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Towards the identification of a Systemic Depopulation Areas Index: the case of Molise

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1. Introduction

Southern European populations are shrinking[1] and over-ageing[2], inverting the classic age pyramid. Over the years 2014-2022 Southern European countries[3] declined by about 1.3 million people and the share of people aged 65+ increased from 20% to 22%. Baseline projections predict a further decline by about 7.1 million in 2065, while the share of people aged 65+ will reach 33%.
The process started in the middle of the 90s of the last century with an increasing speed. Many studies already sounded the alarm for a long time about an approaching "demographic winter" (Lallo and Tomassini 2023, Franklin 2020, 2019, Clements at al. 2018, Carbonaro et al. 2018, Coleman and Rowthorne 2011, Kohler et al. 2002, Golini 1997, Demeny 1997, Sauvy 1966). Concerns about the negative effects of a severe population shrinking on the future economic and social development of Europe, are increasingly taking over in official documents, debates and policy planning, in supranational organizations like the UN and EU (e.g. UNFPA 2023, EU Parliament 2021, EESC 2020). In many national and local contexts, depopulation is already a main issue in the political agenda, especially with respect to urban/rural and regional imbalances (Italian Presidency of the Council of Ministers 2023, Barca & Carrosio 2020, Barca 2015, Barca et al. 2014). However, despite the concerns, some implemented policies and the importance in public debates, the process is far from over, maybe is even far to slow down.

This mismatch between the raising attention in scientific and political agenda and the negligible impact on the demographic process in place, has two main reasons.

[1] The words "shrinking population", "depopulation" and "population decline" are used interchangeably in this paper to indicate the descriptive phenomenon of a population that is diminishing its size. The definition of "systemic depopulation" is explained in the following sections of the paper.

[2] Ageing is the classic phenomenon predicted by the 4th phase of the Demographic Transition Theory. As the final situation of equilibrium of the transition, it is being not considered necessarily a problem. On the contrary, an intense population ageing may have potentially severe consequences. Some authors called it "de-rejuvenation", but "over-ageing" is proposed in this study: like the metallurgic process of tempering, there is a point of ageing that is optimal: under-ageing and over-ageing makes the metals less strong.

[3] Portugal, Spain, Italy, Greece and Malta. Data from Eurostat. Last Access on 28.07.2023. https://ec.europa.eu/eurostat/databrowser/view/DEMO_PJAN/default/table?lang=en.

First, population shrinking is both an outcome and a process, in a self-powered cycle with a high degree of inertia, as a big cruise ship at full speed that try to suddenly stop (Newshame and Rowe 2022, Franklin 2020, Benassi et al. 2023a, Reynaud et al. 2020, Elshof 2014). The opportunity window to avoid the start of this cycle and then rapidly invert the march route has been lost many years ago. Effects of policies implemented today to counter-act depopulation processes may produce first significant effects in the medium term, if they are kept stably at work for a sufficient amount of time, like a long-term investment (Sobotka et al. 2019). Provide stability and continuity of such policies could be very difficult though, in a political context of rapid changes and short evaluation times. A new tool, designed to promptly capture signals of slowdown in the shrinking process, could help to maintain the route or operate some changes only when strictly necessary.

Second, geography of depopulation, administrative boundaries and policy targets could not necessarily overlap. Local administrative units are usually both the beneficiary and the end-implementers of policies designed at regional/national/supranational level. This present two orders of problems: geographic heterogeneity and administrative heterogeneity.
Populations are not distributed homogenously within a regional and local administrative unit (Lucchetti and Morettini 2022, Salvia et al. 2021, Reynaud and Miccoli, 2018, Reynaud et al. 2020, Zambon et al. 2019), especially when the unit is located in a mountainous territory or, even worst, in a territory that enclose both mountainous and coastal territory (that is not so uncommon in countries like Italy or Greece, for example). When a policy is designed at national level and the target territories are selected via average indicators, computed by robust, but little sensitive statistic measures, this can lead to an ineffective allocation of resources. Moreover, if the process of shrinking and over-ageing has been already ongoing for a long period of time, even the quality of local policymakers could be negatively affected, assuming for example that migrations could operate an inverse selection on the local population in terms of human and social capital (under the hypothesis that young and better educated leave first). As consequence, local policymakers of territories involved by severe shrinking and over-ageing processes (theoretically the very first target territories) could have difficulties both in carrying out policies and also to stay in the political debate, mining even the possibility to obtain the resources allocated by the regional/national/supranational level (cf. Viesti 2023, 2022, Resce 2022, Antulov-Fantulin et al. 2021). Ironically, this happens more when the policy is designed to be the result of a co-decision bottom-up process, since this assumes the ability of local communities to take part in the process. A statistic measure designed to be objective and simple, sensitive and locally observed, without bringing additional burden to the local administration, could help to mitigate these problems.

In this paper a first attempt to design such a tool, moving from the concept of systemic depopulation, is proposed. In the background section (2) a view of depopulation in Europe is described, focusing on Southern Europe, with the recent evidence, considerations and measures elaborated to analyse the process. The following section (3) will focus on Molise, a small region in the South of Italy, that is the case study of this work. In this section this choice will be justified in the light of its demographic history, geomorphological characteristics, and the current status of policies implementation.
The fourth section will introduce the proposal to measure the systemic depopulation in local areas when the objective is monitoring the impact of policies aiming to reverse the process: the Systemic

Depopulation Areas (SyDAs) index, whose results will be discussed in section 5 (Results and Discussion). Finally, in section 6 will point out some first conclusions.

2. Systemic depopulation measures: background and state of the art

2.1. Depopulation in Europe: state of the art and a brief literature overview

One of the first considerations and concerns about European depopulation and ageing process were probably done by Alfred Sauvy and David Victor Glass in the middle of the last century (Sauvy 1949, 1966, Glass 1940) that had observed the first important fall of fertility rates in Europe and North America. They remained skeptical about the predicted slowdown of this fall, once reached the level of around 2 births per woman (the replacement-level), theorised in the same years by Notestein (1945) as the new final equilibrium of populations development, i.e. the 4^{th} phase of the demographic transition. Even if population growth is the final product of three demographic flows, i.e. deaths, births and migrations, they paid particular attention to fertility since low levels of both emigration and mortality in the richest countries had left this one as the most influential factor on the table. Thanks to the economic, social, technological and institutional development, the majority of the countries in the western world had already broken the so-called Malthusian trap in the middle of XIX century and severe episode of depopulation due to mortality and emigration crisis were just a far object study for historians (Lutz and Gailey 2020, Livi Bacci 2011, 1998).

The depopulation question and related concerns faded away from the scientific and political agendas until the beginning of the 90s, thanks also to the post war *baby-boom*, that increased temporarily the fertility rates between the 50s and the 60s, and mislead the scholars of that period, confounding the quantum and tempo effects, how lately explained by Boongarts and Feeney (1998). Depopulation remained in the scientific debate only as a rural/urban redistribution process (e.g. Sonnino 1975, 1978, 1979, Ruggieri 1976, Sonnino et al. 1990). The increasing internal migration from rural to urban areas and the consequent shrinking of marginal areas, were considered inside a bigger process that would have led in the end to a general increase of the population and, via spill over, to a territorial rebalance (Beeson 2017, Fujita et al. 2001). Moreover, international migration in-flows (Harper 2016) and the unstopping increase of life expectancy (Oeppen and Vaupel, 2002) enabled populations to remain stable or even increase in numbers for a while, at the cost of radical changes in their age structure (Goldstein and Schlag 1999), especially in Southern Europe.
When depopulation did knock the door of western world, it was already in the house: “They will know you arrived before they knew you are arriving”[4].

Dirk Van de Kaa in 1987 and Paul Demeny in 1997 were among the first demographers who have questioned the assumption of stabilisation of fertility rates around the replacement level in developed countries. They pointed out that such assumption was evidence-free and, on the contrary, empirical data showed fertility rates constantly below the replacement level from the 70s of the XX century. Indeed, the fall of fertility rates did not stop its run until today, reaching levels

[4]Tito Livio, Ad Urbe Conditam, Liber 22, 51-61. “Sequere; cum equite, ut prius uenisse quam uenturum sciant, praecedam”. The aphorism is attributed to Maarbal, a cavalry commander under the great general Hannibal during the Italian campaign in the second Punic war.

below 1.5 in all Southern European countries. For example, using the averages computed for the years 2017-2021, fertility rates in Southern European countries were: Malta 1.21, Spain 1.26, Italy 1.28, Cyprus 1.32, Greece 1.33, Bosnia 1.36, North Macedonia 1.39 and Portugal 1.39[5]. These unprecedented low values of fertility rates induced some authors (Kohler et al. 2002) even go as far as to create a new definition: the "lowest-low" fertility rates countries, referring to values below 1.5 births per woman. Other scholars (Van de Kaa 1987, Lesthaeghe 2011, 2020) elaborated a new theory explaining trends in fertility after the end of the 4th phase of demographic transition in developed countries: a "Second Demographic Transition" where fertility could stay stably below the replacement-level. Age structure also play an important role: if fertility rates remain constantly below the 2 births per woman for a sufficient amount of time, let say 30 years, the progressive reduction of new young and adult cohorts becomes a *per se* factor of depopulation, reducing the demographic base for new births (Goldstein et al. 2004).

Moreover, after the collapse of Soviet Union in 1991 in the east and the increasing territorial economic inequalities inside the countries of western world, out-migration flows have turned to be one of the significant engine of depopulation at local level, especially in Southern and Eastern Europe, amplifying the effects of low fertility and contributing to create a vicious circle: depopulation leads to lower economic growth and less public services that results in emigration of the younger cohorts that produces even lower birthrates and therefore causes depopulation (see: Martins and Davino 2023, Alamá-Sabater et al. 2021, Lutz and Gailey 2020, Reynaud et al. 2020, Franklin, 2020, Christiaans 2017, Ubarevičienė and van Ham 2017). For example, considering the regions (NUTS level 2) of Southern Europe (including Italy, Spain, Portugal and Greece) and the average value between years 2017-2021, 26 regions out of 60 showed a negative net migration rate, i.e. a little less than the half, with an average negative value of -4.3‰[6]. Since emigrations usually involve the young, the negative impact on birth rates is straightforward, regardless the fertility rates level.

Finally, even the specter of mortality crisis has raised its ugly head once more, for a while, but only in Eastern Europe so far (Leksin 2021, Meslé and Vallin 2002).

Indeed, depopulation (as the opposite, of course) is both an outcome and a process: a path-dependent process (Newshame and Rowe 2022, Franklin 2020) with a high degree of inertia, as all demographic processes usually are (Sauvy 1957): contrariwise to many economic models in modern social sciences, the demographic structure of a population has a very good memory. A change is possible only if we power the reverse process for as long as it takes: structural changes need time. The trigger of the process may have been the fall of fertility rates, but now the circle is self-powering, especially at local level and for small communities (Reynaud and Miccoli 2018, Elshof 2014). The establishment of such a self-powered circle of population decline has been named here a "systemic depopulation" process[7].

From the beginning of this century, studies on population shrinking and related (usually negative) socio-economic consequences have become more and more frequent in the demographic literature

[5] Data from United Nations, Population Division. https://population.un.org/dataportal/home Last access: 28.07.2023

[6] Data from Eurostat. https://ec.europa.eu/eurostat/databrowser/view/TGS00099/default/table?lang=en. Last Access: 28.07.2023

[7] It is preferred to label such process as "systemic" instead of "structural" or "systematic", to call attention to the complex interplay of different social phenomena, both demographic, economic and institutional, that are intrinsic in the society and inseparable. From the Oxford Dictionary, systemic: "affecting or connected with the whole of something, especially the human body or a society".

(e.g. Lallo and Tomassini 2023, Franklin 2020, 2019, Clements at al. 2018, Carbonaro et al. 2018, Coleman and Rowthorne 2011, Golini 1997). In 2009 the EU-COST Program funded a research network to study, mapping and classifying European shrinking cities and regions[8], and in 2021 the Wittgenstein Centre for Demography and Global Human Capital organized an international conference in Wien with a focus on depopulation and its socio-economic consequences[9]. At the same time the issue raised the first places in national and supranational institutions political agendas (e.g. UNFPA 2023, Italian Presidency of the Council of Ministers 2023, EU Parliament 2021, EESC 2020). Governments usually focused on pro-natalist policies, giving subsidies and expecting fertility rates to raise as an empiric evaluation tool of policy efficacy in the short run. Such policies found their rationale in the results of some studies (e.g. Gauthier 2007, Beaujouan and Berghammer 2017) that provided evidence of a gap between the desired fertility of young couples and the actual fertility rates in high developed countries. However, this policy approach has been recently questioned due to the different meaning of tempo and quantum effect. Moreover, fertility is influenced by cultural and social norms, and by expectations for the future, that cannot be easily modified only assigning (especially when irregular) cash benefits (e.g. Sobotka et al. 2019, Hakkert 2014, Neyer and Andersson 2008, McDonald 2002). Fertility intentions need time to change, even more time to produce significant results in terms of birthrates, and finally they are just one piece of the systemic depopulation process. Finally, such policies can be unlikely differentiated between local communities, as municipalities, leading sometimes to contradictory results when studying the policy efficacy at higher territorial level, as the regional or national ones. Population decline can co-occur with population growth: depopulation can take place within a larger context of growth and vice-versa (Franklin 2019, Wolff and Weichmann 2018).

2.2. New measures of depopulation processes

The systemic characteristics of depopulation process has led some of the most recent studies on this matter to adopt a holistic, diachronic and local-scaled approach (considering Southern Europe: Benassi et al. 2023a, 2023b, Newshame and Rowe 2022, Lucchetti and Morettini 2022, Salvia et al. 2021, Caselli et al. 2020, Reynaud et al. 2020, Zambon et al. 2019). Where some studies (Benassi et al. 2023a, 2023b, Lucchetti and Morettini 2022, Salvia et al. 2021, Reynaud et al. 2020, Zambon et al. 2019) focused on the different geographies of population decline, exploring the spatial heterogeneity of the phenomenon and its demographic and socio-economic determinants, others investigate the temporal path-profile of the process (Newshame and Rowe 2022), and others try a comprehensive analysis of the socio-economic determinants of shrinking populations at municipal level, identifying potential clusters of different combinations inside the systemic process (Caselli et al. 2020).

In particular, Newshame and Rowe (2022) applied a sequence analysis to the population growth of European local geographic units (NUTS level 3, 696 units), between 2000 and 2008. After transforming numeric annual growth rates into categorical classes, the authors were able to classify

[8] COST CIRES TU0803 – Cities re-growing smaller- fostering knowledge on regeneration strategies in shrinking cities across Europe. https://www.cost.eu/actions/TU0803.
[9] The Causes and Consequences of Depopulation, 29.11—01.12.2021, Wittgenstein Centre Conference, Wien. https://www.oeaw.ac.at/vid/events/calendar/conferences/the-causes-and-consequences-of-depopulation.

seven different paths of population change[10]. Among these paths, Persistent Decline, Accelerating Decline, Persistent Moderate Decline and Accelerating Moderate Decline can identify a population trapped inside a systemic depopulation process. Among the analyzed geographic units, 57,8% are classified in these paths, mainly located in Southern and Eastern Europe (especially Southern Italy, Portugal, Balkans and virtually the whole Eastern Europe), including around 72 million of people in 2000 with a decline of about 15,2 million of people by the 2008 (representing a fall of 21%). The method proposed is very innovative and captures utterly the path-dependence of the systemic depopulation process, but, in a policy efficacy evaluation perspective, it is little sensitive to first changes in direction and very dependent by the transformation from numeric growth rates to categorical classes.

Caselli et al. (2020) aim to understand which combinations of contextual factors in small and mid-sized Italian shrinking municipalities affected the dynamics of population decline. They analysed 3500 municipalities whose population declined in both the periods 1991-2011 (therefore before the national decline) and in the subsequent 5 years (2012-2016), for a total of 25 years. They used a multilevel and multiscale analysis and were able to identify 7 cluster of different combinations of 5 factors related to systemic depopulation: Ageing, Wealth/Poverty, Business Performance, Unemployment, Peripherisation[11]. The different clusters identify different combinations of factors and then different aspects to prioritise to reverse the systemic depopulation process. This model of analysis, define by the authors as "Performance-based Cluster Model", might become a valid tool for orienting policy intervention, but, concentrating the field of application by definition only on populations already in a systemic depopulation, detecting any initial signal of a reverse in the systemic process is impossible.

Finally, from a spatial point of view, where Reynaud et al. (2020), Lucchetti and Morettini (2022) called for attention on territorial characteristics (such as altitude or accessibility to public services) and self-powered cycles of depopulation, Benassi et al. (2023a, 2023b) showed that the determinants of local population changes are not spatially constant, but that they vary in their effects at different geographical scales and spatial structures, inviting further research on depopulation to go beyond classic OLS models and to consider spatial dimensions both using global regression models– such as spatial global regression models, like the spatial lag model, the spatial error model, and the spatial Durbin model – and local regression models (like GWR and MGWR)[12]. This suggestion questions the actual overlapping between administrative areas and the most efficient minimum "geographic unit" of resources allocation. Even at the lowest level of administrative unit, i.e. the municipality, if the determinants vary in their effect at different geographical scales, it is far from certain that the boundaries of the two units (the administrative and the most efficient ones) always overlap. Answering to this last question and understanding the determinants of systemic depopulations is beyond the scope of this article, but these considerations on spatial heterogeneity are useful to reinforce our choice of a local-scaled index of systemic depopulation. Nevertheless, our index might be used as an outcome in predictive models designed on the basis on such studies. As Neumark & Simpson (2015) pointed out, reversing the systemic

[10] The 7 paths are: Persistent Decline, Accelerating Decline, Diminishing Decline, Persistent Moderate Decline, Accelerating Moderate Decline, Diminished Decline, Temporary Decline.

[11] The 5 indicators compare local measures to the national average, Ageing: Old Age Index; Wealth/Poverty: Per capita income; Business Performance: Labor productivity; Unemployment: Unemployment rate; Peripherisation: Marginal areas classification according to official statistics.

[12] Geographically Weighted Regression (GWR), Multiscale Geographically Weighted Regression (MGWR). Benassi et al. (2023a) highlighted a significant effect of the primary school presence in the territory on the birth rates.

depopulation call for “place based policies”, that in turn require appropriate monitoring tools (see also: Muti 2023). We aim to design such a tool, useful for both policy evaluation and further scientific computation purposes.

Summarising, all these recent studies agree that depopulation is a demographically complex and geographically heterogeneous phenomenon, that should be studied as: i) a path-dependent process; ii) using a local level of geographic detail and iii) using a diachronic approach. This article proposes a simple index able to capture the initial indication of a reverse in the systemic depopulation process, a monitoring tool for place based policies.
In the next section the focus will be on Molise, justifying this choice in the light of its demographic history, geographical characteristics and the current status of policies implementation.

3. The Molise case study

Southern Italy is one of the European region undoubtedly most involved in a systemic depopulation process (Newshame and Rowe 2022, Reynaud et al. 2020). Molise is one of the regions in the South of Italy that showed the strongest population decline, the lowest fertility and net migration rates (Figures 1 and 2). In 2002 the Italian Institute of Statistics (ISTAT)[13] estimated population of Molise to be around 320 thousand, while in 2021 this dwindled to 294 thousand: a negative annual growth rate of -4.4‰[14]. This value is extremely low when compared to the growth rate in Italy of around 1.8‰ in the same period. Looking at 2014-2023, i.e. the years of the continuous national population decline (see figure 2), the Italian population decrease was around -0.8‰.
Average Total Fertility Rate (TFR) in Molise in the years 2017-2021 was 1.12 and Net Migration Rate (NMR) was -4‰, while in Italy were 1.28 and 0.7‰ respectively. Moreover, Molise Region, though has a coastal zone in the North-East, includes a large share of mountainous territory (figure 3). Indeed, according to ISTAT (2022), the 76.5% of Molisan municipalities (that host 68.6% of the population), are located in “Inner Areas”, i.e. marginal areas far from public services (Figure 4)[15].
As pointed out by Reynaud et al. (2020) and Lucchetti & Morettini (2022), geographic remote areas and difficulties in accessing public services are important catalyst of a systemic depopulation process: Molise seems to fill all the prerequisites to be a “shrinking region”.

[13] Data retrieved from: https://demo.istat.it/. Last Access: 28.07.2023

[14] We used continuous growth rate: $\frac{\ln P_{(t+n)} - \ln P_{(t)}}{n}$

[15] ISTAT defines an “Inner Area” as a municipality where the distance from the combination of three essential public services (hospitals, railway stations and high schools) is more than 40 minutes driving. More info at: https://www.istat.it/it/archivio/273176.

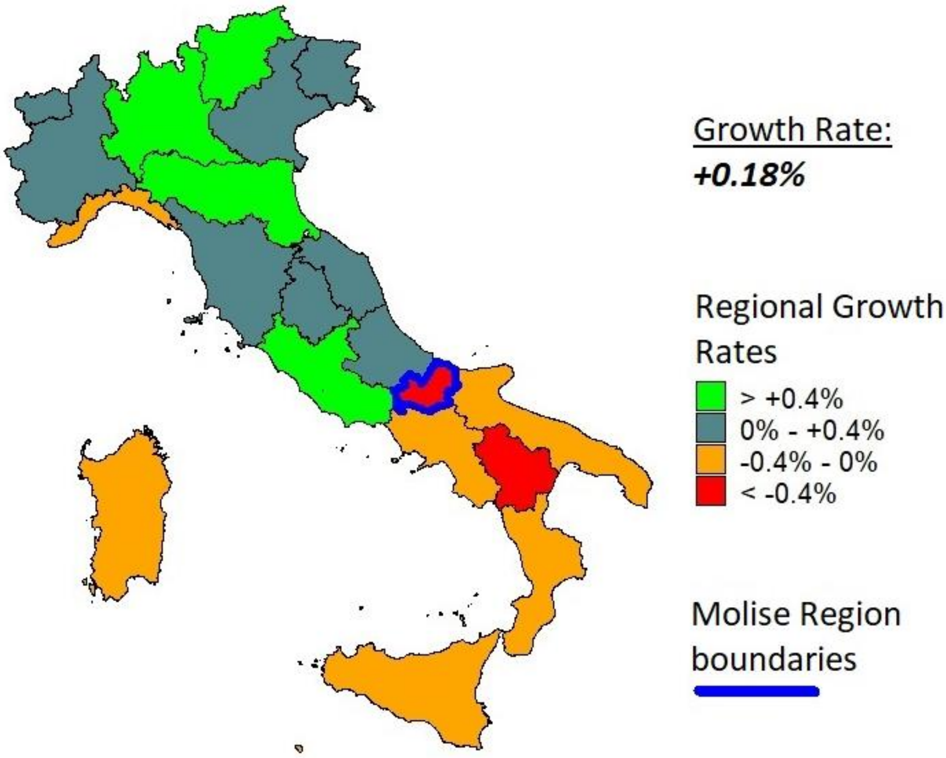

Figure 1. Italian and Regional Population Growth Rates, years 2002-2021.
Source: Own Elaborations on ISTAT data.

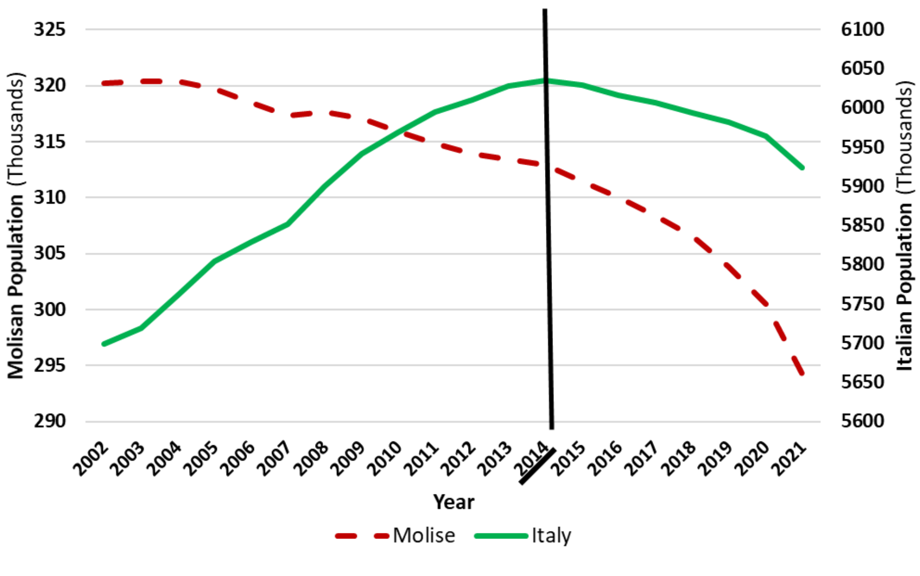

Figure 2. Italian and Molisan population dynamic, years 2002-2021. *Source: Own Elaborations on ISTAT data.*

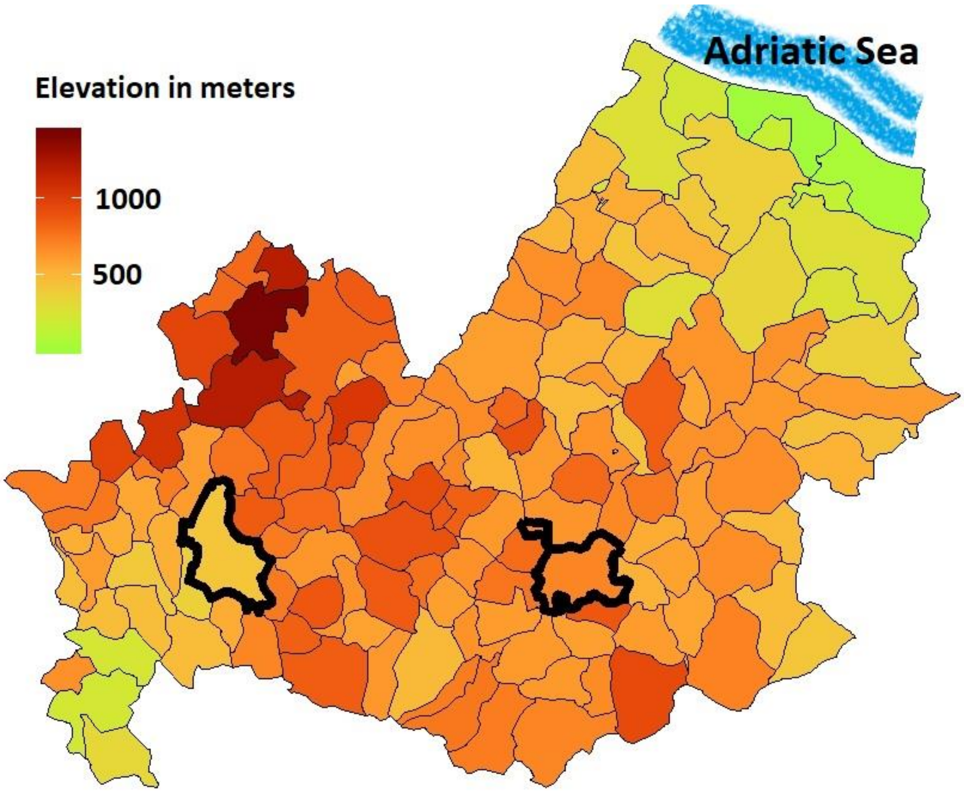

Figure 3. Elevation of Molisan municipalities.

Source: Own Elaborations on ISTAT data.

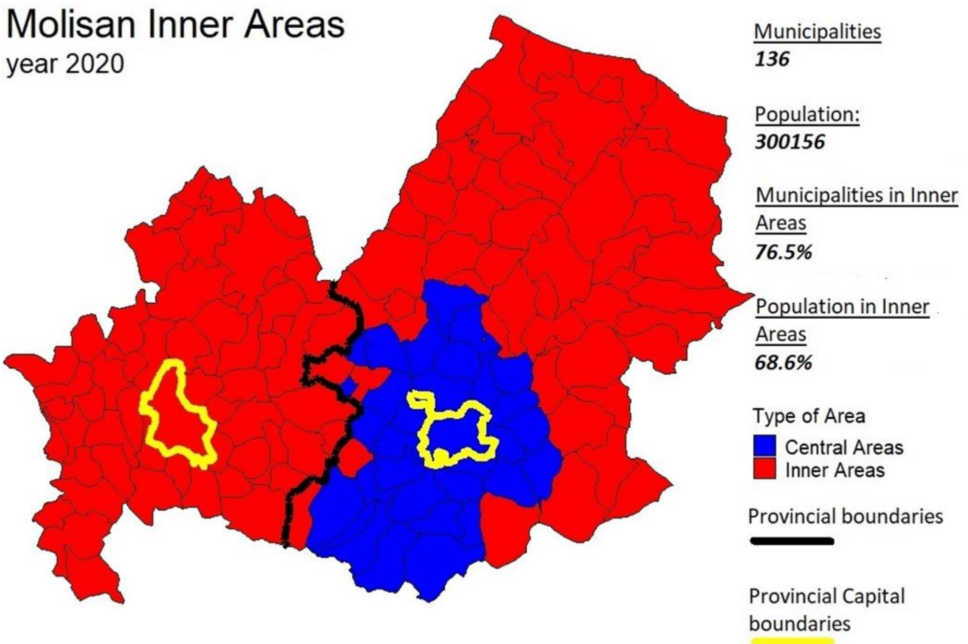

Figure 4. Molisan Inner Areas, year 2020.

Source: Own Elaboration on ISTAT data.

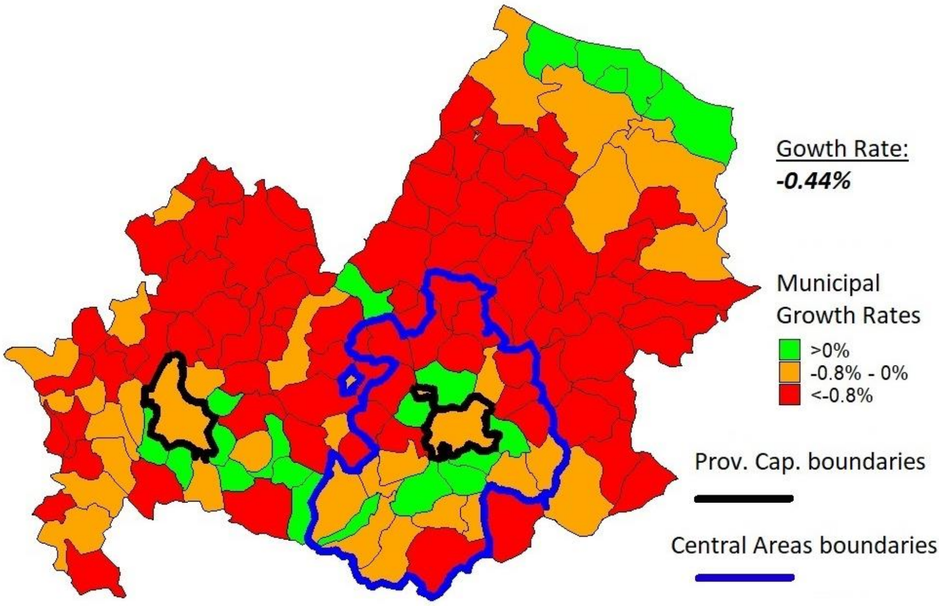

Figure 5. Molisan regional and municipal population growth rates, years 2002-2021.

Source: Own Elaborations on ISTAT data.

Nevertheless, local spatial heterogeneity still matters. Italy has a long tradition of regional demographic and geographic studies, being the Italian scholars well aware of the Italian extreme geographic heterogeneity (e.g. Tomassini & Billari 2021, Benassi et al. 2021, Salvati et al. 2020, Reynaud et al. 2020, Casacchia et al. 2005, Del Panta & Detti 2019, Golini et al. 2000). Moreover, depopulation in marginal and mountainous areas of Italy is a frequent topic of research from the 50s of the last century (e.g. considering the marginal areas of Abruzzo and Molise Regions : Pecora 1955, Ruggieri 1968, 1982, Muscarà 2008, Marchetti et al. 2017, Sarno 2019). Heterogeneity emerges when looking at the growth rates computed by municipal area in Molise, for the years 2002-2021 (figure 4). As Franklin (2019) pointed out, “population decline can co-occur with population growth: depopulation can take place within a larger context of growth and vice-versa”: even if the regional population is declining, some municipalities (located in areas classified as “marginal”) show population growth. Moreover, some municipalities classified by ISTAT like “central areas”, show severe population shrinking.

This being the case, it is not surprising that Molise has become one of the target of the most important Italian policy designed to counter-act depopulation processes at local level: The National Strategy for “Inner Areas” (SNAI). Unlike classic pro-natalist policies, The National Strategy aims to promote and protect “Inner Areas” assets and local communities, enhancing their natural and cultural resources, creating new employment circuits and new opportunities – in short, counteracting the massive demographic decline through a socio-economic structural change (Barca & Carrosio 2020, Barca 2015, Barca et al. 2014). In 2023, 72 municipalities of Molise have been targeted by this policy, roughly the 53% of the Molisan municipalities[16]. There are 4 different areas of interventions, with own specific objectives determined by the geographic and socio-demographic

[16] See below figure 9, Section 5, for a geographic visualization.

situation: Alto Medio Sannio (AMS, High-Middle Samnium), Fortore (F), Mainarde (Mai), and Matese (Mat)[17]. The interventions started in 2015, but the projects are becoming operative only recently. Finally, a considerable fraction of the large investments planned in the extraordinary financial plan called "Resilience and Recovery Plan"[18], approved in 2020 by the European Council (209 billion in loans and subsidies at 2018 values) should be used to improve the infrastructures of marginal areas (Italian Council of Ministers, 2021).

In conclusion, the demographic history and current characteristics of Molise, its spatial heterogeneity and geomorphological characteristics, the continuous and significant attention received by geographers and demographers, and the investment policies that soon could potentially have an impact on a considerable fraction of its territory (SNAI and RRP projects), makes Molise a good case of study for a first attempt to design and apply a simple systemic depopulation index at local level.

4. The SyDAs Index: a proposal (definitions, methods and potential applications)

Systemic depopulation is a spatial-temporal-dependent process. It is spatially heterogeneous at very local level, involving all demographic engines (mortality, birth rates/fertility rates, migrations) and the age structure of population (share of older people), that has in turn a direct impact on birth rates and mortality. Since population structure has long memory, systemic depopulation has a high degree of inertia, but at very local level and for small communities, some erratic and seasonal temporary changes can occur without consequences in the mid-long run.

The goal of this study is to design a simple index for policy evaluation and monitoring purposes, able to take into account these characteristics of the depopulation process. To this scope, the analysis of the change over time in population size of municipalities appears to be the best fit, in terms of robustness and relatively easy access to data. Using municipalities, that are the smallest available statistical unit, we aim to map the territory's heterogeneity without taking into account spatial correlation effects. Such a map could then serve the scope of further spatial regressive models, including the study of socio-economic determinants and correlations (like GWR and MGWR, see: Benassi et al. 2023a, 2023b). This approach presents some similarities to time-series analysis, and such methodology has been adopted in the present study. This is not the first attempt to use time series analysis for demographic applications (e.g. Vanella et al. 2023, 2020, Shang & Hyndman 2017), but this is the first attempt to create a simple index to evaluate a policy efficacy when the objective is to reverse a systemic depopulation process.

Time series analyses have two main goals: to identify the nature of the phenomenon represented by the sequence of temporally ordered observations, and to forecast future values of the time series variables. The nature of time series can be affected by seasonality (i.e. fluctuations with fixed time frequency, seasonal factors such as the time of the year or the day of the week), cyclicity (i.e.

[17] Specific materials are available at: https://www.agenziacoesione.gov.it/strategia-nazionale-aree-interne/regione-molise-aree-interne/. Last Access: 28.07.2023.

[18] The plan has been named "Recovery and Resilience Plan" (RRP) by the Italian Government, however, according to the European Council, the official name is "Next Generation EU". More info at: https://www.italiadomani.gov.it/content/sogei-ng/it/it/home.htm.

fluctuations that are not of a fixed frequency, the "business cycle"), autocorrelation (i.e. when the values at time t+n depends on the value at time t), and finally, trend (i.e. a long-term increase or decrease in the data). In short, time series methods allow to confirm the existence of a temporal trend after removing the effects of seasonality, cyclicity and autocorrelation (Hyndman & Athanasopoulos 2021, Pankratz 1991): a goal very close to ours. In this study, the approach of "stationarity and differencing" of time series, as described in Hyndman & Athanasopoulos (2021, chapter 10) has been adopted.

In the simplest case, after selecting the populations affected by a severe shrinking[19], a regression model allows for a linear relationship between the population size in certain year t (Pop_t) and a single predictor variable, the time, i.e the year t.

$$Pop_t = \beta_0 + \boldsymbol{\beta_1} * t + \varepsilon_t \quad [1]$$

In this case we could robustly consider the existence of a systemic depopulation process, if the parameter $\boldsymbol{\beta_1}$ is significantly negative (i.e. p-value lower than 0.001) and the R^2- adjusted index of the model is bigger than 0.95, in order to evaluate the goodness of fit of the linear assumption. However, it is needed to consider cyclic fluctuations, volatility and autoregression in the structure of population change. If we include these factors, the regression model becomes:

$$Pop_t = \beta_0 + \boldsymbol{\beta_1} * t + \eta_t \quad [2]$$

with:

$$\eta_t = \delta * \eta_{t-1} + \gamma * \varepsilon_{t-1} + \varepsilon_t$$

where δ capture the autoregressive and cyclic component and γ capture the volatility component, i.e. an ARMA process (Autoregressive and Moving Averages, see: Box et al. 2016). In this case it could robustly consider the existence of a systemic depopulation process similarly to [1]. Nonetheless, ARMA models do not include seasonality effects, where ARIMA models can do it. ARIMA is an acronym for Auto Regressive Integrated Moving Average and allow to model seasonal data as follows:

$$Pop_t = Pop_{t-1} + \boldsymbol{trend} + \eta'_t \quad [3]$$

with:

$$\eta'_t = \delta * \eta_{t-1} + \gamma * \varepsilon_{t-1} + \varepsilon_t$$

where η'_t is an ARIMA process, since we "differencing" the value of Pop_t by 1 (Pop_{t-1}). This last model differs from the [2] not only because incorporates seasonality, but also because the trend is stochastically determined, i.e. the error structure is not stationary and we do not assume linearity. There is an implicit assumption with the deterministic trends in [2]: the slope of the trend is not

[19] Once chosen a population growth index, a time period and a threshold in population shrinking, it is possible to select the populations affected by severe shrinking. In this paper we used a continuous growth rate, the period 2002-2021 and a threshold of -0.8% annual (as in Reynaud et al. 2018).

going to change over time. On the other hand, stochastic trends can change, and the estimated growth is only assumed to be the average growth over the historical period. This makes the estimates more robust (especially for projections, but is also valid in this case). Unlike the [1] and the [2], in this case will be considered the existence of a systemic depopulation process only if the *trend* parameter is significant and negative: an R^2- adjusted index would result meaningless since the model is not linear and other indices would be unnecessary, since only the variable population on time is regressed. This last binary index is the SyDAs Index.

Concluding, a simple binary index, a Systemic Depopulation Areas (SyDAs) Index is created. Such simplicity loses information on the process (cf. Caselli et al. 2020), but it is a small price to pay, considering the purposes of this index. When the stochastic ARIMA trend, computed on an ordered time sequence of population amounts in a selected geographic or administrative unit, is negative and significantly different from zero, the existence of a systemic depopulation process is recognised. Inversely to other diachronic approaches (Newshame and Rowe 2022), the index is sensible to any variation in the trend, but only after controlling for erratic volatility, cyclic and autoregressive structure, and seasonality (cf. Lucchetti & Morettini 2022, Reynaud et al. 2018), making SyDAs a good candidate among policy evaluation indices, where the objective is to capture any significant signal of a reversing in a systemic depopulation process at local level. Moreover, mapping the territory's heterogeneity applying the SyDAs Index, that does not take into account spatial regressive effects, could serve the scope of further spatial regressive models, including the study of socio-economic determinants and correlations (like GWR and MGWR, see: Benassi et al. 2023a, 2023b).

In the next section SyDAs is calculated for the Molisan population at municipal level, for the years 2002-2021 is. Official data from ISTAT on population by municipality of Molise were used. The analysis was carried out in the R environment for statistical computing and visualization, and using the "forecast" package (Hyndman and Khandakar 2008).

5. Results and Discussion

Figure 6 shows a general view of depopulation in Molise (see also figure 5, section 3).

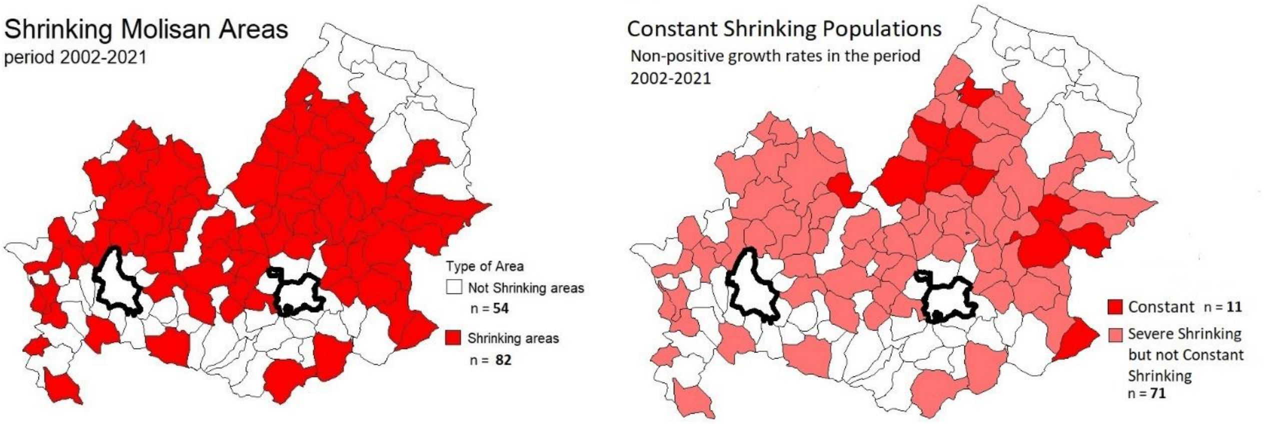

Figure 6. Molisan shrinking areas (municipalities with continuous growth rate below the -8‰) between the year 2002 and 2021, and constant shrinking populations in the period 2002-2021.

Note**:** Bold black boundaries identify the provincial main town, Isernia on the left and Campobasso on the right in each figure.

Source: Own elaborations on ISTAT data.

Populations of 82 municipalities out of 136 (i.e. around the 60%) declined from 2002 to 2021 at a continuous growth rate lower than -8‰: a severe shrinking. At the same time only 11 municipalities (8% of all municipalities and 13% of the shrinking areas) showed a continuous decline during the period 2002-2021, i.e. a non-positive growth in every year, from 2002-2021. As pointed out, at local scale and for small communities, erratic changes and volatility occur frequently.

By using a simple linear regression ([1], section 4], 45 municipalities (33% of all municipalities and 55% of shrinking areas) show a significant negative linear trend (figure 7, on the left). In order to take into account of the autoregressive structure of population change, we computed the ARMA Deterministic Trend ([2], section 4).

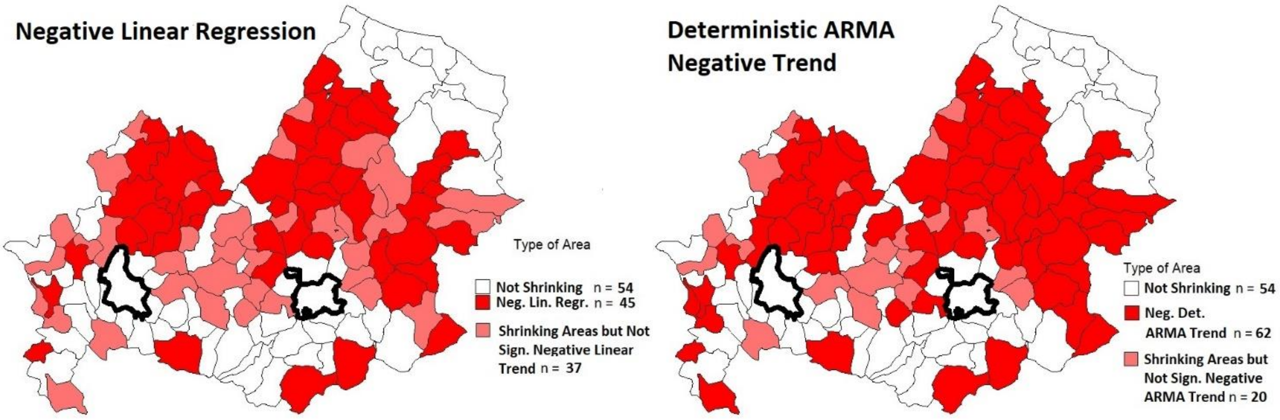

Figure 7. Molisan Shrinking areas (municipalities with continuous growth rate below the -8‰) between the year 2002 and 2021, significant linear regressions and significant negative ARMA deterministic trend
Note: Bold black boundaries identify the provincial capitals, Isernia on the left and Campobasso on the right in each figure.
Source: Own elaborations od ISTAT data.

In this case, 62 municipalities (46% of all municipalities and 76% of shrinking areas) show a significant negative trend (figure 7, on the right). The increase of municipalities is due to the relaxing of linear assumption, thanks to the ARMA process.

Finally, taking into account also for seasonality, the analysis of the population changes by identifying the existence of a stochastic negative trend including an ARIMA process is showed: i.e. the SyDAs Index ([3], section 4) represented in figure 8. In this case the systemic depopulation process is identified in 55 municipalities (40% of all municipalities and 67% of shrinking areas) a lower number than expected using a deterministic ARMA trend (due to robust estimate and seasonality effect) but higher compared to a simple linear regression (relaxing linear assumption and controlling for autoregressive structure).
Excluding the North-East area, that is the coastal zone of Molise, and the areas surrounding the two provinces (Campobasso on the right and Isernia on the left), most of the mountainous territory of Molise is characterised by a systemic depopulation process.
Nevertheless, there are some interesting exceptions: municipalities in the north belt of Isernia and in the lowlands, i.e. the North-East in the immediate surroundings of the coastal zone, show a systemic depopulation, while the municipalities on the mountains between the two provincial capitals did not[20].

[20] Cf. the elevation of Molisan municipalities in figure 4, Section 3.

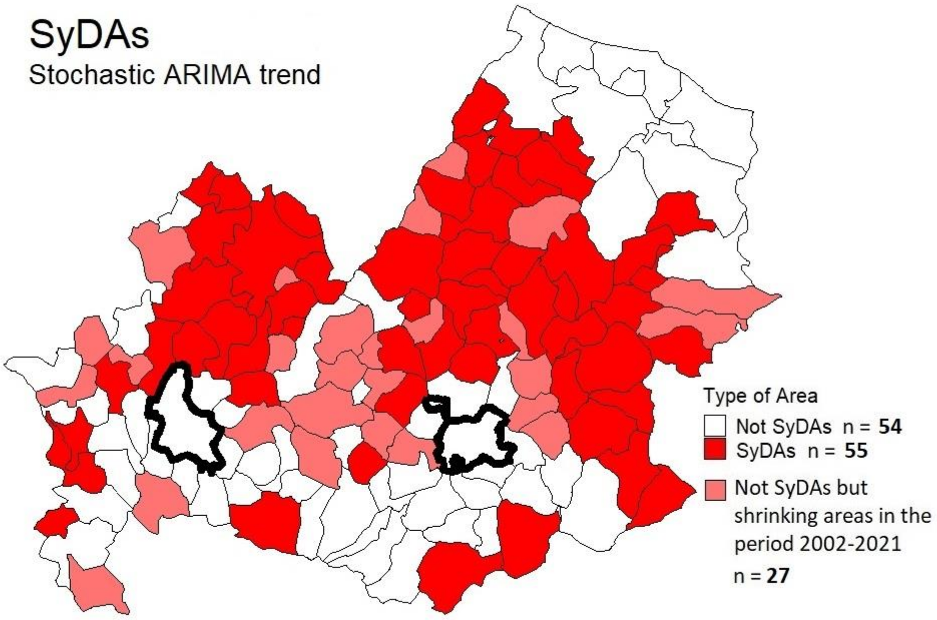

Figure 8. SyDAs Index. Bold black boundaries identify the provincial capitals, Isernia on the left and Campobasso on the right.

Source: Own elaborations od ISTAT data.

A differential analysis including spatial autoregressive effects on the combinations of demographic and socio-economic characteristics in these groups might explain such exceptions and give valuable insights for policy planning (see: Caselli et al. 2020, Benassi et al. 2023a, 2023b).

Finally, as practical application example, we overlapped the SyDAs and the municipalities participating to the SNAI policy program (figure 9). The SNAI program involves 72 municipalities where the SyDAs index identifies only 55 municipalities that are affected by a systemic depopulation process. Nevertheless, 20 municipalities affected by a systemic depopulation process according to the SyDAs Index result excluded by any of the 4 intervention zones of the SNAI program (36% of municipalities identified by the SyDAs index).
These municipalities are mainly concentrated in the lowlands in the North-East of the Region, near to the coastal zone. On the other hand, 37 municipalities included in the SNAI program, are not characterised by a systemic depopulation process, according to the SyDAs Index (47% of municipalities not identified by the SyDAs Index). These municipalities are mainly concentrated in the mountains between the two province town. It is interesting to observe that these two zones are the same that have been already detected as unusual, when commenting the first results from the application of SyDAs index. It is conceivable that the SyDAs index was able to capture a very early signal of new vitality in some municipalities, as to identify hidden deflecting processes in others.

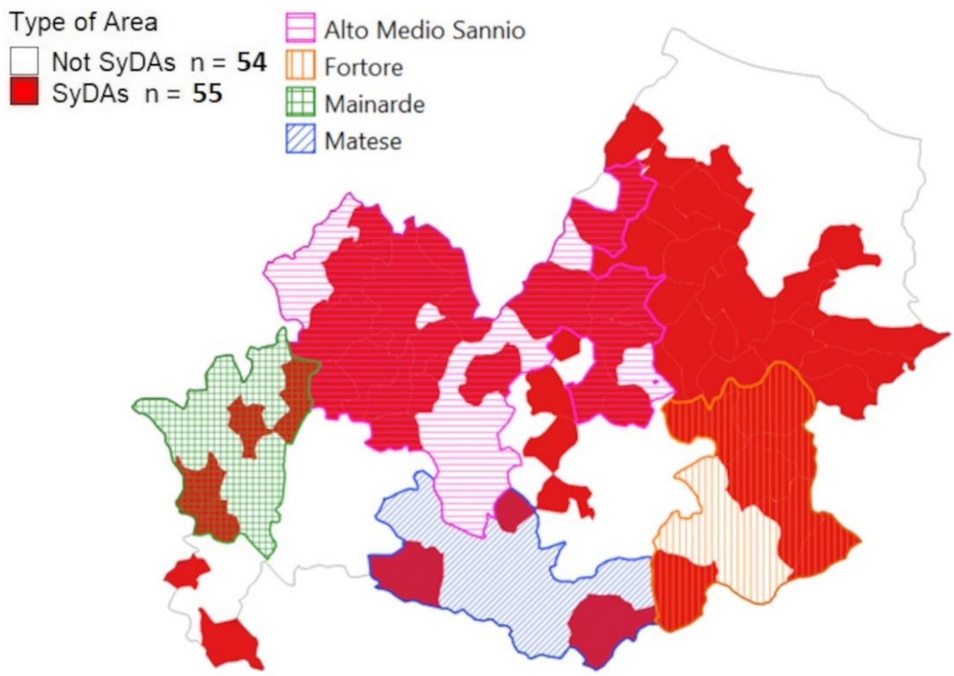

Figure 9. SyDAs Index and SNAI Areas of intervention.

Source: Own elaborations od ISTAT data.

If the process of shrinking and over-ageing has been already ongoing for a long period of time, even the quality of local policymakers could be negatively affected, increasing structurally the share of older people and assuming that migrations could operate an inverse selection on the local population in terms of human and social capital (under the hypothesis that young and better educated leave first). The quality of local administrators is a crucial factor of local economic performances, as pointed out e.g. by Resce (2022) and Antulov-Fantulin et al. (2021). This could partly explain the mismatch that we observed between the SNAI areas and the SyDAs.

6. Conclusions

Winter is coming, but the darkest hour usually precedes a new dawn: are we ready to capture the very first light? In introducing the SyDAs index, the goal is exactly this. The Index has been designed to be very sensitive in detecting the inversion of a systemic depopulation process, but at the same time able to ignore some volatility in population changes that can occur analysing very small populations. It has been designed to be very simple in assumptions and computations, and parsimonious in data requirements, in order to be applied at local level. In future, this index would be a useful tool to evaluate the policy efficacy (SNAI and RRP) with respect to depopulation at local level. Moreover, results showed a potential mismatch between geographic areas of policy intervention, determined via administrative procedures, and the local areas more in need of an intervention to stop the population decline. This last result call for some further considerations on the local administrators' ability level, that in turn could be related to the population decline itself, ending to be part of the self-powering systemic depopulation process.

7. References

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