Spatial Indicators to Evaluate Urban Fragmentation in Basilicata Region

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Abstract. The increase of artificial land use represents a relevant indicator in land management policies and practices. It is a useful tool in assessing the quality of settlement processes and the protection and enhancement policies in rural and natural areas. Over time land take processes have been caused by different phenomena: urban or industrial expansion, realization of infrastructures, the development or the productive exploitation of territorial areas characterized by the presence of specific resources (natural, mining, etc.). This phenomenon is no longer a direct consequence of a real need of new expansion areas throughout Italian national territory. In the past the phenomenon was mainly due to residential, productive or tertiary sector needs, and it was generated by demographic growth and the consequent urbanization process. In the last two decades land take is more and more related to a weak territorial governance, generally linked to an inefficiency of urban and territorial planning instruments and sometimes of speculative real estate initiatives. In this paper a spatial analysis procedure oriented to calculate indicators of urban fragmentation for Basilicata Region has been presented. Such indicators could drive to the identification of two phenomena: urban-sprawl and urban-sprinkling according to the literature classification proposed in several researches by Romano et al. The results represent a useful contribution in order to improve regional normative system concerning urban development. The research is part of a wider project on environmental and territorial indicators (INDICARE) promoted by FARBAS (Environmental Observatory Foundation of Basilicata Region) in collaboration with the University of Basilicata.

Keywords: Fragmentation · Urban sprawl · Basilicata region
Land take

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1 Introduction

In the last decades, in Europe, urban fabric is developing according to the sprawl model [1–4]. Among the main impacts of this model of territorial development the destructuring of settlement fabric, urban fragmentation, insulation, natural landscape degradation can be certainly included.

In particular, the fragmentation process of natural landscape can be divided in two main components: one relates to the disappearance of natural environments and reduction of their surface; the other one concerns the progressive insularization and redistribution of residual environments in the space. The continuous expansion of the anthropized areas transforms agricultural and natural soil in new residential areas, often characterized by low residential density. This constantly growing trend determines not negligible environmental and social effects, leading to the formation of medium-small urban centres, geographically decentralized with respect to the main poles [5, 6]. Among other effects, land cover dynamics influence the spatio-temporal evolution of RUI (Rural Urban Interface), which are the areas most prone to human-caused forest fires [7]. In 2015, the wooded and non-wooded areas of Basilicata Region crossed by fire were 1.6 m^2 over 1000 km^2 [8].

Scattered settlements generate an increase the demand of infrastructure and transport services, producing an increase of costs which goes over sustainable thresholds [9, 10, 24]. Italian settlement models show non-negligible differences compared to the European ones, thus justifying the use of the term *sprinkling* [11].

This work aims at the evaluation of spatial fragmentation indicators allowing to characterize current urban development processes, as sprawl or sprinkling [12]. It is part of a larger research project, called "INDICARE", which deals with the indexing of regional environmental critical issues (of Basilicata Region) in several environmental fields. The operational approach proposed by the research project is based on the construction of a methodology linking knowledge to actions, information and participation. Through advanced tools and techniques, useful results for regulatory and procedural innovation in the field of territorial governance and monitoring of dynamics under way have been achieved.

Among the main components characterizing the wider research, great importance has been given to the evaluation of urban growth and its effects in terms of territorial fragmentation and degradation of natural-environmental system. More in particular, it is oriented to obtain qualitative and quantitative assessment framework defining territorial exposure to stress factors considered in spatial and temporal dimensions. The proposed indicators are configured as a decision support tool for the construction of territorial management models considering the mitigation of impacts as a priority. This study will be also finalized to enrich the spatial database already available on the RSDI[1] [13] platform of Basilicata Region.

[1] RSDI: acronym for Regional Spatial Data Infrastructure. Is an infrastructure for the Territorial Information, aligned with the indications of the European INSPIRE directive, open to the participation of local authorities and local companies interested in territorial information systems, according to the logic of data sharing and cooperation and geographic services. All data are open.

The paper starts from the description of the study area, discusses the methodology used and presents the main results. Conclusions concern reflections on obtained data and any future developments.

2 Materials and Methods

In this paper the evolution of settlement system according to information coming from three official sources will be analysed: geo-topographic regional database (RSDI Basilicata Region); ortho-photos from the national geo-portal of the Ministry of the Environment and IGM (Military Geographic Institute) cartography. Concerning temporal dimension of the analysis, selected sources allow us to identify five time phases: 1950 – 1989 – 1998 – 2006 – 2013 according to which we calculated territorial fragmentation. Furthermore, we compared such results with census data.

2.1 Study Area

The study area includes the whole territory of Basilicata region in southern Italy (Fig. 2), which covers about 10.000 km^2, and has a population of 570.365 inhabitants (ISTAT [14], 2016) with a density of 57.93 inhabitants/Km^2.

Table 1 shows the statistical data relative to the two provinces. The population of the region has been continuously decreasing since 1980s, this trend is completely in contrast with urban settlement development which actually increased during the same period (Fig. 1).

No correspondences could be found between population growth and new housing demand. This means that urban growth is mainly due to a lack in urban regulation and in the implementation of planning tools at municipal and regional level. All this has led, in most cases, to a high fragmentation.

2.2 Data Acquisition

In order to build the spatial datasets describing settlement evolution of the study area, several sources of information were considered: the main reference is the regional cartography (scale 1:5000) of Basilicata Region at 2013. This spatial dataset is available as open data on the RSDI website. Such information has been used as a starting point to extract buildings. Starting from the buildings at 2013, the date of the last photogrammetric survey, we proceeded backwards: analysing [1] the ortho-photos available as *wms* service on National Geoportal of the Ministry of the Environment and Protection of Land and Sea [15] and considering different dates of photogrammetric flights at 2006, 98/2000 and 1988/89. Comparing the current regional cartography with previous ortho-photos several backwards maps have been constructed.

In order to identify a source of information after the Second World War, corresponding to the greatest urban growth in Italy, maps at 1: 25000 scale, realized by the Military Geographical Institute (IGM) in 1950 have been used. Despite they are not very detailed maps, they represent the oldest reliable technical representation of Basilicata Region, allowing to recognize single buildings.

Table 1. Distribution of population (2016, date of the last census – ISTAT), territorial surface, Population density and number of municipalities in the two Provinces of Basilicata Region.

Territorial area	Population (inhabitants)	Territorial surface (Km^2)	Population density (inhab/Km^2)	Municipality (number)
Province of Potenza	370.680	6.541	57.68	100
Province of Matera	199.685	3.443	58.42	31
Basilicata region	**570.365**	**9.984**	**57.93**	**131**

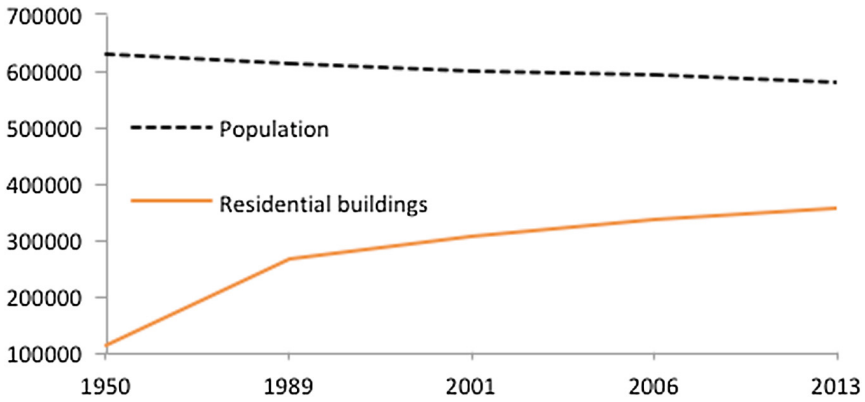

Fig. 1. Comparison between settlement evolution concerning residential buildings and population evolution from 1950 to 2013.

Concerning demographic data, Italian National Institute of Statistics (ISTAT) databases have been used.

Data at municipalities aggregation have been analysed, considering the population at different years: 1950 – 1989 – 1998 – 2006 – 2013, in order to compare population and urban growth. In addition, data on demographic projections at provincial and regional level were analysed.

2.3 Methodology

The regional technical map, provided by RSDI, contains the representation of the built environment dated 2013 for the whole region. In particular, the shape file of the 'volumetric units' was used. The information included in the file allowed us to derive area and volume for each building.

From the comparison between the shape file of the volumetric units and the ortho-photos from National geo-portal and IGM maps, five shape files have been created representing the built environment at different dates:

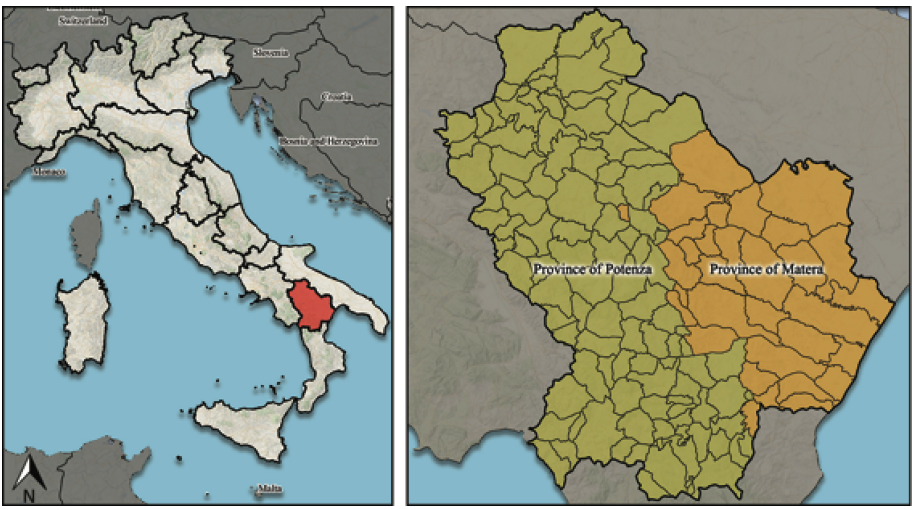

Fig. 2. The location of Basilicata region in Italy on the left and the location of the Provinces of Potenza and Matera with their relative municipalities on the right.

- Volumetric units in 2013: directly from the regional technical map of the Basilicata region.
- Volumetric units in 2006: from digital colour ortho-photos of the Italian territory with a resolution of 1:10000 and viewable only at scales above 1: 100000 in *wms* service.
- Volumetric units in 2000: from digital color ortho-photos of the Italian territory with a resolution of 1:10000 and viewable only at scales above 1: 100000 in *wms* service. The dates of the photogrammetric flights vary according to the area from 1998 to 2000.
- Volumetric units in 1989: from black and white ortho-photos of the Italian territory with a resolution of 1:10000 and viewable only at scales above 1: 100000 in *wms* service. The dates of the photogrammetric flights vary according to the area from 1988 to 1989.
- Volumetric units in 1950: from the topographic map of Italy to scale 1: 25000 (IGM).

For each temporal phase, data about resident population, buildings number and volumes were reported.

Since the regional technical map does not contain information on the use of buildings, a crosscheck with data collected during the residential buildings census realized by ISTAT at 2011 was performed.

2.3.1 Aggregates Formation

Once the historical evolution of buildings was completed, the aggregates were formed. The advantage of studying urban aggregates is to understand in detail the path of settlement evolution. It is important to underline that the increase of buildings may

correspond to an increase in the number of aggregates or, alternatively, to an increase of the aggregate area, which is explained by a growth in buildings around pre-existing urban areas. Aggregates are orthogonal polygons constructed starting from a distance between single original elements, in this case buildings, which can be, from time to time, modified. Aggregation occurs only when two polygon limits are within the specified aggregation distance. The aggregation can take place with orthogonal or not orthogonal features (Fig. 3).

It is necessary to specify that the urban aggregates do not contain perimeters of built up centres. In fact, the built-up centre is delimited, for each inhabited nucleus or inhabited centre, by an uninterrupted perimeter including all areas built with continuity and interclused lots. In this context we simply refer to a new strategy representative of groups of buildings clustered together within an urbanized area.

2.3.2 DA Index

A fragmentation index has been adopted for the assessment of the fragmentation degree of the territory. More in detail, the Density index of Aggregates DA [16] index has been used. DA (1) allows to analyse the variation in the number of aggregates and their areas in order to evaluate the degree of fragmentation of each municipality of Basilicata Region.

$$DA = \frac{\Delta NA}{\Delta A_{Average}} \tag{1}$$

Where:

- ΔNA represents the variation in the number of aggregates present in every municipality of Basilicata in the considered historical phase.
- $\Delta A_{Average}$ represents the variation in average of the areas of all the aggregates present in every municipality of the regional territory. The area of the larger aggregate, generally represented by the main urban centre, will be subtracted from this value.

The bigger the DA absolute value will be, the greater the degree of fragmentation of a territory will be [17]. alues very close to zero will correspond to an almost null degree of fragmentation, while higher values will correspond to a medium-high fragmentation degree. For the assessment of the index, the absolute value will be considered. The negativity of index is depending on:

- $\Delta NA < 0$: the number of aggregates between two historical phases decreases i.e., existing aggregates are merged. Such a phenomenon does not cause an increase in fragmentation. An example is shown in Fig. 4.
- $\Delta A_{Average} < 0$: between one historical phase and another the average of the areas of all the aggregates decreases. This corresponds to the formation of new small aggregates, a phenomenon that negatively affects the degree of territorial fragmentation.

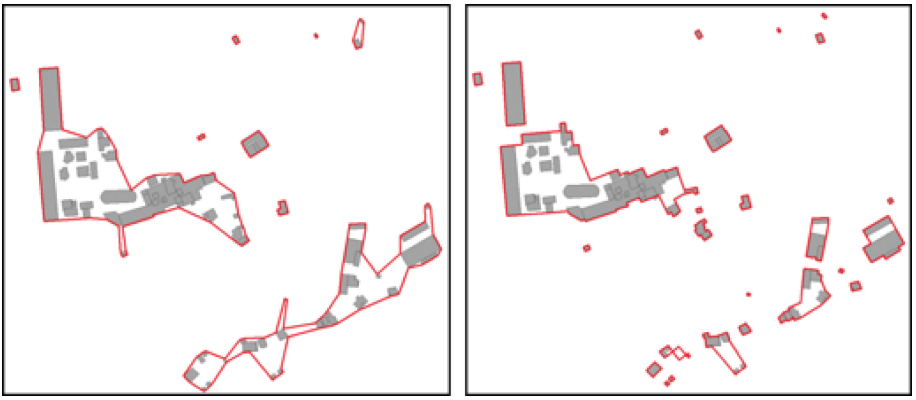

Fig. 3. Aggregations of buildings: with not orthogonal features on the left and with orthogonal features on the right.

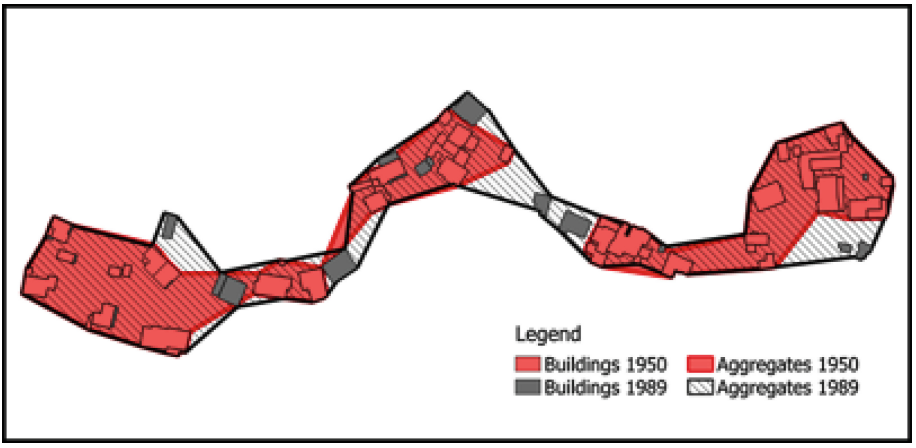

Fig. 4. Example of negative variation of aggregates number.

In order to identify the degree of fragmentation of each single municipality of the region brought about by the constructions that took place during certain years, the DA index will be calculated on the variation of the data between 1950 and 1989 and between 1989 and 2013.

3 Results and Discussion

The analysis of the historical evolution of the building was carried out on the regional territory, obtaining results for all the 131 municipalities. Table 2 shows the results grouped for the entire region for each considered phase. It can already be seen from this first analysis how the population decreased and the number of buildings increased from 1950s up to nowadays (Fig. 1).

Table 2. Variation of population and buildings in Basilicata region over time.

Years	Pop (inhab)	Building (n)	Volume (m^3)	m^3/inhab	Building/inhab	m^2/inhab
1950	627.586	113.479	90.974.952	144.96	0.18	48.32
1989	610186	266.409	223.249.429	365.87	0.44	121.96
1998	597.468	307.649	263.237.360	440.59	0.51	146.86
2006	591.338	335431	291.679.901	493.25	0.57	164.42
2013	578.391	356785	304.459.018	526.39	0.62	175.46

Table 3. Variation of number of aggregates and their surface, variation of urban density (DU) and population density.

Years		Basilicata Region	Province of Potenza	Province of Matera
1950	N. of aggregates	27.062	20.712	6.350
	Surf. of aggregates *(Km^2)*	34.06	26.19	7.87
	DU *(%)*	0.34	0.40	0.23
	Dp *(inhab/km^2)*	62.85	68.06	52.98
1989	N. of aggregates	56.958	37.981	18.977
	Surf. of aggregates *(Km^2)*	106.93	74.72	32.21
	DU *(%)*	1.07	1.14	0.94
	Dp *(inhab/km^2)*	61.12	61.39	60.70
1998	N. of aggregates	62.818	42.518	20.300
	Surf. of aggregates *(Km^2)*	130.52	93.63	36.89
	DU *(%)*	1.31	1.43	1.07
	Dp *(inhab/km^2)*	59.84	60.11	59.34
2006	N. of aggregates	66.127	45.161	20.966
	Surf. of aggregates *(Km^2)*	148.40	106.34	42.06
	DU *(%)*	1.49	1.63	1.22
	Dp *(inhab/km^2)*	59.22	59.29	59.11
2013	N. of aggregates	68.941	47.126	21.815
	Surf. of aggregates *(Km^2)*	160.56	115.19	45.37
	DU *(%)*	1.61	1.76	1.32
	Dp *(inhab/km^2)*	57.93	57.67	58.42

Buildings inhabitants were 0.62 in 2013 over 0.18 buildings inhabitants in 1950. The datum is very high if we consider that we are not talking about rooms but of whole buildings. The rate regarding the surface available for each inhabitant, calculated assuming an inter-floor space of 3 m, is also vertiginously increasing.

For each of the five phases of settlement evolution, buildings have been aggregated with a methodology explained in Sect. 2.3.1, by the non-orthogonal features and considering a minimum distance of 50 ms. Such distance was the most appropriate to represent the aggregation of buildings in Basilicata Region. The 50 m aggregation was chosen among the various aggregates obtained with distances set at 50, 100 and 200 m

and has allowed the perimetration of urban aggregates for each temporal phase. This analysis allows a preliminary assessment of number of urban aggregates variation, their area and urban density (DU). DU, the urban density index is expressed as a percentage and it is calculated as the ratio between the surface of all aggregates and the whole surface of the municipality. The results are summarized in Table 3, grouped at Provincial and Regional level. In Table 3 it is reported also the Dp (Density Population) index measured as inhabitants/Km^2. It has been calculated for the five temporal phases, for each municipality of Basilicata Region, as the ratio between the population (number of inhabitants) and the territorial surface (Km^2) (cfr. Table 2) [18].

Table 4. Degree of urban fragmentation according to the value of DA.

Fragmentation	DA
Not fragmented	$DA = 0$
Little fragmented	$0 < DA < 1$
Fragmented	$1 \leq DA < 10$
Highly fragmented	$DA \geq 10$

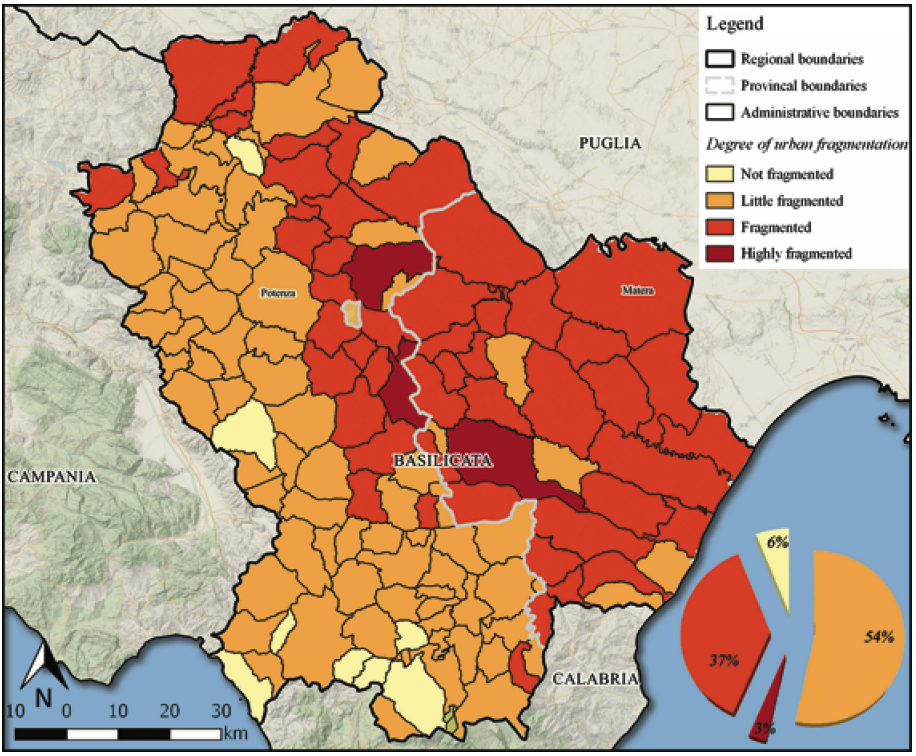

Fig. 5. Degree of urban fragmentation of 131 municipalities of Basilicata region. 1950–1989.

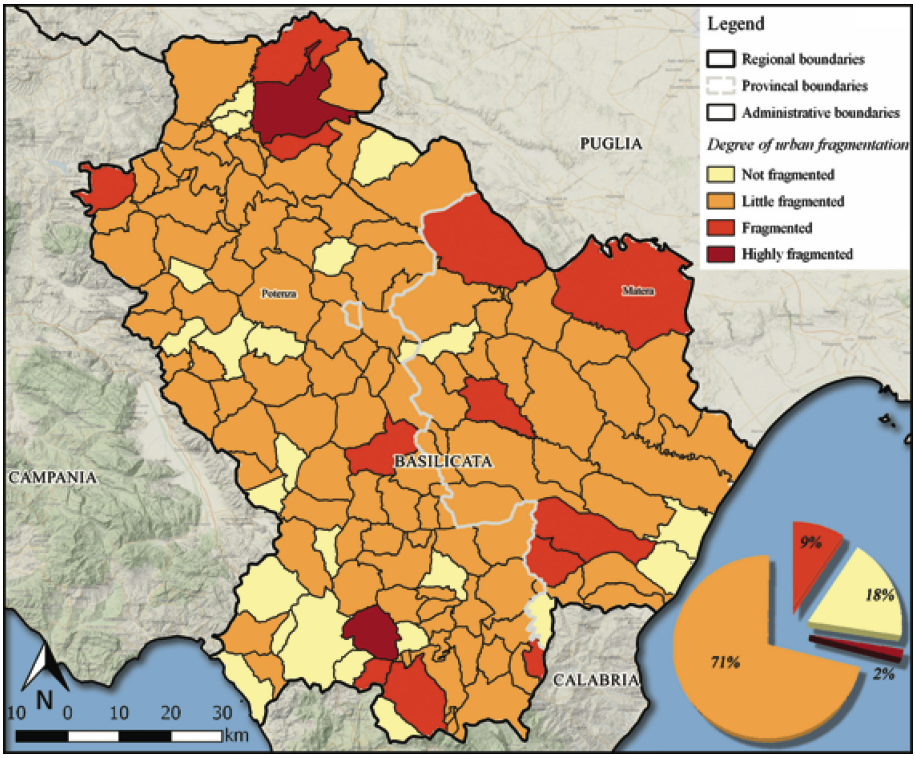

Fig. 6. Degree of urban fragmentation of 131 municipalities of Basilicata region. 1989–2013.

The DA (1) index was calculated, for each municipality, based on the variation of the number of aggregates and their surfaces between 1950 and 1989 and between 1989 and 2013. It can assume values varying between $-\infty$ and $+\infty$, depending on reference territorial extent with respect to which the index is calculated. In our case, the values obtained oscillated in a range between −20 and +20. As anticipated in Sect. 2.3.2 the DA index is considered as absolute value and values very close to zero will correspond to an almost zero degree of fragmentation, while higher values willl represent degrees of medium-high fragmentation. A schematization is shown in Table 4.

A little rate of fragmentation represents a little variation in the number of aggregates and an increase in the average of aggregates surface. This means that the aggregates expand and incorporate the existing ones, as shown in Fig. 4.

A highly rate of fragmentation represents an increase in number of aggregates and in average of their surfaces. This means that the buildings evolution variation occurred in a given period has led to the birth of numerous big aggregates far from the existing ones.

Figure 5 shows the degree of fragmentation of each municipality according to building development that took place between 1950 and 1989. Figure 5 highlights a degree of medium-high fragmentation in most of municipalities of Matera province and a low degree of fragmentation in large part of municipalities in Potenza province. In the

whole Region only 6% of the municipalities are not fragmented, 54% are little fragmented, 37% are fragmented and 3% are highly fragmented.

Figure 6 shows the degree of fragmentation of the territory following the recent urban development, i.e. between 1989 and 2013. Considering the 131 municipalities of Basilicata, 18% are not fragmented, 71% are little fragmented, 9% are fragmented and 2% are highly fragmented, according to the settlement development occurred between 1989 and 2013.

Comparing the two images, it is possible to observe that great part of fragmentation occurred between the '50s and the '80s, a period when housing demand was correlated to a huge demographic growth and great part of urban growth was governed by plans.

4 Conclusions

The described analyses aim to provide spatial and temporal indices of soil consumption for building purposes. The results, from 1950 to 2013, show an ever increasing trend in the number of urban aggregates. This involves on one side a decrease of aggregates average area and on the other side their increase in number. The whole territory is subject to a growing fragmentation of the settlement system. Throughout the region, urban expansion takes place with a pulverized growth model, to the disadvantage of the urban aggregation that would have led to an improvement in land management, also improving the infrastructural system organization. This fragmented structure of territorial system increases land take and has a significant environmental impact [19–22].

Although the main Italian law (n. 1150/1942) on urban planning is quite old Basilicata Region has always shown delays. The region approved his first territorial government law only in 1999 and since then this law has not been implemented at all. Before 1968 no municipality had an approved plan, between 1968 and 1978 only 15 municipalities had a plan and in 1985 only 26 municipalities approved a plan [23]. This means that in the greatest expansion period only a few municipalities adequately managed this phenomenon. This justifies the high degree of fragmentation generated by the urban expansion that took place between 1950 and 1989, without adequate planning tools. Another aspect that characterizes Basilicata region is the huge decrease of population, especially in small municipalities, which generates abandonment of housing.

A particularly useful future development of this paper could be the monetary quantification of fragmentation, based on the distance between the scattered settlements and the compact centre calculating all extra costs related to all the infrastructural and transport networks. The monetization of the index makes it possible to give greater importance to the analysed phenomenon making it comparable with other quantities.

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