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Spatial analysis of longevity in a Northern Italian region

Massimiliano Marino, Rossella Miglio, Rosella Rettaroli, Alessandra Samoggia
Department of Statistical Science, University of Bologna, Italy

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Abstract

It is well known that human longevity patterns show regional variations. Starting from this point, we applied different techniques of Spatial Analysis (based on Scan statistics) in Emilia Romagna, a Northern Italian region, to identify aggregations of areas (municipalities) characterized by a statistically significant level of the phenomenon. We identified areas with higher propensity to longevity in the South-eastern part of the region opposed to others in the North-eastern direction characterized by lower intensity of the phenomenon. Comparing the results of the different spatial scan statistic methods we have obtained a combined solution that could provide insight to identify possible longevity "clusters" and their persistence. These results are at first glance confirmed by lower standardized mortality rates in the areas of high longevity than in other parts of the region. On the whole, the results show the usefulness of spatial analysis in revealing geographical longevity patterns.

1. Introduction

The development of human longevity is certainly a relevant and widespread topic that has drawn the attention of researchers (demographers, gerontologists, geneticists, clinicians) in the recent decades. The growing interest in this subject is mainly due to the recent great increase of nonagenarians and centenarians, the so-called oldest olds in the developed countries (Kannisto 1988; Robine and Caselli 2005). The main aspects underlined by the literature relate to three important items at least. Firstly, previous studies on centenarians both in different countries and in various Italian regions have detected the existence of geographical areas where their number is higher than elsewhere (Caselli and Lipsi 2006; Montesanto et al. 2008). Secondly, an intriguing feature is that the female/male ratio among centenarians can vary enormously both in the level and in the direction: female/male ratios are usually 5-6:1 in developed countries but are, for instance, very different in two Italian regions: 2.7:1 in Sardinia and is 6.6:1 in Emilia-Romagna – (Robine and Caselli 2005). Finally, till now there is a widespread opinion that the existence of a greater or a lesser number of oldest olds largely depends on mortality features between 80 and 100 years (Kannisto 1994, 1996; Jeune and Vaupel 1995; Thatcher 2001). The explanatory analysis of disparities in the frequencies of the oldest-old population reminds of environmental and genetics features at a geographical level.

In order to deepen the different aspects of this complex phenomenon, one of the scientific approaches aims at mapping the geographical diffusion of extreme longevity using different methods of spatial analysis (SA) techniques in order to identify areas, or clusters of areas, characterized by particularly high, or low, concentration of oldest-old population. The resulting geography can be linked to different mortality features in terms of causes of death or of specific genetic structures (Caselli and Lipsi, 2006).

We know from the literature that the analysis of geographical distribution of biological, social, linguistic or survival variables constitute a very powerful instrument to disentangle complex traits in population processes. Even though there is relatively little in the literature devoted to the comparison of the results obtained by different methods.

In the first part of this study we attempt to draw a spatial representation of longevity in an Italian region, Emilia Romagna, characterized by a deep ageing process and by a great amount of elderly population. In particular, we want to know if propensity to longevity patterns is homogeneous within Emilia Romagna region; if that is not the case, we want to know where longevity is mostly concentrated. So, we analyze the propensity to longevity in the region identifying aggregations of areas characterized by a significant level of the phenomenon; we carry on preliminary information for successive studies and surveys (multidisciplinary fields: genetics, biology and demography); we use new spatial clustering methodologies and make a comparison by the obtained results.

The second part is devoted to a description of mortality profile in the region and to a first attempt in analyzing the different causes of death of elderly population in order to verify if the greater or lesser number of oldest old is linked with specific death profiles.

2. Materials and Methods

2.1. Data

Emilia Romagna, one of the North-Eastern Italian regions (Figure 1), is appropriate for studies on longevity because it shows one of the oldest age structures in the world (with 22.6% persons aged 65+, and 6.8% persons aged 80+ in 2008 related to a total population of 4,275,802). The region is characterized by a great geographical variability: mountains, hills and a wide flat land, with a consequent heterogeneity in environmental context, social conditions and economic resources. Emilia Romagna area is split up into nine provinces (Piacenza, Parma, Reggio Emilia, Modena, Bologna, Ferrara, Ravenna, Forlì-Cesena, Rimini) and 341 municipalities (Figure 1).

Figure1 – Political and physical map of Emilia Romagna and its provinces

First of all, we need to choose an indicator of longevity that can allow us to measure the different diffusion of the phenomenon in the regional area. The choice has fallen on a modified version of the

Centenarian Rate (*CR*), proposed by Robine and Caselli (2005) and Robine *et al*. (2006). The CR permits to measure and compare the dimension of longevity in different areas by dividing the observed number of oldest old not by the number of birth in the corresponding generation, but by the number of survivors at the age 60 in the corresponding generation, in order to take into account the effects of the work-related migration. It is well known that in Italy, and in Emilia Romagna too, migration was very common, especially during working ages, and also among people who now belong to the oldest-old population. Using the CR is possible to remove the unknown influence of the migration process. The CR index is independent from the size of birth cohorts, infant mortality, past migrations, and policies of naturalization (Robine and Caselli 2005; Robine and Paccaud 2005).
We have adopted a modified version[1] of CR that we indicate as CR_{95+}. It is represented by the ratio between the number of individuals aged 95and over living in an area and the number of 55-59 years old persons living in the same area forty years earlier. Our hypothesis is that after the age of 55 years work-related migration becomes negligible. Therefore, following this approach, we assume that the individuals resident in an area 40 years before year *t*, are the population exposed to the "risk" of becoming long-lived or, similarly, that long-lived population observed in year *t* comes from the cohort of individuals resident 40 years earlier in the same area.
We use the official data from the 1961 Italian census and the population distributions by age and sex at the end of each calendar year for the period 2000-2004 for each municipality.
The 1961 census provides the number of individuals resident in each municipality of Emilia Romagna who were 55–59 years old, while the 2000-2004 dataset provides the number of individuals resident in each municipality who were 95+ years old in this period (Table1). The 95+ years old population amounts to 6,813 individuals, with a huge prevalence of women (5,509) compared with men (1,304), and a femininity ratio of nearly 4.22. With respect to mortality features we have used indicators obtained from the Regional Office of Statistics dataset on mortality by cause of death (Regione Emilia-Romagna, 2007).

Table 1 - Distribution of population at 95+ years in 2000-2004 and at 55-59 years in 1961, by provinces.

Provinces	**population 95+ years old in 2000-2004**					**population 55-59 years old in 1961**				
	Male		**Female**		**Total**	**Male**		**Female**		**Total**
	N	**%**	**N**	**%**	**N**	**N**	**%**	**N**	**%**	**N**
Piacenza	111	8.5	457	8.3	568	8,917	8.7	9,294	8.5	18,211
Parma	136	10.4	656	11.9	792	11,879	11.6	12,499	11.5	24,378
Reggio Emilia	118	9.0	591	10.3	688	11,036	10.8	11,689	10.8	22,725
Modena	170	13.0	714	13.0	884	14,219	13.9	14,559	13.4	28,778
Bologna	318	24.4	1,346	24.4	1,664	24,058	23.5	26,728	24.6	50,786
Ferrara	87	6.7	417	7,6	504	11,156	10.9	11,828	10.9	22,984
Ravenna	168	12.9	591	10.7	759	9,003	8.8	9,005	8.3	18,008
Forlì-Cesena	119	9.1	469	8.5	588	7,809	7.6	8,294	7.6	16,103
Rimini	77	5.9	289	5.2	366	4,437	4.3	4,808	4.4	9,245
Emilia-Romagna	**1,304**	**100.0**	**5,509**	**100.0**	**6,813**	**102,514**	**100.0**	**108,704**	**100.0**	**211,218**

[1] The change we have introduced concerns the ages involved in the index: instead of centenarians, we have considered all the population older than 94 years, in order to avoid inconsistency or lack of data in some municipality.

2.2. Spatial clustering methods based on Scan statistics

Spatial analysis refers to a variety of techniques aimed at defining the spatial location of the units under study, and extracting or creating new information about a set of geographical features.
The scan statistic is designed to detect a local excess of events and to test if such an excess can reasonably have occurred by chance.
We assume that an area is divided into M regions, with a total population N and C total cases. Defining the zone Z as any set of connected regions, the objective is finding, among all the possible zones, which one maximizes a certain statistic, thus defining the most likely cluster. Under the null hypothesis (there are no clusters in the map), the number of cases in each region follows a Poisson distribution. Define L(Z) as the likelihood under the alternative hypothesis that there is a cluster in the zone Z, and L_0, the likelihood under the null-hypothesis. The zone Z with the maximum likelihood is defined as the most likely cluster. If μ_Z is the expected number of cases inside the zone Z under the null hypothesis, c_Z is the number of cases inside Z, $I(Z)=c_Z/\mu_Z$ is the relative incidence inside Z, $O(Z)=C- c_Z/(C-\mu_Z)$ is the relative incidence outside Z, it can be shown that:
$LR(Z)=L(Z)/ L_0= I(Z)^{cZ} O(Z)^{C-\mu Z}$
when I(Z)>1, and 1 otherwise. The zone that constitutes the most likely cluster maximizes the likelihood ratio LR(Z) (Kulldorff, 1997).
To find the distribution of the test statistic under the null hypothesis, Monte Carlo hypothesis testing is required. The assessment of the statistical significance of the clusters is done through a process of Monte Carlo simulation by sampling the number of cases c_z expected in each area from a Poisson distribution with parameter $(C/N)n_z$ under the hypothesis of uniform distribution.
A complete scan of the collection of the possible zones searching for the most likely cluster is an infeasible task and several statistical methods have been suggested to obtain an approximate solution of this maximization based on a parameter-space reduction and/or stochastic optimization methods.
The spatial scan statistic proposed by Kulldorf has been applied to a wide variety of epidemiological studies for cluster detection. This method uses a circular (SSS) or elliptic (ESSS) window of variable size to define the potential cluster areas (Kulldorff, 1997, 2006). The size limit depends on the percentage of the population at risk that could be included in the window.
Using scanning window of regular shape results in low power for detection of irregularly shaped clusters. Different methods, also using the scan statistic, were proposed even recently to detect connected clusters of irregular shape.
Tango and Takahashi (2005) proposed a flexibly shaped scan statistic (FSC) that can detect irregular shaped clusters within relatively small neighborhood of each region. For each centroid a neighborhood is generated that include the K region closest to it; in this way the maximum size of the cluster is limited by the number K of considered areas.
Duczmal et al. (2007) penalize the zones in the map that are highly irregularly shaped through a measure of compactness and approach the problem of finding the most likely cluster by a genetic algorithm (GA) specifically designed for dealing with this problem structure. Increasing the compactness parameter determines cluster of more regular shape.
Yiannakoulias, Rosychuk and Hodgson (2007) propose to improve the effectiveness of irregular event cluster detection, through an adaptation of the methods of Tango, Duczmal and Kulldorff; this method (GGS) penalizes very irregular cluster shapes using a measure of connectivity (non-connectivity penalty) and reduce the research avoiding to combine smaller clusters into large super-clusters (depth limit); the depth limit parameter identifies the number of attempts that are needed to find adjacent areas that determine the greatest improve in the likelihood. Moreover the search process is controlled also by the maximum size of the clusters, expressed as the percentage of population at risk.

Even though several statistical methods have been suggested to assess the location of spatial clustering, there is relatively little in the literature devoted to the comparison of the results achieved from them. We chose to compare the different methods proposed for examining spatial disease/event patterns and based on a local test for clustering. Our proposal consists in a new procedure, based on multigraph theory, that combines the results obtained by these different methods.
The entire territory can be schematically represented by a graph whose vertex represent the centroid of municipalities while the edges represent the adjacency among them; then, a cluster is identified by a set of one or more adjacent areas that correspond to a geographical neighborhood. The solution obtained from the different methods could be represented through a graph.
A multigraph consists of the intersection of s graphs, with the same number of vertex, where an edge between two vertexes is present if it recurs at least a number t ($t \leq s$) of times in the single graphs. The value t represents the *t-projection* of the multigraph and is fixed a priori by the researcher.
We propose to use the concept of multigraph in order to compare the results obtained from the different methods and identify "persistent" areas characterized by particularly high level of longevity.

3. Results

The geographical analysis of the longevity distribution in Emilia Romagna has shown some peculiar features.
Table 2 reports some descriptive statistics related to the CR_{95+} index obtained at a municipality level and calculated by sex and province of residence.

Table 2 - Distribution of CR_{95+} by province and sex (M=male, F=female)

Province	Sex	Min	max	mean	SD	Median
Bologna	M	0	.0416667	.0147016	.0088715	.0127518
	F	.016	.1418919	.0581624	.0229648	.0547386
Modena	M	0	.0316456	.0129378	.0076358	.0124224
	F	.0074627	.0986547	.0506749	.0176711	.0480000
Reggio Emilia	M	0	.0310078	.0102410	.006831	.0104712
	F	.0211268	.0803571	.0496108	.0150538	.0466667
Parma	M	0	.0265487	.0100394	.0067707	.0106383
	F	.0217391	.1200000	.0503756	.0173047	.0472973
Forlì-Cesena	M	0	.0506329	.0156438	.0101545	.0133353
	F	.0178571	.0970464	.0522788	.0212019	.0522592
Ravenna	M	0	.0392157	.0190027	.0082512	.0179052
	F	.0353982	.1176471	.0699435	.0201155	.0692084
Ferrara	M	0	.0164835	.0073738	.0054926	.0069048
	F	.0088496	.0603015	.0343762	.0125037	.0342242
Rimini	M	0	.0396825	.0159398	.0119079	.0159086
	F	.0181818	.1168831	.0468307	.0230544	.043798
Piacenza	M	0	.080000	.0146121	.0144124	.0111166
	F	.009901	.0846154	.0467386	.0183961	.0474782
Region	M	0	.080000	.0130385	.0096639	.0119048
	F	.0074627	.1418919	.0509466	.0200846	.0480000

These results show mean and median values higher than the regional ones in the municipalities belonging to the provinces of Ravenna, Bologna and Forlì-Cesena. On the other side, the municipalities of the province of Ferrara are characterized by lower values of the CR_{95+} index, showing a scarce propensity to longevity.

When gender is considered, the areas of the Adriatic coast (the Eastern part of the region) still stand out for high values of CR_{95+} for both sexes: the province of Ravenna is characterized by the highest values compared to all other provinces. The municipalities of the province of Bologna are characterized by a high value of the female CR_{95+} while the province of Ferrara confirms its reduced longevity both for males and females.

We give now a brief description of the results obtained from the different spatial scan methods described in the previous paragraph.

First of all, some explanations on the choice of the required setting parameters are necessary.

Indeed, we have not an *a priori* information that could help us to set the parameters driving the spatial scan research: to offset this lack of information we considered a low presence of the phenomenon in the territory.

Furthermore we need to set the parameters of each method suitable to obtain comparable results. Several of the previously described methods require to limit the dimension of the cluster in order to obtain a predefined fraction of population at risk of presenting the phenomenon: we choose a 5% of risk in the overall population that correspond to the 90^{Th} percentile of the CR_{95+} index distribution. For the FSC method and for both sexes, we considered 17 municipalities as the maximum size of the cluster which includes the 5% of population at risk as in the other different methods we performed. Moreover, in order to control the shape of clusters defined through SSS, ESSS and FCS methods, we set the penalty parameter to 0 (no penalty), to 0.5 (intermediate penalty) and to 1(strong penalty).

With respect to the GGS method we need to specify two control parameter □(≥0) and *u* (≥1) related to the non connectivity parameter (it limits irregular shape in clusters) and the depth limit parameter (it controls the complexity and speed of the searching process). Simulations on our data lead us to consider suitable for our study the values of 1 and 2, respectively for these parameters. The *p*-value of the statistical test is based upon the null distribution of likelihood ratio test statistic obtained with 999 Monte Carlo replications of the data set generated under the null hypothesis.

Figures 2 to 7 show the results get for both sexes with the different methods (clusters of high longevity are reported in green color). We can observe that only municipalities belonging to four provinces contribute to the obtained clusters and particularly the municipalities of Bologna and Ravenna provinces; these latter municipalities are prevailingly located in piedmont and mountain zones. Tables 3 and 4 report the amount of municipalities grouped in each main cluster[2] by method and province, in the latter column relative risks and p-values are reported.

The SSS and ESSS methods determine also a complementary cluster characterized by a reduced risk of longevity for each sex (in dark red on the map). These clusters are both located in the province of Ferrara and are made up of 15 and 18 municipalities, for male and female respectively.

With respect to the different methods, the study shows that some provinces of the region compete among themselves in the process of defining the clusters. It should also be noted that the procedures for spatial clustering allow to identify possible combinations of municipalities, but they are unable to delineate the precise boundaries of real cluster.

Through the proposed procedure based on multigraph, we compare the different methods results in order to identify “persistent” areas. We used the 4-projection of multigraph (t = 4) or, equivalently, we considered edges that are present in at least 4 results out of 5 (80%). Accordingly, areas deemed "persistent" are identified by those municipalities present in at least 4 results out of 5. The choice of a particularly restrictive cut-off point is due to the need of localizing few geographic areas where the phenomenon is particularly relevant.

[2] The amount of secondary cluster is in brackets, when present.

Table 3 - Numbers of municipalities in each cluster by method and province, relative risk and p-value - Male

	Provinces										
	Bologna	Forlì-Ces.	Ravenna	Modena	Ferrara	Rimini	ReggioE	Parma	Piacenza	RR	p-value
Method											
SSS	19	1	6							1.66	0.008
ESSS	19	1	5							1.71	0.008
FSC	2(9)	1	12							1.53	0.001
GA	21		2							1.91	0.004
GGS	16			11						1.82	0.095
Multigraph											
Persistence of 80%	6		1							1.92	<0.001
Persistence of 60%	17		2							1.97	<0.001

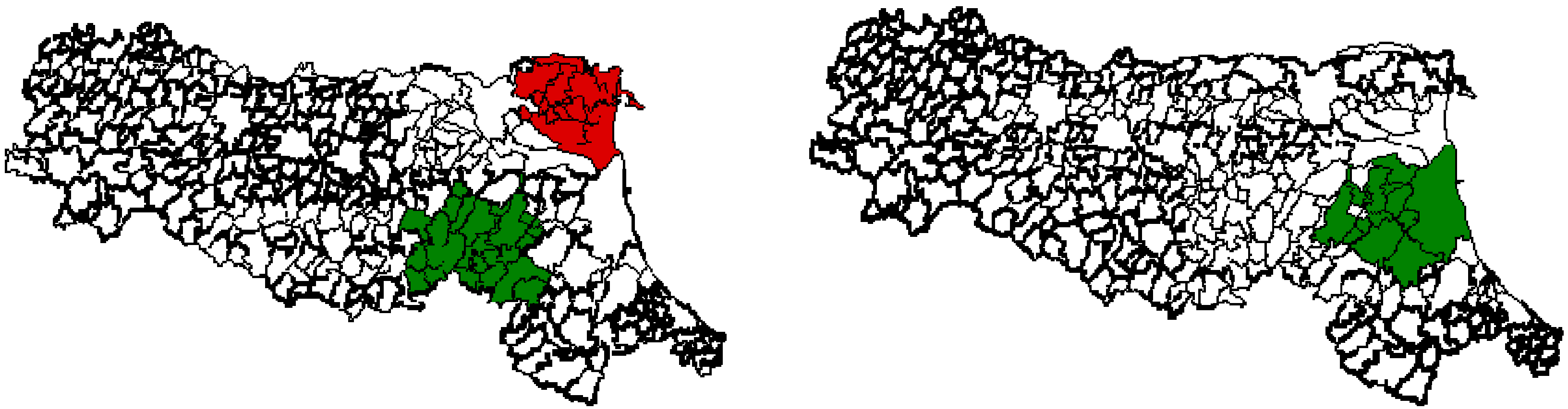
Table 4 - Numbers of municipalities in each cluster by method and province, relative risk and p-value - Female

	Provinces										
	Bologna	Forlì-Ces.	Ravenna	Modena	Ferrara	Rimini	ReggioE	Parma	Piacenza	RR	p-value
Method											
SSS	19	1	6							1.45	<0.001
ESSS	13	(6)	4(2)							1.51	<0.001
FSC	2(8)	1	12							1.33	0.001
GA	21		4							1.58	0.001
GGS	14			6						1.62	0.001
Multigraph											
Persistence of 80%	6		3							1.56	<0.001
Persistence of 60%	14		3							1.46	<0.001

This lead us to consider a cluster composed of 7 municipalities (6 belonging to Bologna and 1 to Ravenna) for males and 9 municipalities for female (6 belonging to Bologna and 3 to Ravenna) as shown in Tables 3 and 4. In the same tables we have reported also the increased dimension and composition of the persistent clusters that could be obtained if we consider a persistence of 60%, that is 3 methods on 5 are consistent in determining an edge between pairs of vertex. It is important to note that the solution obtained from multigraph allow us to identify two clusters for each considered scenario.

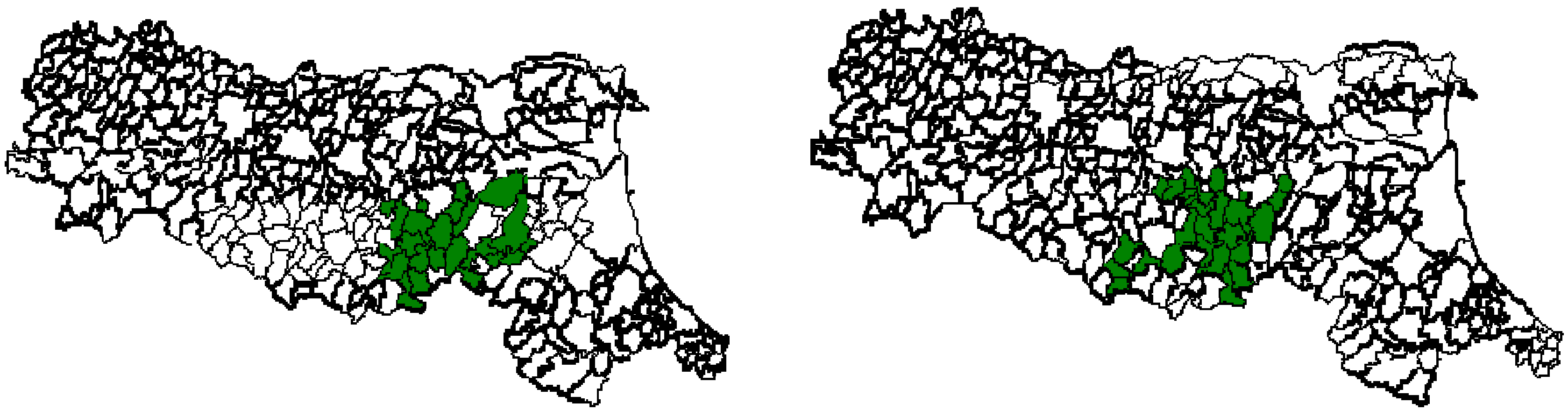
The analysis of the relative risks (RR) related to the persistent clusters highlights a greater value for male than female, and this fact underlines a stronger contrast for male among high longevity areas and all other areas.

Finally, it is interesting to note that the male persistent cluster (at 80% level) and the female one share five municipalities, 4 belonging to the Bologna province and 1 to Ravenna.



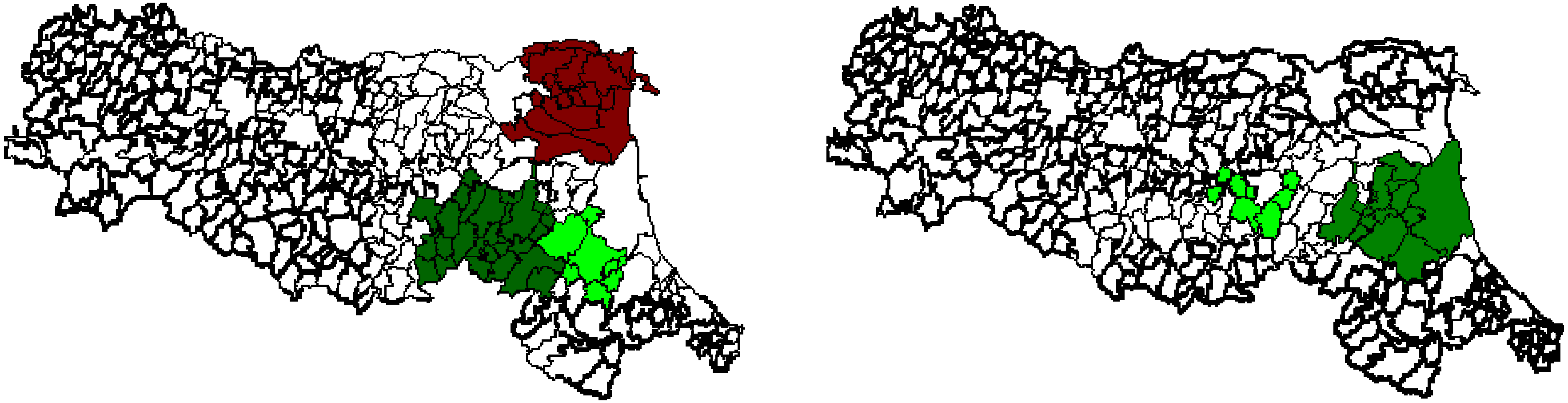
a) b)

Figure 2 – a) Map of male CR_{95+}; SSS method of detection. Circular cluster. (green=high longevity, red=low longevity);
b) Map of male CR_{95+} ;FSC method. Primary cluster.



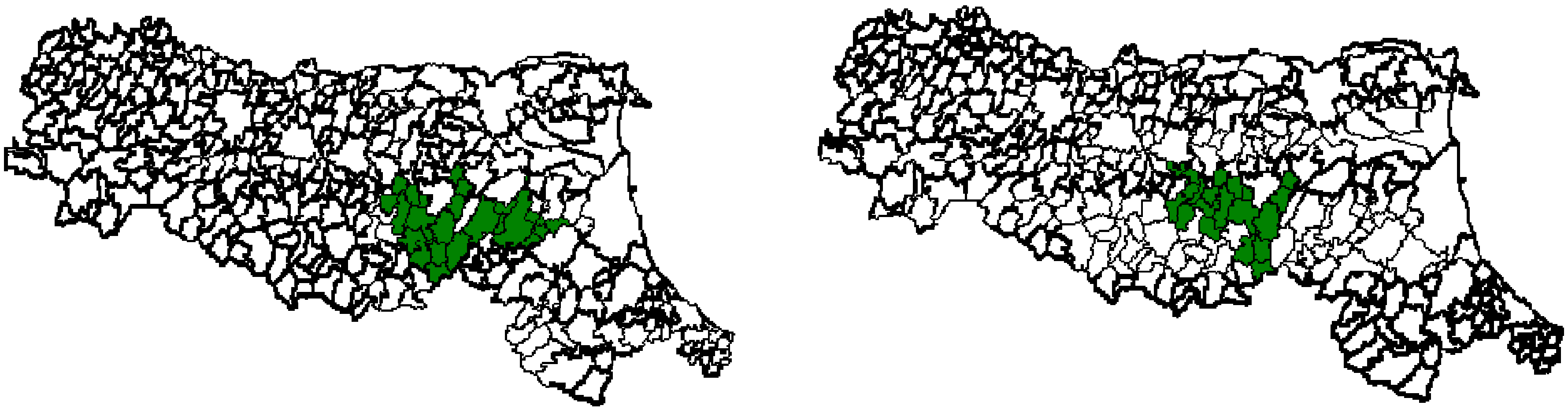
a) b)

Figure 3 – a) Map of male $CR_{95+;}$ GA method. Non-compactness penalty a=0.5;
b) Map of male CR_{95+}; GGS method.



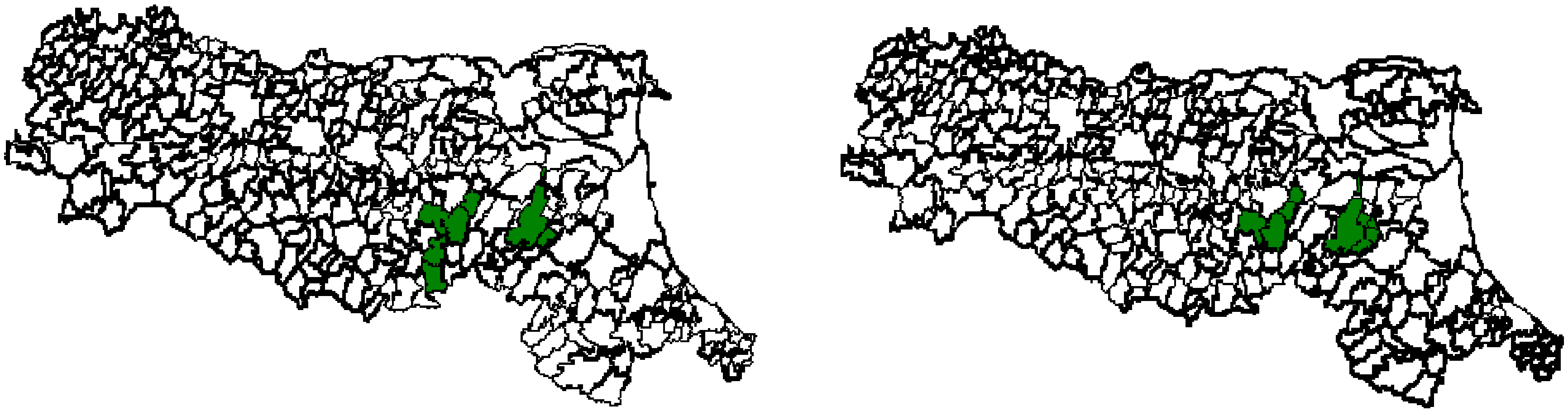
a) b)

Figure 4 – a) Map of female CR_{95+}; SSS method. Circular cluster. (green=high longevity, red=low longevity (secondary), light green=high longevity (secondary));
b) Map of female CR_{95+}; FSC method. (dark green=high longevity (primary), light green=high longevity)



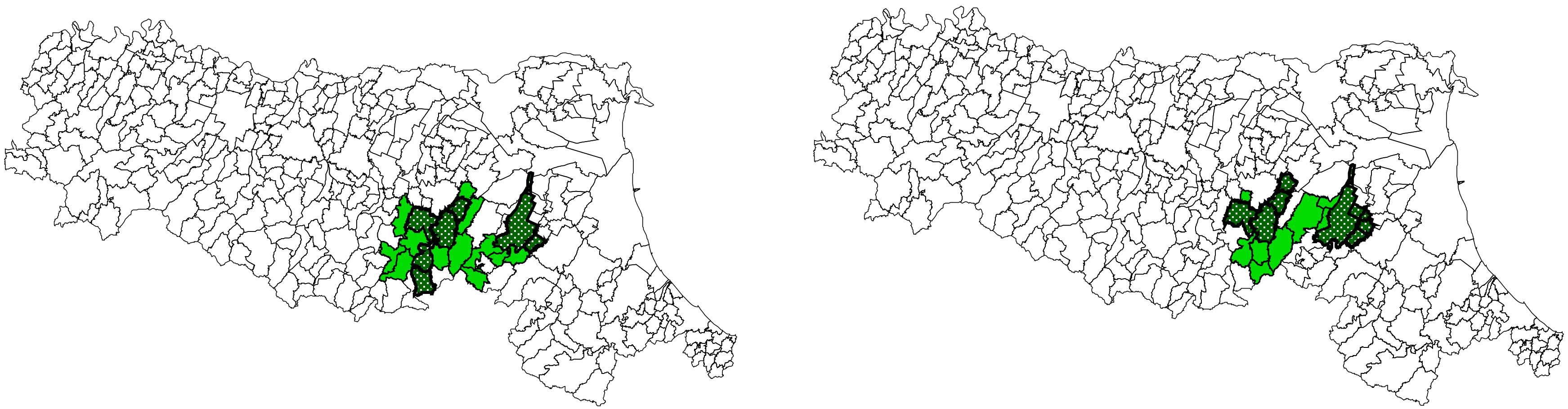
a) b)

Figure 5 – a) Map of female CR_{95+}; GA method. Non-compactness penalty a=0.5;
b) Map of female CR_{95+} ;GGS method.



a) b)

Figure 6 – a) Map of male CR_{95+} Persistent cluster (80%);
b) Map of female CR_{95+} .Persistent cluster (80%).



a) b)

Figure 7 – a) Map of male CR_{95+}. Persistent cluster at 60% (the dark areas are persistent at 80%);
b) Map of female CR_{95+}. Persistent cluster at 60% (the dark areas are persistent at 80%).

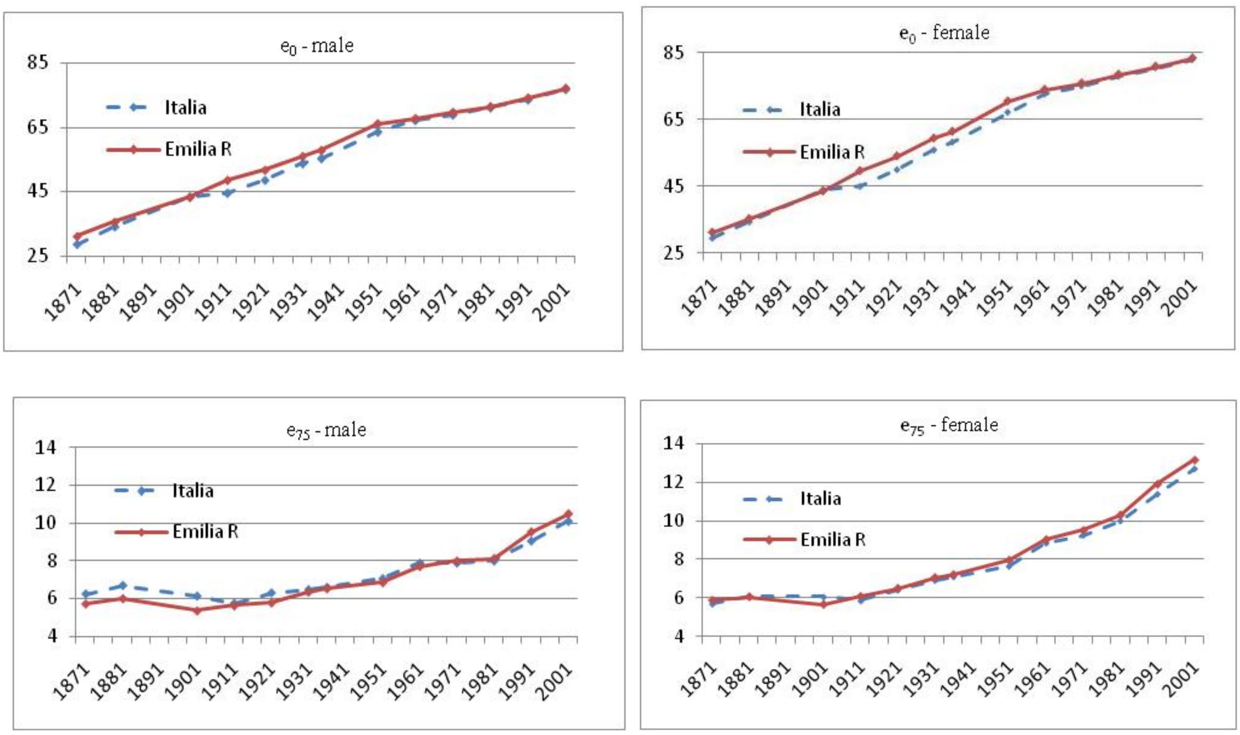
4.A glance at mortality in Emilia-Romagna

There is a widespread opinion that the existence of a greater or a lesser number of long-lived persons probably depends on mortality features at younger ages. In our study we suppose that the number of individuals aged 95 and over could depend, among others, on mortality between 75 and 95 years. In this part we try to cast a glance at our knowledge of elderly mortality differentials by cause of death, in Emilia Romagna, and attempt to verify if there are some similarities between the geography of longevity and that of some mortality features. To do so, a first and explorative attempt of analysis is conducted on causes, age and sex mortality distributions at municipal level. Results don't always confirm our expectations. As in the previous case, our units of analysis are provinces and municipalities.

To offset problems of differentials in demographic features and population heterogeneity and to detect similarities in mortality within the regional area, we have performed a spatial analysis of mortality after age 75. We used municipal standardized mortality ratios (SMR) calculated by the Emilia Romagna Statistical Office to define the regional *Atlas of mortality* for the period 1998-2004 (Regione Emilia-Romagna, 2007). This time interval overlaps well that of longevity indicator used in the previous parts of the paper.

SMRs by age groups are particularly suited in mortality mapping due to the fact that these ratios are the maximum likelihood estimations of relative risks when death events could be considered a realization of a Poisson distribution. Maps based on SMR are affected by unexplained variability and don't allow any easy detection of the geographical risks distribution. Several statistical models have been developed to deal with these problems: among them, Bayesian models have a leading position (Mollié 1996). We used a hierarchical Bayesian model based on the conditional autoregressive (CAR) process that spatially smooths SMR or risk estimates by allowing each site to borrow strength' from its neighbours.

Generally speaking, Emilia- Romagna shows a profile of age mortality below the national level for both sexes at the onset of the 21st century (Figure 8).



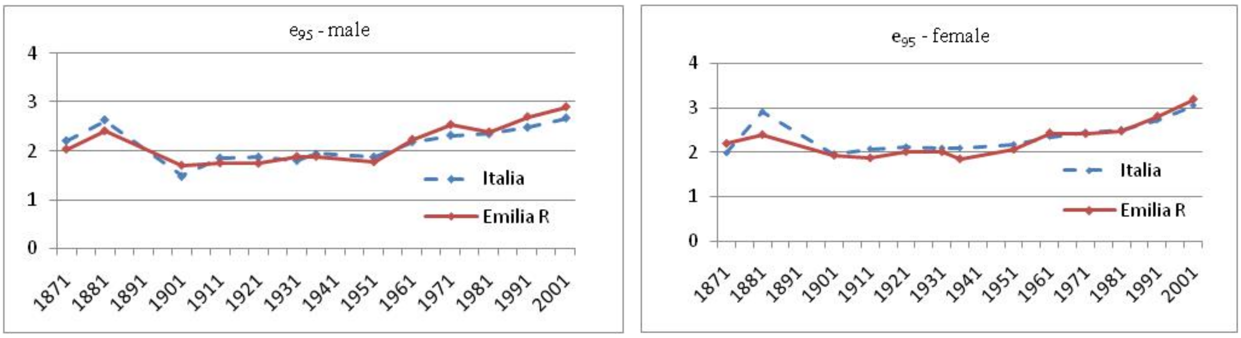


Figure 8 – Life Expectancies in Emilia Romagna and Italy at different ages (1871-2001)

Nevertheless literature on this topic reports that if specific causes of death are considered, the analysis of regional standardized mortality rates (from 1986 to 2004) shows for cancers a decreasing trend but still markedly above the national level for women and slightly above for men. As far as the other death causes are concerned, the Emilia-Romagna trend is nearly always below the national feature and decreasing with time. Some exceptions are represented by infarction – the standardized rate is the same as the national one - and other heart ischemic diseases - that do not present relevant variation in the considered period.

Table 5 - Life expectancies at 0 and 75 years in 1998 and in 2004 - Emilia Romagna by province.

	1998						**2004**					
	e_0		**e_{75}**		**e_{95}**		**e_0**		**e_{75}**		**e_{95}**	
Province	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**
Piacenza	74.9	81.5	9.9	12.6	2.6	2.8	77.3	83.5	10.1	13.4	2.7	4.2
Parma	75.8	82.3	9.8	12.5	2.0	2.7	77.8	83.6	10.8	13.6	2.9	3.6
Reggio Emilia	76.3	82.2	9.7	12.7	2.9	2.8	78.9	84.7	10.8	14.1	2.8	4.3
Modena	75.6	82.2	9.9	12.7	2.4	2.9	78.5	84.2	10.7	13.7	2.9	3.7
Bologna	76.4	82.2	10.0	12.6	2.5	2.8	78.9	84.2	11.0	13.8	3.0	4.1
Ferrara	74.6	81.8	9.5	12.1	2.0	2.4	76.8	82.9	10.1	13.0	2.8	3.3
Ravenna	76.6	82.8	10.5	13.2	2.6	3.4	79.3	84.3	11.6	14.0	3.2	3.6
Forlì-Cesena	77.2	82.7	10.3	13.0	2.3	3.2	79.2	85.1	10.9	14.3	3.4	4.2
Rimini	76.3	82.8	9.8	12.7	3.3	2.4	79.0	84.5	11.0	13.9	2.9	4.2
Emilia Romagna	76.0	82.2	9.9	12.6	2.4	2.8	78.5	84.1	10.8	13.6	2.9	3.4

The analysis on geographical sub-areas shows a certain homogeneity in all-causes mortality; some statistically significant mortality excesses, however, are recorded in the provinces of Piacenza and Ferrara and in the mountain areas of those of Parma and Bologna, while the Romagna mortality level is below the regional one. Such distribution is confirmed also for the main cause of death (over all cardiovascular diseases); others are characterized by specific geographical distributions that demonstrate the presence of particular patterns of risk factors: lung cancers (in particular provinces of Ferrara and Piacenza), stomach cancers (Romagna, particularly in the mountain areas), liver cancer (high risk in the provinces of Piacenza and Parma) and car accidents (mainly along the Adriatic coast).

If we refer to the total population and examine SMR values(Tables 6 and 7), we can see that the provinces of Cesena, Forlì, Rimini, Ravenna, Bologna and Reggio Emilia are characterized by a lower mortality than the regional level. On the contrary the highest mortality features are found in the provinces of Ferrara, Piacenza and Parma. When gender is taken into account, both male and female mortality appear higher in the provinces of Parma, Piacenza and Ferrara.

Table 6 – Absolute number of deaths, crude death rates and standardized mortality rates (x 100,000 inhabitants) in 2004. Males

Province	Deaths	Crude rate	Standardized rate	Standard Error
Piacenza	1,712	1,286.68	1,172.42	28.48
Parma	2,322	1,157.46	1,107.53	23.11
Reggio Emilia	2,339	974.38	1,048.49	21.81
Modena	3,274	1,011.48	1,068.42	18.79
Bologna	5119	1125.744	1032.4	18.775
Ferrara	2,184	1,306.65	1,180.94	25.56
Ravenna	1,930	1,087.39	958.78	21.98
Forlì-Cesena	1,843	1038.612	990.58	32.773
Rimini	1,321	946.71	1,036.08	28.80
Emilia-Romagna	22,044	1092.5	1058.6	7.2

Table 7 – Absolute number of deaths, crude death rates and standardized mortality rates (x 100,000 inhabitants) in 2004. Females

Province	Deaths	Crude rate	Standardized rate	Standard Error
Piacenza	1,717	1220.8	1078.0	26.1
Parma	2,533	1191.6	1098.5	21.9
Reggio Emilia	2,371	960.3	1017.0	21.0
Modena	3,260	969.7	1035.0	18.2
Bologna	5,431	1110.3	1041.4	19.0
Ferrara	2,249	1231.4	1131.9	24.1
Ravenna	2,033	1082.1	1006.3	22.4
Forlì-Cesena	1,800	966.1	966.5	32.3
Rimini	1,288	873.8	1002.0	28.1
Emilia –Romagna	22,682	1063.1	1042.4	7.0

The subsequent figures for females and males allow us to make a comparison between the municipality and province map of Emilia Romagna and the all-cause and some cause-specific mortality for the 75 and over population in 1998-2004 years.

Female 75+ **Male 75+**

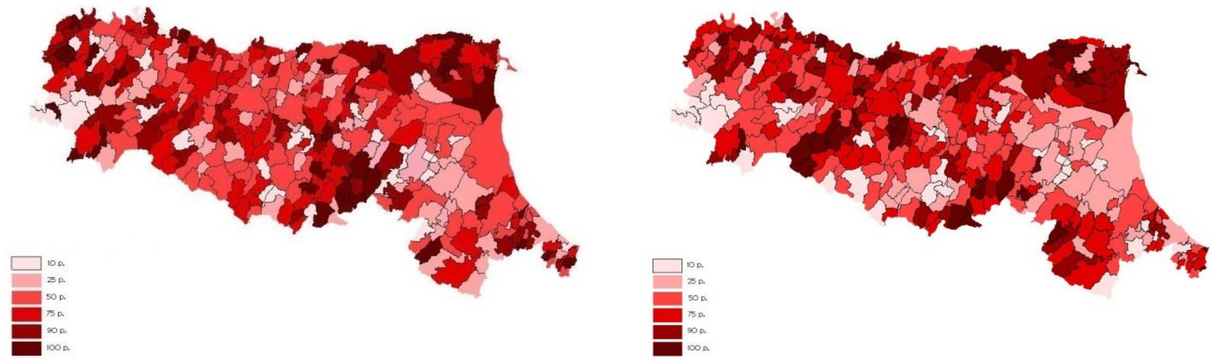


Figure 9 - SMR estimates for all-cause in female and male population aged 75+.

The geography of all-cause mortality (Figure 9) highlights some interesting points. First, as was mentioned above, similarities among the provinces and municipalities may conceal different realities. For example, for men and women, the areas comprising the municipalities of Ferrara (with low life expectancy at age 75, see Table 5) show high mortality. A second area of interest is that comprising the municipalities of Bologna province for women, which show high mortality as in the previous example.

Third, an area of low male and female mortality is situated in the mountain zones of the province of Piacenza, even if Piacenza shares the lowest expectation of life with Ferrara.

A comparison by sex shows that low mortality zones only partially overlap. Substantial differences occur for the province of Bologna characterized by the highest female and a medium male mortality.

To identify which causes of death are responsible of this pattern, the geography of all-cause mortality can be compared with mortality from both cardiovascular and cancer diseases.

These two causes of death account for 56% of the total deaths for population aged 65+ and for 60% of the total deaths for population aged 80+ and can be considered as the more representative for the elderly population.

a) cancers - female b) cancers - males

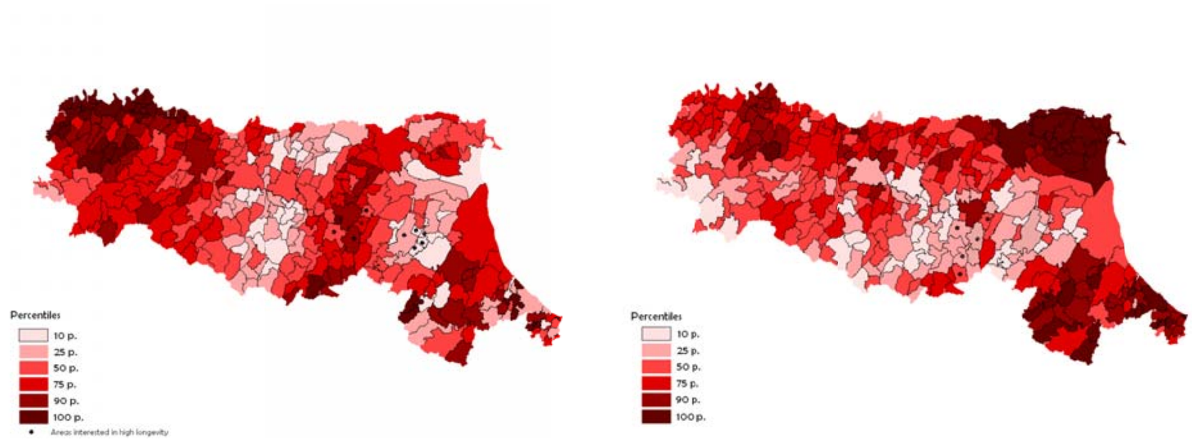


Figure 10 - SMR estimates for cancers in male and female population aged 75+.

When the geography of cancers deaths is examined (Figure 10) considerable differences among the provinces and between men and women occur: for men a lower mortality (light pink) is discernable for the municipalities in the provinces of Modena (mainly in the hills), Bologna and Ravenna (mainly in the hills and mountains). On the contrary, male mortality from cancer is relatively high in municipalities near the city of Piacenza, in the province of Ferrara (North-east) and in the South-eastern part of the region.
Females show a different concentration of high and low mortality for cancer. Generally speaking Figure 10 indicates a minor presence of low mortality areas than for males. These latter areas are found in the Southern municipalities of the province of Modena, in those of Ravenna and Forlì-Cesena.
Figure 11 shows that the recent geography of mortality from cardiovascular diseases only partially corresponds to the geography seen so far. Mortality is particularly high in the municipalities of Ferrara, in some municipalities in the north-west of the province of Piacenza and in few areas of the Western Bolognese mountains both for males and females. On the contrary, the areas of the provinces of Ravenna and Bologna are characterized by a permanence of low mortality from cardiovascular diseases more pronounced for men. In contrast with cancer mortality, the territory surrounding Bologna city emerges as an area with low risk of death from cardiovascular diseases.

a) cardiovascular diseases – females b) cardiovascular diseases - males

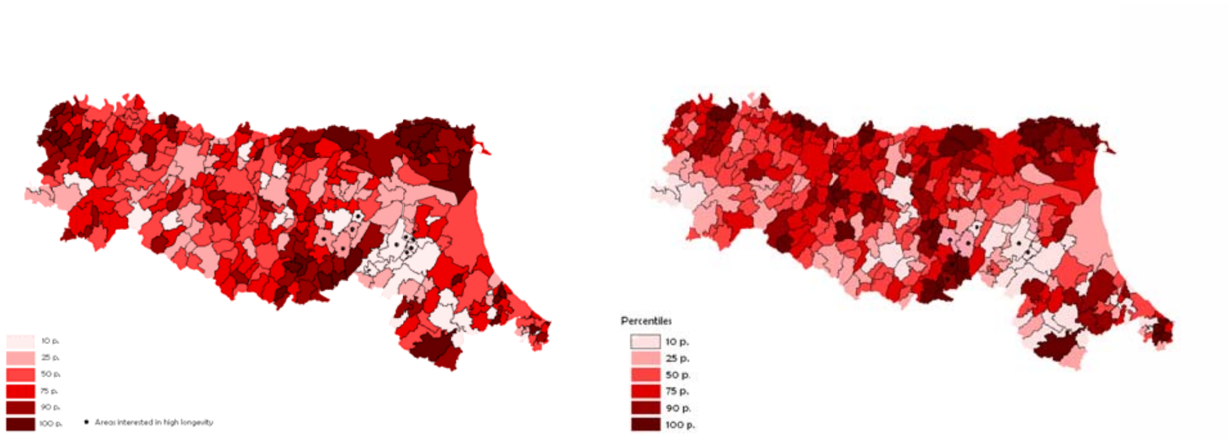


Figure 11 - SMR estimates for cardiovascular diseases in male and female population aged 75+.

In summary, the geography of elder men and women mortality confirms the presence of low mortality areas that had already emerged from the analysis of provincial mortality for cancer and cardiovascular diseases, even though, for the latter causes, mapping underlines a more puzzling situation. Nevertheless three areas of low mortality emerge from the analysis: the mountain part of the province of Piacenza, an area spread between the provinces of Modena and Bologna and a persistent set of municipalities in the province of Ravenna.
For women, the province of Ravenna's advantaged position is due to mortality from both cardiovascular diseases and cancers, but in other provinces the two causes of death compensate each other showing alternatively high or low risks.
There are some exceptions where the geography of mortality from cancers and cardiovascular diseases is different for both sexes: on average higher for men and lower for women underling specific geographical and environmental situation should be studied in more details.

5. Discussion

The frequency of longevity cases has been booming over the last years, even if with remarkable differences between sexes and across different geographical contexts. We have analyzed the phenomenon in a North-eastern region of Italy through the development of suitable indicators for the period from 2000 to 2004. Our study highlights the existence of high longevity areas in the South-eastern part of the region opposed to others in the North-eastern direction characterized by lower values of the CR_{95+} index, with no relevant differences between men and women. More specifically we have observed higher index values in the provinces of Ravenna, Bologna and, to a lesser extent, Forlì-Cesena and Modena. The low longevity area is particularly spread in the province of Ferrara, that also shows the lowest level of residual life expectancy at age 75, and in the northern municipalities of Piacenza, Parma, Reggio Emilia e Modena.

The result of the different spatial analysis methods, summarized with a multigraph technique, has identified the presence of a persistent cluster composed of several municipalities belonging to Bologna and Ravenna provinces.

An intriguing aspect that needs to be studied in depth is the relationship between the geographical pattern of longevity and the orographical features: more long-lived persons in the hilly and mountain zones, less long-lived persons in the “Padania” plain. This fact could probably be linked to differences both in climate factors, more hot and wet in the plain, and in economic activities, less industrialized area in mountains and hills.

A further attempt of this study was to compare the spread of longevity with mortality pattern and the diffusion of the main causes of death for elderly. An in-depth analysis of cause-specific mortality differences and information on lifetime morbidity would be particularly useful. The results of these analyses could shed light on the factors that affect longevity in the population. Our first results has shown that where all-cause mortality is low cardiovascular and cancer mortality are also low and it is possible to find high longevity values.

With regard to gender the study hasn’t highlighted relevant differences in the geography of all causes and cardiovascular mortality. Instead cancer mortality shows different patterns by gender: in some municipalities a high longevity is not necessarily linked to low cancer mortality for women. This particular aspect could be probably related to sex differential in mortality and morbidity by cancer site.

With respect to the different used methodological approach, the study showed that some provinces of the region compete among themselves in the process of defining the clusters, thus, it may change its geographical location. It should also be noted that the procedures for spatial clustering allow to identify a possible combination of the phenomenon on the examined territory but they are unable to delineate the precise boundaries of real cluster.

Finally, the method proposed in the study may represent an innovative approach for the comparison between the results obtained with the different methods of spatial clustering even though its effectiveness remains constrained by the inherent subjectivity in choosing the search parameters by the researcher. One further development of the methods could include measures of distance between the various clusters to make more objective selection of persistent areas.

Because mortality and longevity may share the same set of (spatially distributed) risk factors, or the level of a specific-cause mortality might encourage or inhibit the presence of longevity over a region we may need a multivariate areal model to properly analyze this kind of data. This will permit modelling of dependence among the multivariate components while maintaining spatial dependence between sites. We will refer to a flexible class of generalized multivariate CAR (GMCAR) models for areal data like the one proposed by Jin, Carlin and Banerjee (2005).

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