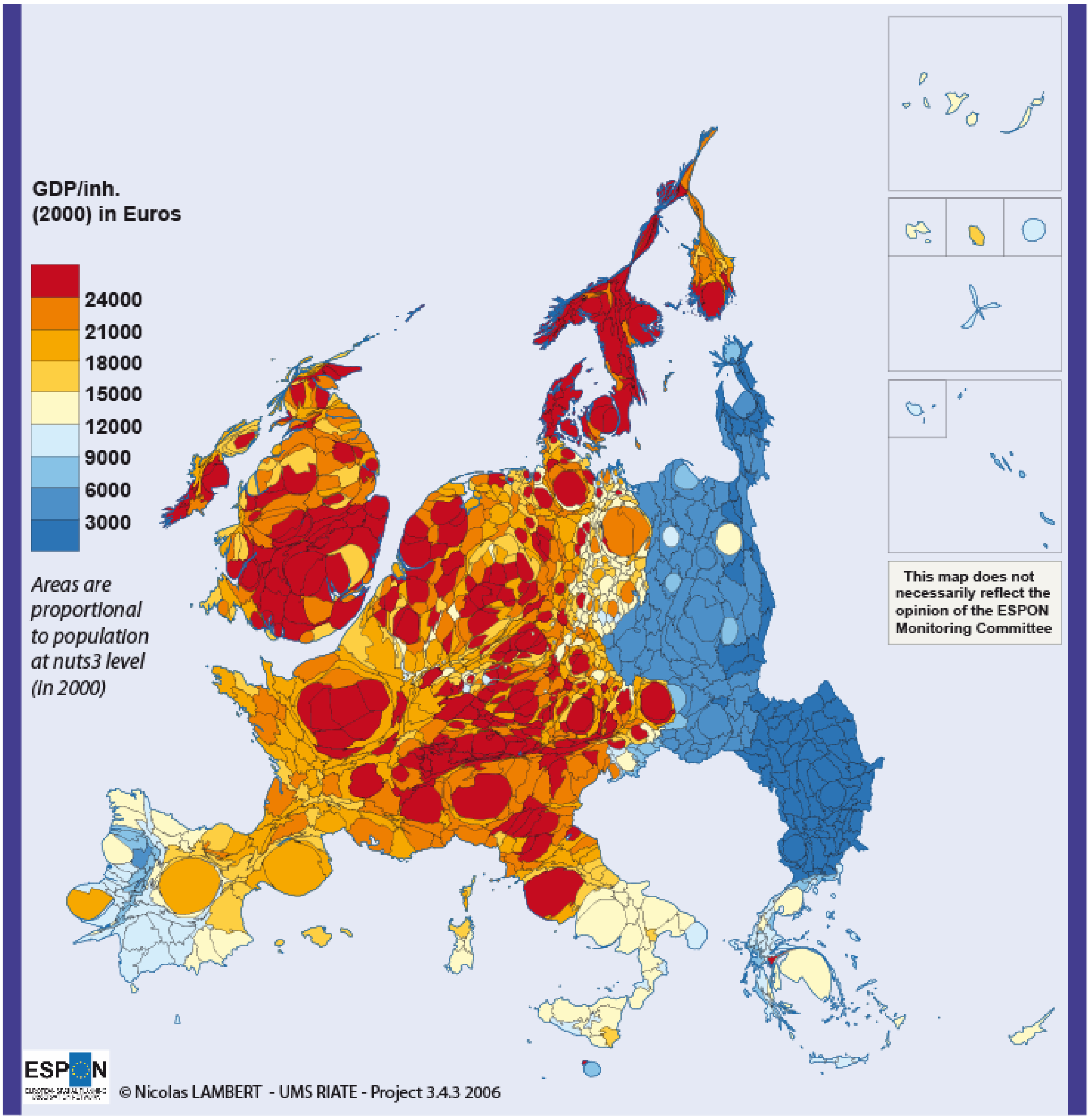


Figure 76 GDP/inh 2000 with anamorphosis proportional to population (NUTS3)

3.3 Discussion of advantages and limits of cartograms for spatial planning.

The review of specialised scientific literature on theoretical and advanced cartography indicate that the opinion is rather divided about the scientific and operational interest of cartograms (Tobler 2004). For some author like Rushton (1971), the cartogram are clearly a progress as they make possible the visualisation of regularity in spatial organisation which are clearly not visible in an ordinary map. He develops the example of spatial distribution of cities according to Christaller's or Lösch's model in order to show that its is only a "population space" that one can reveal the expected regularities. The same demonstration is made by P.J. Taylor (1977) which present a cartogram transformation on the coversheet of its famous manual "Quantitative models in geography" (Figure 77)

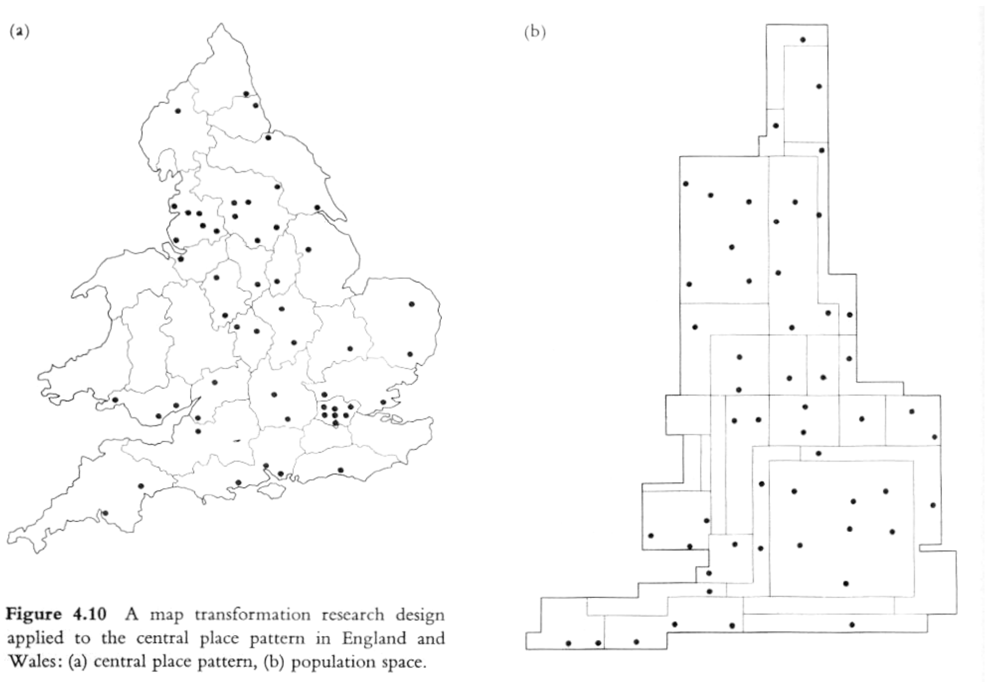


Figure 77 The evaluation of spatial concentration according to the choice of ordinary spatial representation or population cartogram

Source : Taylor P.J., 1977

Commenting this figure, P.J. Taylor explains that in the ordinary geometric space, we have the feeling that commercial centres of England are very concentrated in few portions of the territory and we could conclude to the existence of territorial imbalance, hierarchical organisation, etc. But if we consider the population space, which is the space of the customers of the commercial centers, the spatial pattern appears perfectly regular which mean that each center has an area of influence which cover more or less the same population.

This pedagogical example can be easily transposed to the question of *polycentrism* which has been a major concern of the ESPON program or to the more general question of the distribution of services of general interest. A regular pattern in the geometric space can be a political objective ("each citizen should find this type of service at less than X. km") but it is also true for a regular pattern in the demographic space ("each service should be built or a minimum population of X. inhabitant").

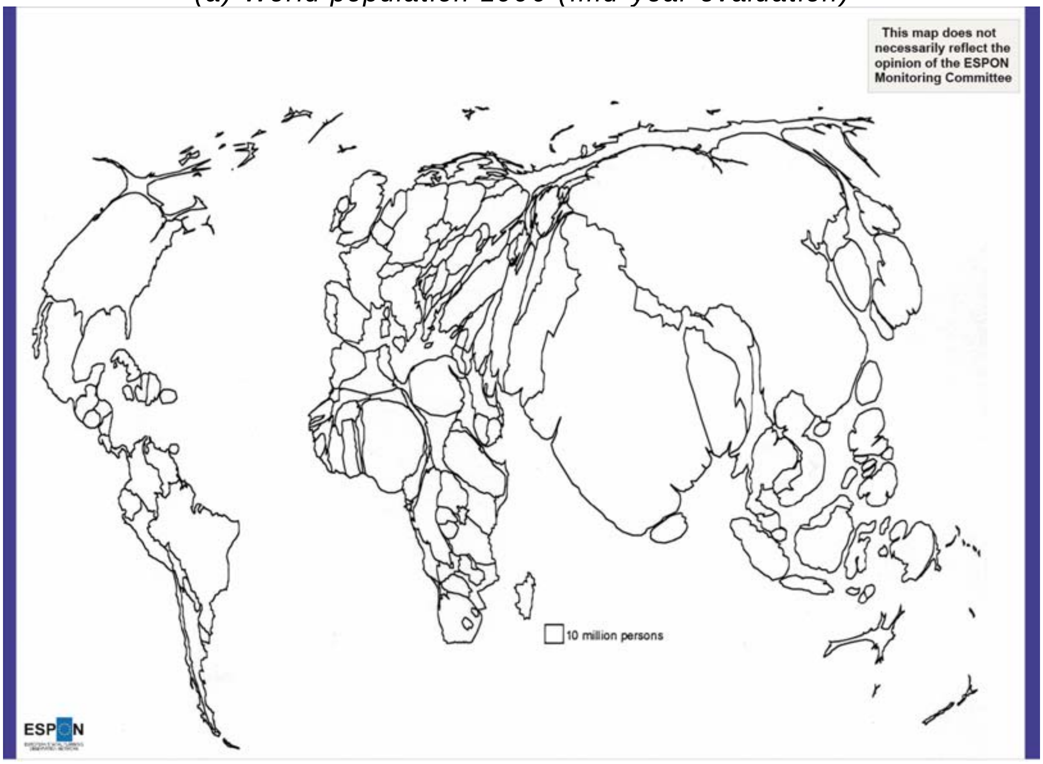
It has been sometime suggested that cartograms are difficult to use and that it can be hard to interpret them without additional information like location of town and cities (Charlton *et al.* 2006). Other authors consider that the difficulty rely on the fact that deformations can not be understood without a good knowledge of the initial map in geometrical space. These criticisms against the use of cartogram are serious but many technical solutions are actually available in order to make easier the interpretation of these innovative methods (Tobler, 2004).

They are certainly some weaknesses in cartogram's method but the same is true for classical cartographic methods which appears to be "natural" but are in fact a major source of error for the user. Consider just two examples:

- The analysis of the situation of Europe in the World in ESPON Project 3.4.1 is based on a northern polar projection which give a great importance to countries of southern hemisphere. Would it not be more correct to propose alternative maps with size of countries proportional to population or GNP as the one of Figure 78?
- The analysis of population variation is generally based on the cartography of the rate of population variation and is presented on a classical areal map. With such representation applied at NUTS3 level in Germany, what is mostly visible is the evolution of rural areas with large surface but low population. Is it not more interesting to analyse this population in a demographic space where the reader has a better appreciation of the real amount of increase or decrease of population as it is done on Figure 79?

As quoted by Tobler (2004) the difficulty is that "many people approach cartogram as just a clever, unsusual display graphic rather than as a map projection to be used as an analogue method of solving a problem, similar in purpose to Mercator's Projection". In reality, cartogram are the expression of scientific and political choices and it is not innocent to use one type of transformation or another one. Territorial cohesion, social cohesion or economic competitiveness implies different cartographic tools for their representation. For exemple, if Lisbonne strategy and competitiveness are the prior objective of EU, then the good cartographic representation should be a cartogram of region proportional to GDP and not not population or area. What would be visible on maps would be the biggest and most competitive regions.

(a) World population 1996 (mid-year evaluation)



(b) Gross national product 1996 (mid-year evaluation)

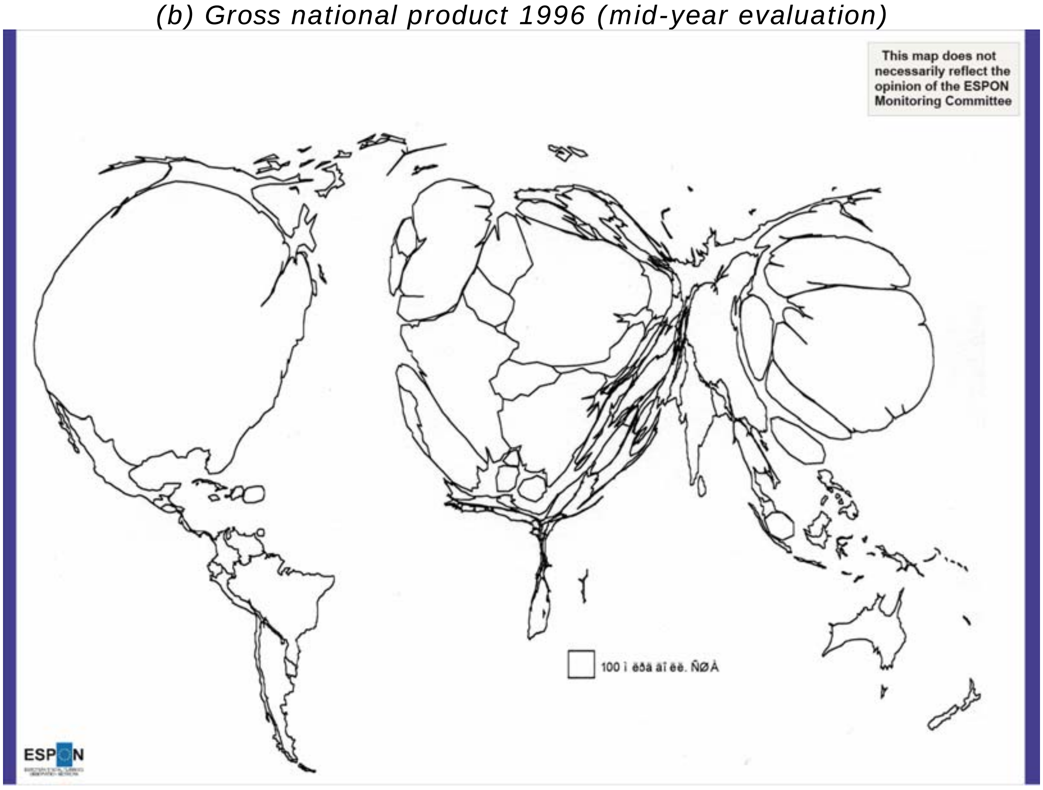
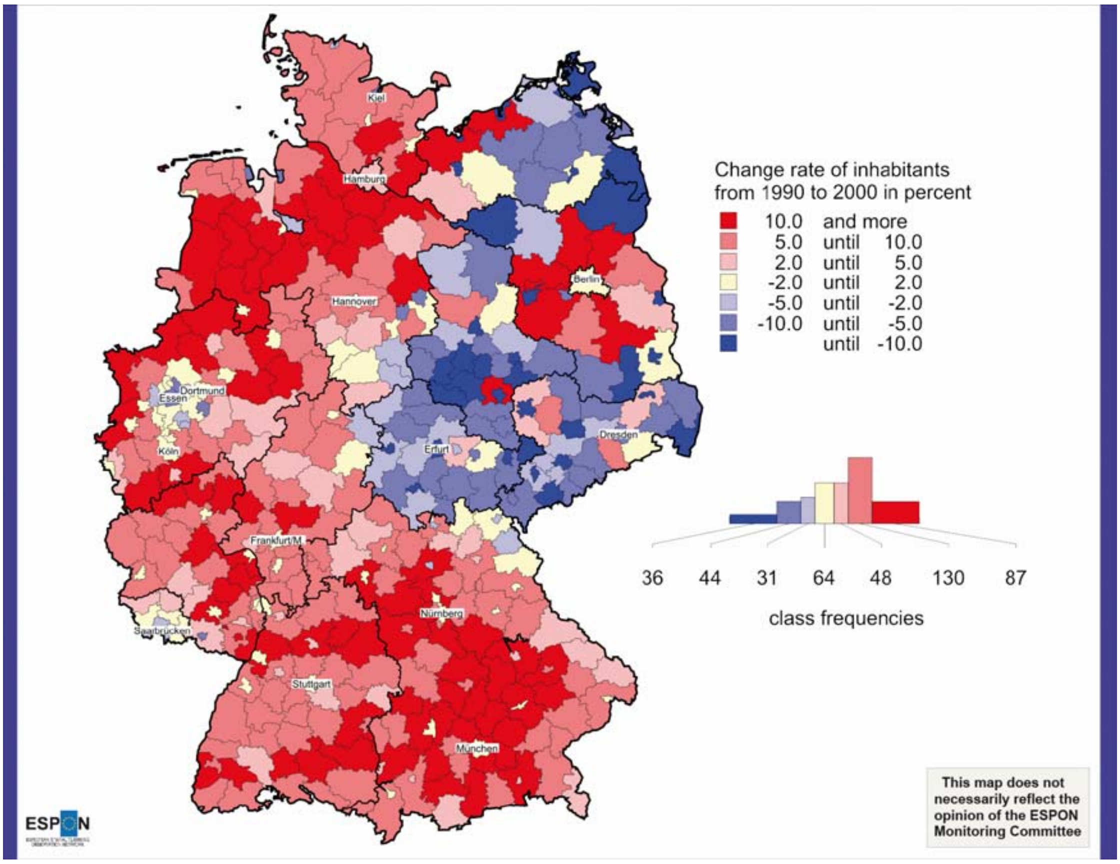


Figure 78 Cartogram of World Population and GNP in 1996

Source : Bogomolov, Rylskiy, Tikunov 2002



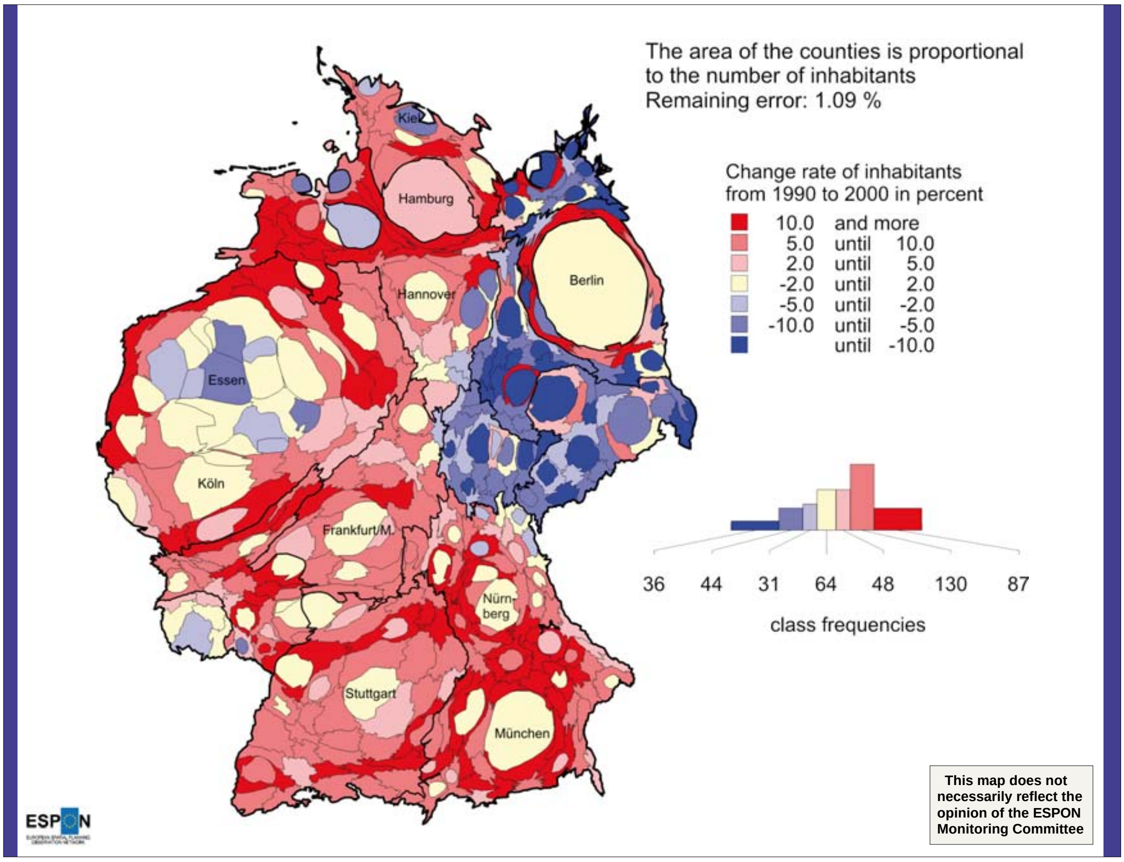


Figure 79 Population variation in Germany 1990-2000 according to NUTS 3 division and cartogram transformation

Source : W.D. Rase (BBR)

4 Exploration of gridding methods

The case study on Sweden presented in the first part of this report (see Part1, §3.1) has revealed the very high potential interest of gridding method for spatial analysis of social facts in general, and for spatial planning in particular. It was clearly demonstrated in this case study that NUTS 2 and NUTS 3 division are generally too aggregated level for the observation of phenomena like poverty or population distribution. More precisely, analysis realised in the framework of official delimitation gains in accuracy when they are completed by further analysis elaborated on grid of different scales which provide a trans-scalar view of the phenomena of interest.

Alas! The generalisation of the results obtained for Sweden toward the all ESPON territory is simply impossible. Indeed, the elaboration of grid at a very small level is possible only when census data are collected at individual level with precise indication of geographical localisation. In Sweden, the geographical resolution of census is lower than 100 meters and the band of possible aggregation levels is very large. But in most countries, the local authority level (NUTS 5) defines the minimum level of aggregation which means a geographical resolution of at less 2 or 5 km in better case (small size of *communes* in France) but often much more.

Taking into account that information available at NUTS 5 level is very poor in Eurostat and that geographical maps of local administrative division are difficult to obtain and are generally unperfect (problems of linkage between statistical and geographical code in earlier version of SIRE and GISCO database), we can really ask if gridding methods are of interest for research developed in ESPON?

4.1 Gridding method can be applied to NUTS 3 database

Starting from the pragmatic assumption that, during a long time, it will remain difficult to obtain complete datasets at local level covering the whole ESPON 29 territory, we have tried to elaborate grid maps starting from information available at NUTS 3 level. As usual, experimentations were made on the distribution of population and GDP in euro for the year 2000.

With GIS tools, it is (relatively) easy to cross the administrative division of NUTS3 level with a regular grid composed of squares or hexagons of fixed size. It is then possible to allocate the population or GDP of NUTS 3 units toward the cells of the grid through the assumption that those count variables are equally distributed according to area inside each territorial unit[30]. It is of course a strong

[30] This method of allocation proportional to surface is not optimal (*Langlois & Lajoie, 1998*) and many other techniques are possible. Many papers has been written about the question of transfer of census data toward regular grid in UK (*see. Bracken 1991 ; Martin & Bracken, 1991 ; Bracken & Martin, 1995 …*). Other authors suggest the use

assumption which would be recognised as false if we were in situation to obtain more precise information (like population at NUTS 5 level). But the error which is induce by this method is decreasing when the size of cells increase and could be neglected if each cell was covering a huge number of territorial units. We have therefore an optimisation problem which is the determination of the grid size which is sufficiently large to reduce the error induce by areal estimation but also sufficiently small to keep the maximum of information on spatial differences. The preliminary experiments that we are realised are not sufficiently précised to determine this optimal level of gridding for NUTS 3 units, but they provide interesting inputs on the interest and limits of this approach.

- **A grid of 20x20 km2** (Figure 80) is clearly not sufficiently large for NUTS 3 data, except may be in some parts of Germany, Belgium or Netherlands where units are sufficiently small. But even in this countries, the average area of territorial units is equal to 700-800 km2 which is more than the size of grid cells (400 km2). As in most countries the average area of NUTS3 units is comprise between 2000 and 5000 km2, it is obvious that gridding effect is very small as most cells are fully included in a NUTS 3 unit. The global pattern of the map is therefore very similar to the classical NUTS 3 areal map and they are no improvements of the result but rather a degradation with uncertainties on the value of cells crossed by regional borders.

- **A grid of 40x40 km2** (Figure 81) is more interesting as the area of the cells is now multiplicated by four (1600 km2) and a process of regularisation of the distribution begin to be observed in countries of north western Europe (Belgium, Germany, Netherlands). In this part of the European Territory, we can consider that the size of gridding is globally correct and the artifical opposition between urban centers and periurban or rural area is globally removed which provide a better view of spatial distribution at upper scale. Unfortunately, this level of gridding remains not sufficient in countries where the average area of NUTS3 territorial units is larger, like France (6300 km2), Spain (9700 km2) or Poland (7100 km2).

sampling methods rather than exhaustive reallocation (for example *Dungan & al. 2002*). More generally, better results are obtained when ancillary information like precise description of land cover are used for the reallocation of socio-economic data (*Langford & al., 1991*) according to the method of "dasymetric mapping" (*Mennis J., 2003*).

(a) General view *(b) Zoom*

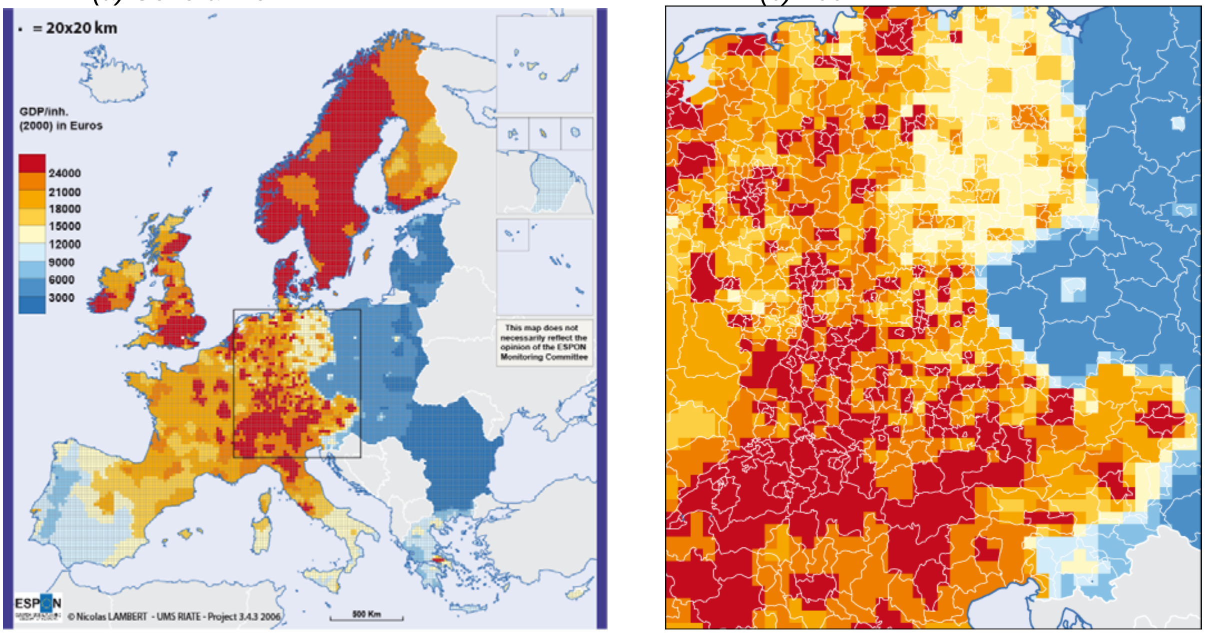


Figure 80 Gridding transformation of GDP/inh. 2000 (square 20 km)

(a) General view *(b) Zoom*

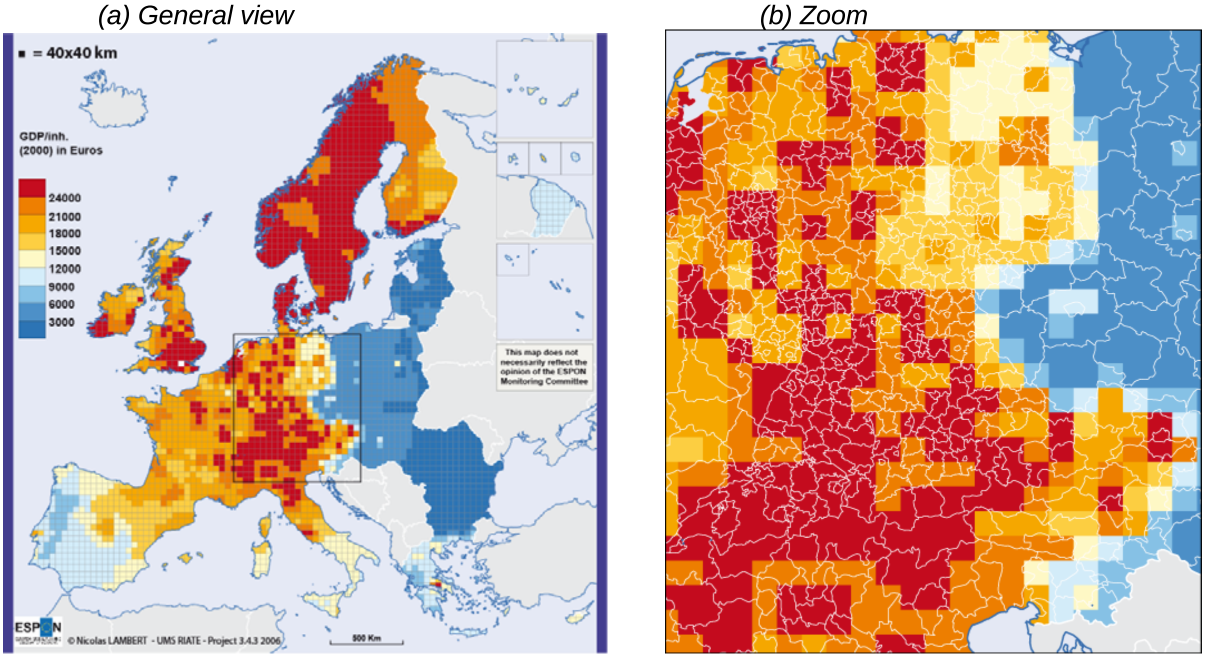


Figure 81 Gridding transformation of GDP/inh. 2000 (square 40 km)

- **A grid of 80x80 km2** (Figure 82) is probably the best possible compromise between conservation of spatial differences and elimination of biases introduced by the conversion from territorial units to grid cells. The size of cells (6400 km2) is indeed the double of the mean size of NUTS 3 territorial units (3300 km2) which means that in the majority of case the value of a cell is an average realised between several spatial units. The exception are of course the Nordic countries with exceptional average area of NUTS 3 units in Sweden (19 600 km2), Norway (17 000 km2), Finland (15 200 km2). This map is relatively similar to the distribution obtained with a mixture of NUTS2 & NUTS3 units or to the smoothed map with a gaussian neighbourhood span 50 km (see §2.2.3). The abstraction which is produced by grid transformation is both an advantage (as it obliges the reader to focus on the general pattern and not on local regional situations) and an inconvenient (as it is impossible for local spatial planners to recognize their territory and as national borders as no more visibles).

- **A grid of 160x160 km2** (Figure 83) is a supplementary degree of abstraction where only major spatial differences remain visible. Its interest is therefore limited is this map is presented alone. But, as we have seen in the survey of the perception of maps by ESPON community (see Part1, §2.1), this very global maps are interesting when they are combined with more detailed ones. We can recall the fact that very few people choose the smoothed map with span 100 or 200 km as "favourite map" but that many of them found interesting their combination with a more detailed map at NUTS3 or NUTS2-3. In other words, the grid maps with large cells are more interesting when combined with other map using smaller cells : *whole is more than parts*. With adapted tools we can imagine an interactive gridding tool where the user can modify interactively the size of cells in a continuous way (and not only by "jumps"), choosing for example grid cells of size 86 km if he/she considers that this reveal the most interesting spatial pattern. Or, in a more ambitious way, producing animation where it is possible to visualize in a dynamic way the progressive modification of spatial organisation when the size of cells change (See Conclusion: Interactive cartography).

(a) General view *(b) Zoom*

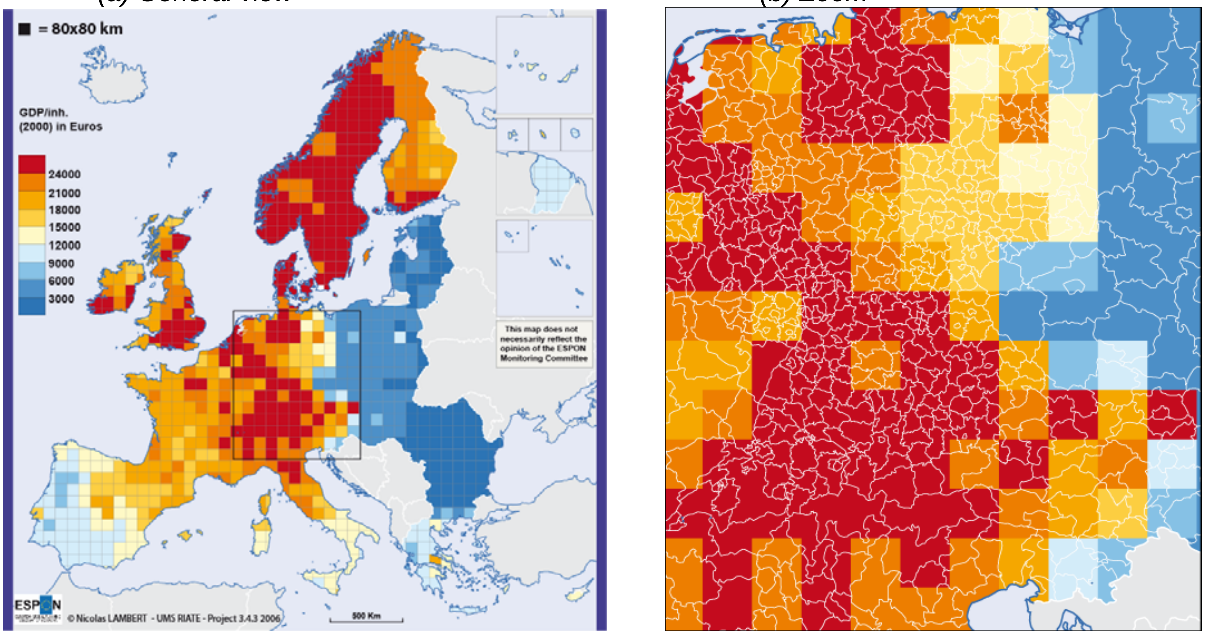


Figure 82 Gridding transformation of GDP/inh. 2000 (square 80 km)

(a) General view *(b) Zoom*

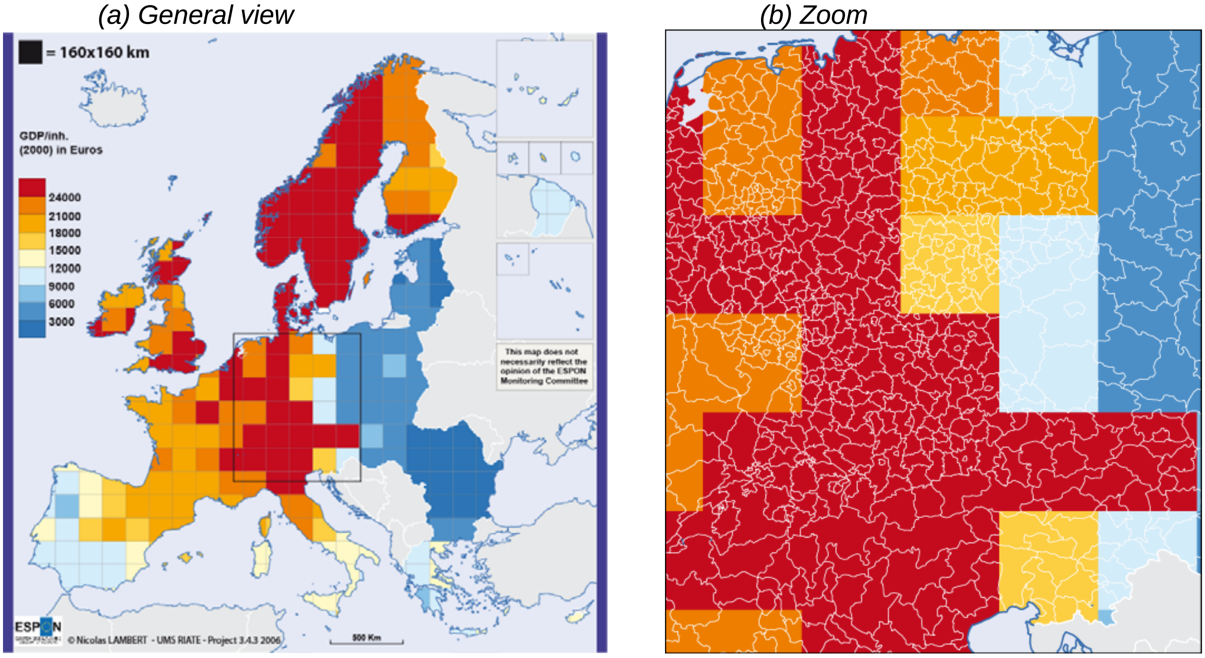


Figure 83 Gridding transformation of GDP/inh. 2000 (square 160 km)

4.2 Gridding method as tool for the integration of heterogeneous databases

One of the most promising application of gridding methods for ESPON is not the transformation of NUTS 3 units but the integration of heterogeneous databases. We can distinguish two potential fields of application:

- **Grid as solution for time harmonisation of changing territorial units**: many publications on gridding methods underline that it is one of the most useful solution for the building of long term database when census tracts or units are changing through time (Bracken & Martin 1995). In this case, the use of grid help to build an harmonised territorial framework where all changing territorial divisions are harmonised and can be further used for the analysis of time variation. Of course, they are many statistical dangers and such operation should be carefully realised (with estimation of errors in the process of reallocation) but ESPON should certainly find great opportunities in the developing of such methods which are actually analysed in the project of Long Term Data Base realised in ESPON 3.2.

- **Grid as solution for thematic harmonisation and combination of heterogeneous spatial sources**: many information of interest for ESPON are not delivered on the basis of NUTS 2 or NUTS 3 units and are normally distributed on other spatial formats like polygons of different from NUTS, grids, point patterns, networks, etc. The actual strategy of ESPON has been since the beginning to transfer all this non-standard information toward NUTS 2 or NUTS 3 units which are the implicit reference. For example, the Corine Land Cover has been recomputed in NUTS units. The same for the number of kilometres of railways, the number of SEVESO plants, the number of risks, etc. This strategy is in our opinion very questionable as NUTS units suffers from very important default and has a very low degree of spatial homogeneity. Information of good quality (as CLC) is therefore transformed into information of bad quality when projected in spatial units which are not adapted. This "Eurostat oriented" strategy could be replaced by another strategy that could be called the "EEA oriented" where all data would be transformed into grid and integrated on this basis. Smaller grid could be aggregated in wider one with methods like "Quadtree" without lose of information. Or, in a consensual way, we could imagine that interoperability could be established between a nuts database and a grid database with automatic procedures of importation and exportation, which is the "Inspire oriented" strategy, certainly the best one.

This question is actually under discussion at EU level (around the umbrella of Inspire and with research developed by the JRC of Ispra) but ESPON II should take an active part in it and not choose automatically the "Eurostat oriented strategy" which has been followed in ESPON I. The results of the project Data Navigator II (*realised in the framework of an addendum to project 3.2*) will provide important results on this topic. In any case, gridding methods are a topic to be explored in more details in the future according to two dimensions:

- *Scientific dimension*: what are the advantage/inconvenient of grid as compared to administrative units for the storage and integration of databases and for the development of statistical and cartographic tools?

- *Political dimension*: what are the advantage/inconvenient of grid as compared to administrative units for the decision makers acting at different levels of governance. In particular, how can we evaluate the fact that grid cells realise mixture of units without any considerations of borders at all levels, from local authorities to states?

5 Conclusion: Interactive cartography

In cartographical terms, the MAUP is associated to questions of scale and level of aggregation which are not directly a problem but rather a difficulty related to the fact that it is not possible to combine several solutions on the same piece of paper when we use traditional method of cartography. Some progress can be realised by better use of the possibilities of traditional cartography like cartograms (Dorling 1995) or combination of several variables on the same map. A classical example is the use of circle proportional to population as basis for the representation of other demographic parameters (Dykes J. & Unwin D., 1998). But this solutions are limited because they are generally complex : the user is not necessary able to interpret cartogram or he can have difficulties to analyse at the same time a variable of size (population) and a variable of intensity (fertility rate). The alternative solution is therefore to avoid too complex maps (Bertin J.) and to propose a multiplication of simple and elementary maps. If we consider that MAUP is a facter of progress, we have therefore to explore more in details the technical solution which make possible the analysis of several maps of the same phenomena, which mean to explore innovative methods of cartography different from the classical static maps (Peterson, 1997). MacEachren (1994) & Openshaw (1994) consider that the dynamic cartographic has an important potential for the development of knowledge and communication tools, which is not the case for classical static cartography.

With the development of computer sciences and multimedia technologies, some former dilemma of cartography related to scale and time can be actually overcome (*Antoni, Klein et Moisy, 2004*). The use of time is a central characteristic of what can be defined as *dynamic cartography* (Dibiase, 1992, p. 205), but it does not mean that the use of **dynamic cartography** is limited to the representation of temporal phenomena. A good example is a *cartographic zoom* as the one presented by Google Earth. The use of multimedia technology for the conception of maps is a major innovation for cartography and some author are speaking from **multimedia cartography** : "*Multimedia cartography can be seen as cartographic application of new media, which includes a range of new delivery and display platforms, among them are the World Wide Web, interactive digital televisions, mobile Internet technologies, interactive hyperlinked services, and enhanced packages that are linked to large*" (Cartwright et Peterson, 1999). Other authors propose the name of **geo-multimedia** (Cartwright 2001) with the same idea that animation and interactivity open the door for new progress in cartography.

The problem of MAUP is may be not so crucial in a framework of interactive visualisation. When Dorling (1993) notices that "the simplest is merely to illustrate it by using multiple boundaries, and with interactive visualization it is possible to redraw images instantly using different boundaries to see the effects of these choices" (p. 177), he describes exactly what has been done in ESPON project with the HyperAtlas which proposes to policymakers different visualisation of the maps at different NUTS levels.

We propose in next sections to explore in more details some of the possibilities of dynamic cartography for future ESPON II program, in relation with the MAUP (Figure 84)

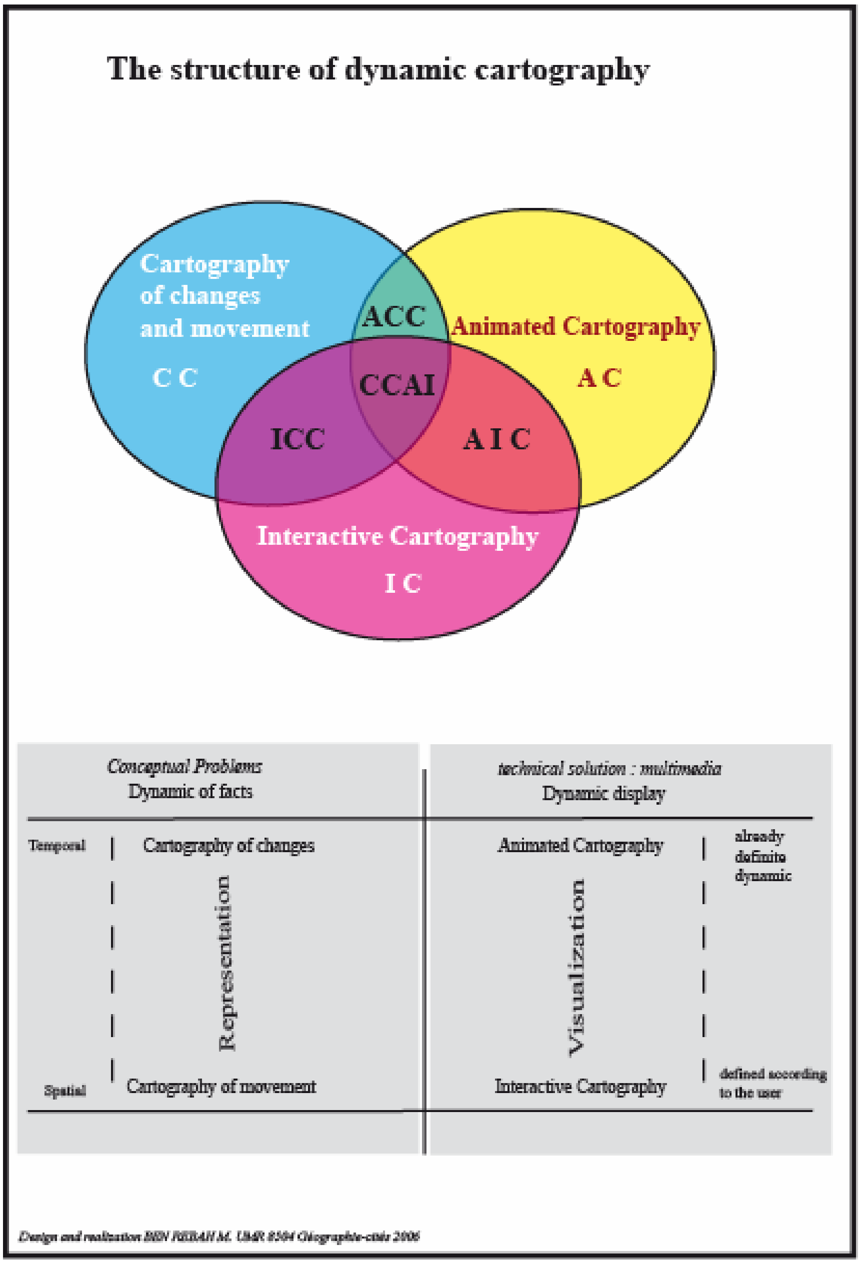


Figure 84 The different areas of Dynamic Cartography

5.1 A technical challenge: cartographic animation and animated maps

From scientific point of view, the MAUP problem was primarily related to the fact that it is not possible to consider that one map of a phenomena is better than the other. Having conclude that different maps are not contradictory but complementary, we have to imagine the technical solutions which make easier the analysis of multiple cartographic representations of the same phenomena. In this perspective animated maps appears as a particularly promising solution.

5.1.1 Basic definitions

Cartographic animation represents one of the technical aspect of dynamic cartography. It can be defined as "a method making possible the feeling of movement through the presentation of a set of successive images through time" (*Baecker et Small 1990, Peterson 1995*). The succession of images create the movement or, at less, the illusion of movement and change *(Roncarelli 1988, Koussoulakou 1990*). Animation produce therefore a continuity in the visualisation of scalar and temporal phenomena with the same technique as "Cartoons".

"The animated map is a series of maps that are shown in quick succession for the purpose of depicting some type of trend or change" (Peterson 1995, p. 185). It is supposed to provide a better visualisation and understanding of process as compared to static maps (Peterson 1994, Block et al. 1999). The change can be a time evolution or not (Armenakis 1991, Dibiase et al. 1992, Dorling 1992, Omerling 1995 et Kraak 1999). Changes which are not related to time can be modification of scale, modification of projection, 3-D animation etc. (Gersmehl 1990, Peterson 1993, Moellering 1980).

5.1.2 Animation of typologies

They are many types of data animation. The most simple one and the most usual one is the modification of classes used for discretisation of quantitative phenomena which is called "*classification animation*" by Peterson (1995). For example, a distrbution of GDP/inh. can be examined with successive maps where the range of values is divided in 2, 3, 4, … 10 classes and a related increase of complexity. The user of such animated map is free to operate the best compromise between efficiency (minimum number of classes in order to have a simple view) and precision (maximum number of classes in order to have more details on local differences of level). Statistical tools like variance analysis can indicate precisely the amount of information which is gain or losed when the number of classes is increased or reduced.

This operation of statistical aggregation can be applied to a single indicator (as in previous example of GDP) or to a set of indicators when the map is the result of a typology. In the case of cluster analysis, the user can freely decide to observe the maps related to different levels of information by "cutting" the tree at different levels corresponding to different levels of simplification (measured by variance explained in the case of the Ward criteria). A free cartographic software like *Philcarto* make possible an interactive mapping of the results of such typologies.

We can easily imagine application of this principle in ESPON where typologies are commonly used. Instead of providing a "flat" typology (e.g. the six types of urban-rural relations established by ESPON 1.1.2), the research team could provide nested typologies making possible to examine the results at different levels of details (e.g. the urban-rural typology could be examined in 2, 3, 6 or 12 classes).

5.1.3 Scalar animation and cartographic zooms

Scalar animation is defined here as the change of the level of spatial aggregation according to official (nuts0, nuts1, nuts2, nuts3, nuts 4, …) or non official levels (nuts2-3, alternative nuts2 and nuts 1 based on equal population or functional areas, etc.). As in previous case, the challenge is to make possible the change of the level of aggregation by a simple click on the mouse in order to visualize alternative representations of the same phenomena. More precisely, the user should has the freedom to define himself the most relevant level of aggregation in a panel of choices and to compare alternative results in real time, what is not possible with static printed maps.

Such tool has been yet developed in ESPON with the HyperAtlas which propose alternative levels of aggregation (nuts 0, nuts1, nuts 2, nuts 2-3) of an initial information available at nuts 3. In this case, it is not one single map but a complete atlas of 8 maps which is interactively recalculated and displayed by a single click of mouse. This tool can be easily completed by the proposal of new levels of aggregation (e.g. the functional Nuts2 and Nuts 3 proposed in previous sections) or by the enlargement of data collection at lower level (nuts 4 and nuts 5) in ESPON II.

Scalar animation is linked to the more classical method of zooming, available both in ESPON Hyperatlas and ESPON Web Gis. When the user try to examine the global pattern of a phenomena for the whole Europe, it is probably more interesting for him to use large territorial units (Nuts 1 or Nuts 2). But when the problem is to examine local differences in cross-border areas, the preferences would be in favour of more detailed spatial resolution (Nuts 3 or Nuts 5). This changes of territorial units according to scale of zooming can be decided freely by the user but we can also propose some automatisation process (e.g. choose the nuts level which allows that they are always a minimum of 50 territorial units and a maximum of 200 on the screen).

The same conclusion can be applied to smoothed maps where the span of neighbourhood can be interactively modified by user, depending on the size of the territory which is under examination. The criteria will be for example the number of “peaks” and “hole” that are present on the screen as we suppose that the reader is interested in spatial differenciation. Therefore, a large span of neighbourhood will be applied for pan-European view (100 to 200 km) but the parameter will be reduced to lower level of smoothing (10 to 50 km)) when the reader has decide to produce a zoom on a more local area. Of course, this is possible only if data are collected at a very local level (nuts 5) as the minimum level of smoothing depend on the size of territorial units.

5.2 A political challenge: interactive and adaptative cartography

From political point of view, animated maps presents at first glance some difficulties as, in a classical normative perspective of political decision, the "official" maps should be one and only one, printed on a paper like the international treaties … Interactive maps available on multimedia support which can be modified interactively by the political decision makers are something very tricking but may be very innovative from political point of view.

5.2.1 Interactive maps

Many authors consider that animated maps are more efficient when they are used in an active way and are not simply observed in a passive way like a movie (MacEachren, 1994, p. 127/128 et Kraak et Ormeling 1996, p. 192). Observing different levels of aggregation or different scales of aggregation with an animated map can produce a feeling of admiration but does not define a real interaction. What is different is the possibility for the user to modify interactively the map and to choose one scale of aggregation or one level of smoothing according to its own questions and choices.

With animated maps, the reader is obliged to follow a predefinite path. With interactive maps, it is offered a network of possibilities (possibly infinite) where the reader has to make pro-active choices and decisions. The possibility to modify the current map (*Dibiase et al. 1992*) give to the user a freedom but also a responsability in the building of the map. This is crucial as we have noticed through the ESPON survey that policy makers are generally less able to control the production of maps than researchers and are generally in a passive situation.

5.2.2 An "open method of cartographic communication"?

The action of spatial planning is realised by many type of actors, many levels of political decision. Each actor/level has specific objectives, specific questions and use therefore different data or different levels of territorial division. It is for example obvious that local actor has less to learn from maps elaborated at NUTS 2 level than national or European authorities. On the contrary, maps elaborated at NUTS 5 level are less useful for European decision makers than for local authorities. In a different perspective, cross-border or transnational decision makers are generally more in favour of smoothed maps (which remove political and administrative borders) than responsible of territories which are more interested in the precise evaluation of their state, their region, their local authority …

What is at stake is not to define a so-called "compromise" between the different actors with different interests and expectation. It is rather to offer an open cartographic tool where each type of actor can produce the maps which fits better with their own expectations but, at the same time, examine the maps which are considered as the most important by the other decision makers. It is in fact the transposition to cartography of the "open method of coordination" which is actually developed in EU for the process of political decision …

Interactive cartography take into account the diversity of territorial actors. The digital format of interactive atlas allows not only for interactivity but also for regularly production of up to date version easily available through the Web. The classical paper atlas are on the contrary normative and difficult to renewal when data become too old because of their cost. They are produced by a group of expert which present the state of the art at a given point of time but they are no subject to cross validation. A web atlas presents the advantage to be eventually coupled with a forum where users can provide criticisms, improvement, complements in a "participative" way.

General conclusion: Recommendations for ESPON II

In this final conclusion of the report we do not repeat the partial conclusion of each the previous part and we focus on selected key message to be addressed to ESPON CU and ESPON MC for the elaboration of the future program ESPON II.

1. **Adoption of a new hierarchy of NUTS division to be used for research and strategic purpose**. We strongly suggest that ESPON II is not obliged to restrict the production of maps to official NUTS 2 and NUTS 3 territorial divisions actually existing as legal instrument in European Union. This official delimitations could be used when needed (for example if the European Commission request a study on Structural funds) but the majority of ESPON production should be based on the revised NUTS division based on functional criteria which is proposed in this report. ESPON like OECD (which has adopted a mixture of NUTS 2 and NUTS 3 units for its regional studies) will gain in credibility at international level with this major change. It is not possible to go on with maps at NUTS 3 level which produce confusion and errors of interpretation because of scale confusion.

2. **Development of interactive cartographic tools making possible the delivery alternative representation of the same phenomena in real time**. Considering that different cartographic representation delivers different political message which are complementary, we suggest to develop the access of policymakers and researcher to alternative representation through multimedia and web technologies. Maps will no more be stored on paper version or picture file but would be generated at the request of the user by interactive systems. The actual tools elaborated by ESPON I (Web Gis, Hyperatlas) should be completed by new ones related to grdding method, picnophylactic interpolation, cartogram, Gaussian smoothing, etc.

3. **Development of research on cartographic perception and political decision process**. If we admit that cartographic is a major tool for decision makers in the field of spatial planning, we should analyse very cautiously and with adapted tools (survey, analysis of eye movement, …) what is the real message which is delivered by maps in order to verify the potential mistakes or bias. Moreover, we have to explore the consequence for political decision of what could be called an "*Open Cartographic Method*" where

different decision makers try to reach a consensus based on a collection of maps of different types, different scales, … Like in Delphi method, we could compare the different interpretations of a set of maps by different experts which are isolated at the beginning and which, in following rounds, are informed of the interpretations of the other experts. At the end of the different rounds, we should obtain a set of maps which are the most relevant and one of several major messages delivered by these maps.

4. **Development of multiscalar statistical analysis methods for a better diagnosis of spatial trends and territorial impacts**. In statistical terms, we suggest to develop the use of tools like GWR or spatial autocorrelation methods which explore the relation between statistical parameters at different scales. As explained in part 2, they are many situations where two phenomena A and B does not display the same level or sign of correlation according to the scale of observation. For example, we can observe spatial segregation and territorial imbalances at local level which disappear at the regional one. We can also determine that structural funds are positively correlated with economic growth in certain part of the European territory and not in others. Multilevel statistical methods are crucial for the development of taylor-made strategies of spatial development which take into account the local contexts and not only the average trends of ESPON territory.

5. **Enlarging scales of analysis in both directions : toward more local and more global levels**. Spatial differences have been sometimes compared to waves of different frequencies (Tobler) and the question of MAUP can be understood as a confusion between different frequencies producing noise in the perception of the message (e.g. NUTS 3 is very "noisy"). Following this comparison, we can state that the actual research develop in ESPON is limited to a relatively narrow band of spatial frequencies (between regional and European levels) which means that many messages are not interpreted and used because they are related to highest (World) or lowest (local) frequencies. It is true that the actual band of frequency (regional-European) is the core of the mission of ESPON, but the interpretation of this band would be much accurate with additional information on World dynamics and local dynamics. It means that, on the one hand, it is necessary to maintain research on the situation of Europe in the world (database at state levels) and, on the other hand, it is necessary to develop case studies at local level (database at LAU1 and LAU2 levels). *"Broadband spatial planning"* is certainly a major challenge for ESPON II.

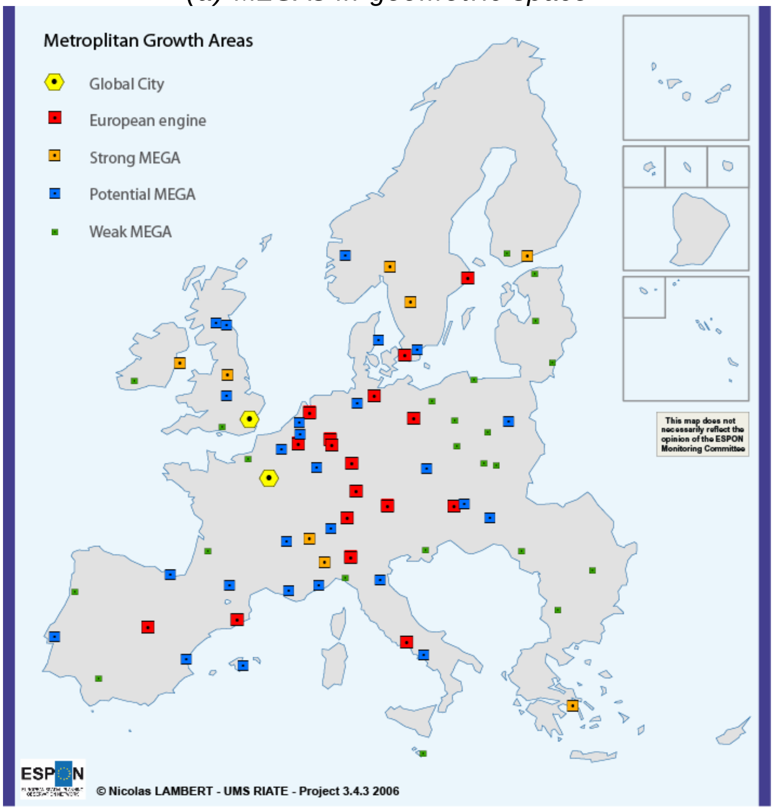
6. **Avoiding scientific support studies realised in too short term with not sufficient budget and too complicated administrative rules.** As last recommendation, not directly related to the MAUP, we would like to underline that the realisation of this project was a scientific dream (cooperation of 7 excellent European research teams which agreed to work for minor allocation of funds) and an administrative nightmare (complexity of ESPON rules and importance of administrative fees as compared to the real allocation of funds). Without the help and comprehension of ESPON coordination Unit (thanks to P. Mehlbye, S. Ferrara and S. di Biaggio) we would not have been able to achieve the project in a reasonable delay. We strongly suggest in future ESPON II to avoid such situation and either (1) to launch small studies with minimum administrative constraints (one partner and subcontractants) or (2) to launch bigger projects of scientific support with several partner but with more important funds and to be realised in a longer period.

If the previous recommendations are adopted by ESPON II, the "Modifiable Area Unit" will be a major factor of progress for the ESPON community. Expected progress will not be purely "technical" but also scientific and political, as it can be illustrated by the question of polycentrism (Figure 94).

It is generally admitted that the Metropolitan Growth areas are spatially concentrated in the Pentagon or in the "blue banana" but this is not a good formulation of the problem. What is concentrated in the pentagon is the wealth and the distribution of MEGAs is determined by the distribution of wealth. If one analyse the distribution of MEGAs in an econometric space (area proportional to GDP), the distribution is nicely regular and is NOT concentrated in the Pentagon or the blue banana. What is at stake from political point of view is therefore NOT to develop new metropolitan areas in the periphery but rather to develop economic growth in the peripheral areas of ESPON. The development of new MEGAs in the periphery will be the consequence of a better repartition of wealth and it does not make sense to "force" the development of new metropolitan areas in territories where the economic basis is not sufficient.

Innovative maps - or innovative statistical tools- are not "funny illustration" but crucial tools for scientific research and political decision. It is an important lesson to keep in mind for ESPON II.

(a) MEGAs in geometric space



(b) MEGAs in economic space

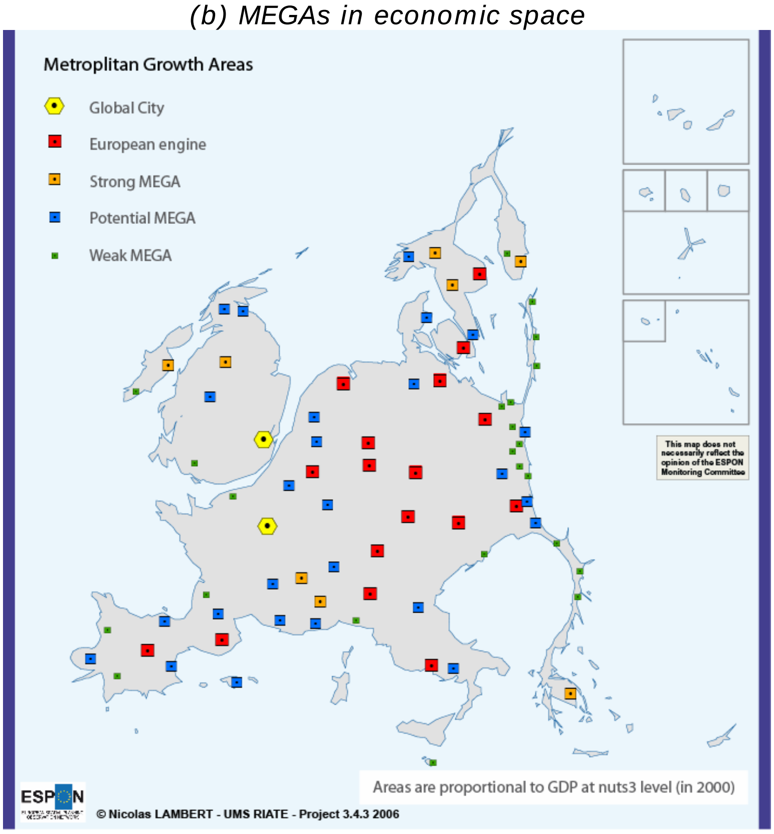


Figure 85 Comparison between distribution of MEGAs in geometric and economic space

References

AMRHEIN C.G. and REYNOLDS H., 1996, Using spatial statistics to assess aggregation effects. *Geographical Systems*, Vol. 3: 143-158.

AMRHEIN C.G., 1995, Searching for the elusive aggregation effect: Evidence from statistical simulations. *Environment and Planning A*, 27: 105–119.

ANDRIENKO G. and ANDRIENKO N. (forthcoming), Exploring spatial data with dominant attribute map and parallel coordinates. *Computers, Environment and Urban Systems*, 25.

ANDRIENKO G. and ANDRIENKO N., 1999, Interactive maps for visual data exploration. *International Journal of Geographical Information Science*, 13 (4): 355-374.

ANDRIENKO N. and ANDRIENKO G., 1997, Intelligent cartographic visualization for supporting data exploration in the IRIS system. *Programming and Computer Software*, 23 (5): 268-282.

ANDRIENKO G. and ANDRIENKO N., 1999a, Data Mining with C4.5 and Cartographic Visualization. In: *UserInterfaces to Data Intensive Systems*, Paton N. W. and Griffiths T. (eds.), IEEE Computer Society Los Alamitos, CA: 162-165.

ANDRIENKO N. and ANDRIENKO G., 1999b, Data characterization schema for intelligent support in visual data analysis. In: *Spatial Information Theory – Cognitive and Computational Foundations of GIS COSIT'99* (Springer-Verlag Lecture Notes in Computer Science 1661): 349-366.

ANDRIENKO N. and ANDRIENKO G., 1999c, Knowledge-based visualization to support spatial data mining. In: *Advances in Intelligent Data Analysis, Proceedings of the Third International Symposium IDA-99*, Amsterdam (Springer-Verlag Lecture Notes in Computer Science 1642): 149-160.

ANDRIENKO N., ANDRIENKO G. and GATALSKY P., 2000a, Supporting visual exploration of object movement. In: *Proceedings of the Working Conference on Advanced Visual Interfaces AVI*, Palermo, Italy, ACM Press: 217-220, 315.

ANDRIENKO N., ANDRIENKO G. and GATALSKY P., 2000b, Visualization of spatio-temporal information in the Internet. In: *Proceedings of the DEXA'2000 Workshop on Web-Based Information Visualization*, Greenwich, IEEE CS Press

ANTONI J-P., KLEIN O. and MOISY S., 2004, Cartographie interactive et multimédia : vers une aide à la réflexion géographique. *Revue Cybergeo*, octobre 2004: 16 p.

ARBIA G., 1989, *Spatial data configuration in statistical analysis of regional economic and related problems*, Kluwer Academic Publisher

BBR (ed.), 2005, *ESPON project 3.1 – Integrated tools for European spatial development (2002-2004)*
http://www.espon.lu/online/documentation/projects/cross_thematic/index.html

BENALI H., ESCOFIER B., 1990, Analyse factorielle lissée et analyse factorielle des différences locales. *Revue de statistiques appliquées*, XXXVIII (2): 55-76.

BENENSON I., TORRENS P.M., 2004, *Geosimulation; Automata-based modeling of urban phenomena*, Wiley, 312p.

BERTIN J., 1967, *Sémiologie graphique: les diagrammes, les résaux, les cartes* , Paris, Mouton-Gauthier-Villars-Bordas, 431p.

BIVAND R., 1998, A review of spatial statistical techniques for location studies, http://www.nhh.no/geo/gib/gib1998/gib98-3/lund.pdf, unpublished

BLOK C., 1997, Dynamic visualization in a developing framework for the representation of geographic data. *Colloque "30 ans de sémiologie graphique"*, Paris, 12 p. http://www.cybergeo.presse.fr/revgeo/semiogra/block/cblock.htm

BOGOMOLOV N., RYLSKIY I. and TIKUNOV V., 2002, Creation of Anamorphoses-Based 3-D Pyramidal Block-Diagrams. Proceedings of the *ISPRS Symposia*, Ottawa, Canada, 9-12 July 2002.
http://www.isprs.org/commission4/proceedings02/paper.html

BRACKEN I. and MARTIN D., 1995, Linkage of the 1981 and 1991 Censuses using surface modeling concepts. *Environment and Planning A*, 27: 379-90.

BRACKEN I., 1991, The generation of socioeconomic surfaces for public policymaking. *Environment and Planning B*, 16: 307-25

BRUNSDON C., FOTHERINGHAM A.S. and CHARLTON M., 1999, Some notes on parametric significance tests for geographically weighted regression. *Journal of Regional Science*, 39: 497–524.

BRUNSDON C., FOTHERINGHAM A.S. and CHARLTON M., 2002, Geographically Weighted Summary Statistics – A Framework for Localised Exploratory Data Analysis. *Computers Environment and Urban Systems*, 26: 501-524.

BURA S., GUERIN-PACE F., MATHIAN H., PUMAIN D. and SANDERS L., 1996, Multi-agents system and the dynamics of a settlement system. *Geographical Analysis*, vol. 28, 2: 161-178.

CARTWRIGHT W. and GARTNER G., 1999, PostScript to Multimedia Cartography. In: *Multimedia Cartography*, Peterson M. P. Cartwright W., Gartner G (eds.), Springer: 327-337.

CARTWRIGHT W. and HUNTER G., 1999, Enhancing Geographical Information ressources with Multimedia. In: *Multimedia Cartography*, Peterson M.P., Cartwright W., Gartner G. (eds.), Springer: 257-270.

CARTWRIGHT W. and PETERSON M.P., 1999, Multimedia Cartography. In: *Multimedia Cartography*, Peterson M.P., Cartwright W., Gartner G. (eds.), Springer: 1-10.

CARTWRIGHT W., 1994, Interactive Multimedia for Mapping. In: *Visualization in Modern Cartography*, MacEachren A.M. and Fraser Taylor D.R. (eds.), Oxford, Pergamon: 63-89.

CARTWRIGHT W., PETERSON M.P. and GARTNER G. (eds.), 1999, *Multimedia Cartography*, Springer: 343 p.

COURGEAU D. and BACCAÏNI B., 1997, Analyse multiniveau en sciences sociales. *Population*, 4 : 831-864.

CURS (ed.), 2005, *ESPON project 1.1.2 - Urban-rural relations in Europe (2002-2004)* http://www.espon.lu/online/documentation/projects/thematic/thematic_7.html

DIBIASE D., MACEACHREN A.M., KRYGIER J.B. and REEVES C., 1992, Animation and the role of map design in scientific visualisation. *Cartography and Geographic Information Systems*, 19 (4): 201-214.

DIBIASE D., REEVES C., MACEACHREN A.M., WYSS M.V., KRYGIER J.B., SLOAN J.L. and DETWEILER M.C., 1994, Multivariate Display of Geographic Data: Applications in Earth System Science. In: *Visualization in Modern Cartography*, MacEachren A.M. and Fraser Taylor D.R. (eds.), Oxford, Pergamon: 1-12.

DING C., 1994, Impact analysis of spatial data aggregation on transportation forecasted demand: a GIS approach. *Proceedings of the 1994 Urban and Regional Information System Association (URISA) Conference*; pp362-375

DING Y. and FOTHERINGHAM A.S., 1992, The Integration of Spatial Analysis and GIS, *Computers, Environment and Urban Systems*, 16: 3-19.

DORLING D., 1992, Stretching Space and Splicing Time: From Cartographic Animation to Interactive Visualization. *Cartography and Geographic Information Systems*, Vol. 19, 4: 215-227, 267-270.

DORLING D., 1993, Map design for census mapping. *The Cartographic Journal*, 30: 167-183.

DORLING D., 1994, Cartograms for visualizing human geography. In: *Visualization in Geographic Information Systems*, Unwin D.J. and Hearnshaw H.M. (eds.), Wiley: 85-102.

DRANSCH D., 1999, Theoretical Issues in Multimedia Cartography. In: *Multimedia Cartography*, Peterson M.P., Cartwright W., Gartner G. (eds.), Springer: 41-50.

DUDLEY G., 1991, Scale, aggregation, and the modifiable areal unit problem. *The operational Geographer*, 9(3): 28-32.

DUNCAN C., 1997, Applying mixed multivariate multilevel models in geographical research. In: *Places and people: multilevel modelling in geographical research*, Westert G.P. and Verhoeff R.N. (eds), The royal Dutch Geographical Society: 9-20.

DUNGAN J.L., PERRY J.N., DALE M.R.T., LEGENDRE P., CITRON-POUSTY S., FORTIN M.-J., JAKOMULSKA A., MIRITI M. and ROSENBERG M.S., 2002, A balanced view of scale in spatial statistical analysis. *Ecography*, 25: 626-640.

DYN N., WAHBA G. and WONG W.H., 1979, Comment to Waldo Tobler's smooth pycnophylactic interpolation for geographical regions. *Journal of the American Statistical Association*, Vol. 74, 357: 530–535.

FOTHERINGHAM A.S. and WONG D.W.S., 1991, The modifiable areal unit problem in multivariate statistical analysis. *Environment and Planning A*, Vol.23: 1025-1044.

FOTHERINGHAM A.S., 1998, Trends in quantitative methods. II. stressing the computational. *Progress in Human Geography*, 22, 2: 283–292.

FOTHERINGHAM A.S., BRUNDSON C.F. and CHARLTON M.E., 2000, *Quantitative Geography: perspectives on spatial data analysis*, Sage, London: 270p

FOTHERINGHAM A.S., BRUNSDON C.F. and CHARLTON M.E., 1999, Geographically Weighted Regression: A Natural Evolution of the Expansion Method for Spatial Data Analysis, *Environment and Planning A*, 30: 1905-1927.

FOTHERINGHAM A.S., BRUNSDON C.F. and CHARLTON M.E., 2002, *Geographically weighted regression: the analysis of spatially varying relationships*, UK: Wiley and Sons, 269 p.

FOTHERINGHAM A.S., CHARLTON M.E. and BRUNSDON C.F., 2001, Spatial Variations in School Performance: a Local Analysis Using Geographically Weighted Regression. In: *Geographical & Environmental Modelling*, Vol. 5 : 43-66

FOTHERINGHAM A.S., DENSHAM J. and CURTIS A., 1995, The zone definition problem in location-allocation modelling. *Geographical Analysis*, n°27: 60-77.

FRANCOIS J.C., MATHIAN H., RIBARDIERE A. and SAINT-JULIEN T., 2003, *Les disparités des revenus des ménages franciliens en 1999: approches intercommunales et infracommunales et évolution des différenciations intercommunales 1990-1999*, Paris, Direction Régionale de l'Equipement d'Ile-de-France, 108 p.

GOODCHILD M., 1979, The aggregation problem in location-allocation. *Geographical Analysis*, Vol. 11: 240-255.

GOTWAY CRAWFORD C.A. and YOUNG L.J., 2004, A spatial view of the ecological inference problem. In: *Ecological Inference: New Methodological Strategies*, King G., Rosen O. and Tanner M. (eds.), Chapter 10: 233-234.

GRASLAND C., 1997, L'analyse des discontinuités territoriales: l'exemple de la structure par âge dans les régions européennes. *L'espace géographique*, 4: 1-18.

GRASLAND C., MATHIAN H. and VINCENT J.M., 2000, 'Multiscalar analysis and map generalisation of discrete social phenomena: Statistical problems and political consequences', *Statistical Journal of the United Nations*, ECE, 17, IOS Press, pp. 1-32.

GRIFFITH D.A, WONG D.W.S. and WHITFIELD T, 2003, Exploring relationships between the global and local regional measures of spatial autocorrelation. *Journal of Regional Science*, Vol 43, 4: 683–710.

GUEROIS M. and PAULUS F., 2002, Commune-centre, agglomération, aire urbaine : quelle pertinence pour l'étude des villes ?. *Cybergeo : Revue Européenne de Géographie*, n°212 : 18 p.
http://193.55.107.45/essoct/guerois/guerois.htm

HOLM E., HOLME K., MÄKILÄ K., MATTSON-KAUPPI M. and MÖRTVIK G., 2002, *The microsimulation model SVERIGE; content, validation and applications, SMC*, Technical report, CERUM Kulturgeografi, Kulturgeografiska Institutionen/SMC, Umea University, Umea, Sweden, (www.smc.kiruna.se)

HOLM E., HOLME K., MÄKILÄ K., MATTSSON-KAUPPI M. and MÖRTVIK G., 2002, *The SVERIGE spatial microsimulation model. Content, validation, and example applications*, Sweden: GERUM, 4.

HOLT D., STEEL D.G. and TRANMER M., 1996, Area homogeneity and the modifiable areal unit problem. *Journal of Geographical Systems*, 3:181-200.

HOLT D., STEEL D.G., TRANMER M. and WRIGLEY N., 1996, Aggregation and ecological effects in geographically based data, *Geographical Analysis*, 28: 244–261.

HORNER M.W. and MURRAY A.T., 2002, Excess commuting and the modifiable areal unit problem. *Urban Studies*, 39: 131–139.

HUNT L. and BOOTS B., 1996, MAUP effects in the principal axis factoring technique. *Geographical Systems*, Vol. 3: 101-121.

ITPS (ed.), 2005, *ESPON project 1.1.2 – The spatial effects of demographic trends and migration*
http://www.espon.lu/online/documentation/projects/thematic/thematic_75.html

JONES K. and DUNCAN C., 1995, Individuals and their ecologies: analysing the geography of chronic illness within a multilevel modelling framework. *Health and Places*, Vol. 1, 1: 27-40.

KING G., 1997, *A Solution to the Ecological Inference Problem: Reconstructing Individual Behavior from Aggregate Data*. Princeton University Press, Princeton, 346p.

KNUDSEN D.C., 1987, Computer-intensive significance – testing procedures. *The Professional Geographer*, Vol. 39: 208-214.

KOUSSOULAKOU A. and KRAAK M.-J., 1992, Spatio-temporal maps and cartographic communication. *The Cartographic Journal*, Vol. 29: 101-108.

KOUSSOULAKOU A., 1999, Geographical Reference in Multimedia Cartography. In: *Multimedia Cartography*, Peterson M.P., Cartwright W., Gartner G. (eds.), Springer: 281-290.

KRAAK M.-J. and ORMELING F.J., 1996, *Cartography: Visualization of spatial data*, Longman, 222 p.

KRAAK M.-J., 1999, Cartography and the Use of Animation. In: *Multimedia Cartography*, Peterson M.P., Cartwright W., Gartner G. (eds.), Springer: 173-180.

KRAAK M.-J., EDSALL R. and MACEACHREN A.M., 1997, Cartographic animation and legends for temporal maps: exploration and or interaction, 7 p.
http://www.itc.nl/~kraak/legends/

LANGFORD M., MAGUIRE D.J. and UNWIN D.J., 1991, The areal interpolation problem: estimating population using remote sensing in a GIS framework. Longman/Wiley. *Handling geographical information*, 55-77.

LANGLOIS P. and LAJOIE G., 1998, Cartographie par carroyage et précision spatiale. *Mappemonde*, 49 (1): 20-22.

MACEACHREN A.M. and GANTER J.H., 1990, A pattern identification approach to cartographic visualization. *Cartographica*, Vol. 27, 2: 64-81.

MACEACHREN A.M. and TAYLOR D.R.F., 1994, *Visualization in modern cartography*, Pergamon, Oxford: 345 p.

MACEACHREN A.M., 1991, The role of maps in spatial knowledge acquisition. *The Cartographic Journal*, Vol.28: 152-162.

MACEACHREN A.M., 1994a, Time as a cartographic variable. In: *Visualization in Geographic Information Systems*, Unwin D.J. and Hearnshaw H.M. (eds.), Wiley: 115-130.

MACEACHREN A.M., 1994b, Visualisation in modern cartography: Setting the agenda. In: *Visualization in Modern Cartography*, MacEachren A.M. and Fraser Taylor D.R. (eds.), Oxford, Pergamon: 1-12.

MACEACHREN A.M., 1995, *How maps work - representation, Visualization, and design*, Guilford, New York: 513 p.

MACEACHREN A.M., 1998, VISUALIZATION - Cartography for the 21st century, *Proceedings of the Polish Spatial Information Association conference*, Warsaw, Poland, 9 p.
http://www.geog.psu.edu/ica/icavis/poland1.html.

MACEACHREN A.M., BISHOP I., DYKES J., DORLING D. and GATRELL A., 1994, Introduction to advances in visualizing spatial data. In: *Visualization in Geographic Information Systems*, Unwin D.J. and Hearnshaw H.M. (eds.), Wiley: 51-59.

MARCEAU D., 1999, The scale issue in the social and natural sciences. *Can. J. Remote Sensing*, 25: 347–356.

MARTIN D. and BRACKEN I., 1991, Techniques for modeling population-related raster databases. *Environment and Planning A*, 23: 1065-1079.

MARTIN D., 1991, Representing the socioeconomic world. *Papers of the Regional Science Association*, 70: 325-335.

MARTIN D., 2000, *Census 2001: making the best of zonal geographies Paper* presented at The Census of Population: 2000 and Beyond, University of Manchester 22-23 June 2000, (http://www.ccsr.ac.uk/conference/Martinpap.doc) , 8p

MENNIS J., 2003, Generating Surface Models of Population Using Dasymetric Mapping. *The Professional Geographer*, 55(1): 31–42.

MOECKEL R., SCHÜRMANN C. and WEGENER M., 2002, Microsimulation of urban land use in Proceedings of *The 42nd Congress of the European Regional Science Association* (ERSA), Dortmund.

MURRAY A. and GOTTSEGEN J., 1997, The influence of data aggregation on the stability of p-median location model solutions. *Geographical Analysis*, 29: 200–213.

NAKAYA T., 2000, An information statistical approach to the modifiable areal unit problem in incidence rate maps, *Environment and Planning A*, 32: 91-109.

NELSON A., 2001, Analysing data across geographic scales in Honduras: detecting levels of organisation within systems. *Agriculture, Ecosystems and Environment*, 85: 107–131.

OPENSHAW S. and BAXTER R.S., 1977, Algorithm 3 – procedure to generate pseudo-random aggregations of n-zones into m-zones, where m is less than n. *Environment and Planning A*, 9: 1423–1428.

OPENSHAW S. and CLARKE G., 1996, Developing spatial analysis functions relevant to GIS environments. In: *Spatial Analytical Perspectives on GIS*, Fischer M., Scholten H. and Unwin D. (eds.), London, Taylor and Francis: 21–38.

OPENSHAW S. and RAO L., 1995, Algorithms for re-aggregating 1991 Census geography. *Environment and Planning A*, 27: 425-446.

OPENSHAW S. and TAYLOR J, 1999, A million or so correlation coefficients: three experiments on the modifiable areal unit problem. In: *Statistical applications in the Spatial Sciences*, Wrigley (ed.), Pion, Londres: 127-144.

OPENSHAW S., 1977, Optimal zoning systems for spatial interaction models. *Environment and Planning A*, 9: 169-184.

OPENSHAW S., 1981, Le problème de l'agrégation spatiale en géographie. *L'Espace Géographique*, 1: 15-24.

OPENSHAW S., 1984, The modifiable areal unit problem*. Concepts and Techniques in Modern Geography*, 38:40-41.

OPENSHAW S., 1994, A Concepts-rich Approach to Spatial Analysis, Theory Generation and Scientific Discovery in GIS Using Massively Parallel Computing. In: *Innovations in GIS*, Taylor and Francis:123-138.

OPENSHAW S., 1996, Using a geographical analysis machine to detect the presence of spatial clusters and the location of clusters in synthetic data. In: *Methods for Investigating Localised Clustering of Disease*, Alexander F.E. and Boyle P. (eds.), Lyon, France, IARC Scientific Publication, 135: 68-87.

OPENSHAW S., 1997, Developing GIS-relevant zone-based spatial analysis methods. In: *Spatial Analysis: Modelling in a GIS Environment*, Longley P. and Batty M. (eds.), New-York, John Wiley: 55-73.

OPENSHAW S., WAUGH D. and CROSS A., 1994, Some ideas about the use of map animation as a spatial analysis tool. In: *Visualization in Geographic Information Systems*, Unwin D.J. and Hearnshaw H.M. (eds.), Wiley: 131-138.

OPENSHAW S.,1994,. Two exploratory space-time-attribute pattern analysers relevant to GIS. In: *Spatial Analysis and GIS*, Fotheringham S. and Rogerson P. (eds.),Taylor and Francis, London: 83-104.

ORCUTT G.H., 1957, A new type of socio-economic system. *Review of Economics and Statistics*, 58: 773-797.

PAEZ A. and SCOTT D.M., 2004, Spatial statistics for urban analysis: A review of techniques with examples. *GeoJournal*, 61: 53–67.

PETERSON M.P., 1994, Spatial visualization through Cartographic Animation: Theory and Practice. *GIS/LIS*: 8 p. http://wwwsgi.ursus.maine.edu/gisweb/spatdb/gis-lis/gi94078.html

PETERSON M.P., 1995a, Evaluating a Map's Image. *The American Cartographer*, Vol. 12, 1:41-45.

PETERSON M.P., 1995b, *Interactive and Animated Cartography*, Prentice Hall, Geographic Information Science, 257 p.

PETERSON M.P., 1996, Between Reality and Abstraction: Non-Temporal Applications of Cartographic Animation, Web, 6 p. http://maps.unomaha.edu/books/IACart/AnimArt/article.html

PETERSON M.P., 1997, Cartography and the Internet: Introduction and research Agenda. *Cartographic perspectives*, NACIS Society, 26 : 3-12. http://maps.unomaha.edu/NACIS/CP26/article1.html

PETERSON M.P., 1999, Elements of Multimedia Cartography. In: *Multimedia Cartography*, Peterson M.P., Cartwright W. and Gartner G (eds.), Springer: 31-40.

PEUCKER T.K., FOWLER R.J., LITTLE J.J. and MARK D., 1978, Digital representation of three-dimensional surfaces by triangulated irregular networks (TIN). *Proceedings Digital Terrain Modeling Symposium*, May 1978, ASP: 516–540.

POVRAY, 2006, http://www.povray.org

RASE W.D., 1998, Modellierung und Darstellung immaterieller Oberflächen. Forschungen des BBR, Band 89, Bundesamt für Bauwesen und Raumordnung, Bonn, Germany

RASE W.D., 1999, Volumenerhaltende Interpolation von Kontinua aus polygonbezogenen Daten. In: *Visualisierung raumbezogener Daten: Methoden und Anwendungen*, Schmidt B., Uhlenküken C., IfGIprints, 6: 73–88.

RASE W.D., 2001, Kartographische Anamorphosen und andere nichtlineare Darstellungen, *Kartographische Bausteine*, Band 19, TU Dresden, Institut für Kartographie (See Annex 3)

RASE W.D., 2006, Cartographic Anamorphoses and Cartogram. Communication presented at the *Berder Scientific Workshop*, 3-5 April 2006, CNRS, France

RAVENEL L., 2003, Dossier pédagogique : la présence d'étrangers entraîne-t-elle le vote pour l'extrême droite. *Espace, populations, sociétés*, 3: 541-547.

RENKA R.J., 1988, Algorithm 660: QSHEP2D, Quadratic Shepard method for bivariate interpolation of scattered data. *ACM Transactions on Mathematical Software*, Vol. 14, 2: 149–150.

RENKA R.J., 1996, Algorithm 751: TRIPACK: a constrained two-dimensional Delaunay triangulation package. *ACM Transactions on Mathematical Software*, Vol. 22, 1: 1–8.

RENKA R.J., 1999a, Algorithm 790: CSHEP2D: Cubic Shepard method for bivariate interpolation of scattered data. *ACM Transactions on Mathematical Software*, Vol. 25, 1: 70–73.

RENKA R.J., 1999b, Algorithm 791: TSHEP2D: Cosine series Shepard method for bivariate interpolation of scattered data. *ACM Transactions on Mathematical Software*, Vol. 25, 1: 74–77.

REYNOLDS H.D., 1998, The Modifiable Area Unit Problem: empirical analysis by statistical simulation, PhD Thesis, Toronto http://www.badpets.net/Thesis/index.html

ROBINSON W.S., 1950, Ecological correlations and the behavior of individuals. *American Sociological Review*, Vol. 15: 351-357.

RUPPERT J., 1995, A Delaunay refinement algorithm for quality 2-dimensional mesh generation. *Journal of Algorithms*, 18, 3: 548–585.

RUSHTON G., 1971, Map transformation of point patterns : central place pattern in areas of variable population density. *Papers and proceedings of the Regional Science Association*, 28: 111-129.

SANDERS L. *et al.*, 2006, Dynamics of the European urban network, in "Time-Geographical approaches to Emergence and Sustainable Societies (TiGrESS)", final report, (UE contract EVG3-2001-00024)

SANDERS L., FAVARO J.-M., MATHIAN H., PUMAIN D., GLISSE B., 2005, Intelligence artificielle et agents collectifs : le modèle EUROSIM, *Proceedings of the SAGEO conference 2005*, Josselin D. and Libourel T. (eds.), Avignon 21-23 juin 2005. (in press)

SERRHINI K., 2000, Evaluation spatiale de la covisibilité d'un aménagement. Sémiologie graphique expérimentale et modélisation quantitative. Thèse de doctorat, Tours, CESA: 481 p.

SHEWCHUK J.R., 1997, Delaunay refinement mesh generation. PhD Thesis, School of Computer Science, Carnegie Mellon University, Pittsburgh http://www.cs.cmu.edu/~quake-papers/delauney-refinement.ps.gz

STEEL D.G. and HOLT D., 1996, Rules for random aggregation. *Environment and Planning A*, 28: 957–978.

SUMMERFIELD M.A, 1983, Populations, samples, and statistical inference in geography. *Professional Geographer*, 35: 143-149.

TATE N.J. and ATKINSON P.M., 2001, *Modelling Scale in Geographical Information Science*, New York, Wiley and Sons: 292p.

TAYLOR P.J., 1977, *Quantitative methods in geography*, Waveland press.

TIKUNOV V., 1988, Anamorphosed cartographic images: Historical outlines and construction techniques. *Cartography*, 17, 1: 1-8.

TOBLER W., 1961, *Map transformation of geographic space*, Ph.D Thesis, University of Wisconsin, Seattle.

TOBLER W., 1979, Smooth pycnophylactic interpolation for geographical regions. *Journal of the American Statistical Association*, Vol. 74, 357: 519–535.

TOBLER W., 1989, Frame independent spatial analysis. In: *Accuracy of Spatial Databases*, Goodchild M., Gopal S. (eds.), CRC Press:115-122.

TOBLER W., 2004, Thirty-Five Years of Computer Cartograms. *Annals of the Association of American Geographers*, 94, 1: 58-73.

TOMLIN C.D., 1990, *Geographic Information Systems and cartographic modelling*. Prentice Hall, Englewood Cliff, NJ

TRANMER M. and STEEL D.G., 1998, Using census data to investigate the causes of the ecological fallacy. *Environment and Planning A*, 30: 817–831.

WADDELL P., 2000, A behavioral simulation model for metropolitan policy analysis and planning: residential location and housing market components of UrbanSim. *Environment and Planning B*, 27: 247-263.

WONG D.W.S., 1996, Aggregation effects in geo-referenced data. In: *Practical Handbook of Spatial Statistics*, Arlinghaus S.L., Griffith D.A., Drake W.D. and Nystuen J.D. (eds.), CRC Press, Boca Raton: 83–106.

WONG D.W.S., 2003, Spatial Decomposition of Segregation Indices: A Framework Toward Measuring Segregation at Multiple Levels. *Geographical Analysis*, Vol. 35, 3: 179-194.

WONG D.W.S., LASUS H. and FALK R.F., 1999, Exploring the variability of segregation index D with scale and zonal systems: an analysis of thirty US cities. *Environment and Planning A*, Vol. 32:507-522.

WRIGLEY N., 1995, Revising the modifiable areal unit problem and the ecological fallacy. In: *Festschrift for Peter Haggett* , Cliff A.D, Gould P R, Hoare A G and Thrift N J (eds.).

WU J. and LI H., 2006, Concepts of scale and scaling. In: *Scaling and Uncertainty Analysis in Ecology, Methods and Application*, Wu J., Jones K.B., Li H. and Loucks O.L. (eds.), Kluwer Academic Publishers: 351p.