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GEOSTATISTICAL METHODS TO MEASURE THE NATURE 2000 HABITAT INSULARIZATION IN ITALY

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Abstract

It is interesting to notice how Nature 2000 is described as an instrument of "widespread ecological network throughout the EU territories", insisting in a definitional imprecision that has been dragging on for more than twenty years, and that was often, also authoritatively, criticized by many. Undoubtedly, many of these elements constitute the focal point of local ecological networks for species conservation importance, but their functionality depends on equally undoubtedly by the presence of ecologically permeable matrices that enable the biotic flows dynamics. The Italian Regions are the subjects of this study, as an expression of homogeneous forms of territorial government and as a reference on the administrative level for the implementation of Community policies for Nature 2000 network. The method followed in the work refers to an evaluate spatial fragmentation conditions methodology and the SCIs are the evaluated patches, which have a high dispersion on the national territory. This research has been conducted to show how the central issue of habitat and species conservation is still currently the fragmentation provoked by mobility infrastructures and urban planning

Keywords

Environmental fragmentation; Urban sprinkling; Landscape planning

Introduction

On the Italian Ministry of Environment, Land and Sea webpage (http://www.minambiente.it/pagina/rete-natura-2000) are described, using didactic language, the aims and goals of Natura 2000 project:

> Natura 2000 is the main European Union policy's instrument for biodiversity conservation. It is a widespread ecological network throughout the EU territory, established according to the Council Directive 92/43/EEC called "Habitat", to protect in the long term the conservation of natural habitats and wild flora and fauna species in danger of disappearance or rare on at the Community level. Natura 2000 network is constituted by the Sites of Community Importance (SCI), identified by the Member States according to the Habitat Directive, which are subsequently designated as Special Area of Conservation (SAC). It also includes the Special Protection Areas (SPA), established according to the Directive 2009/147/EC called "Birds", concerning the conservation of wild birds. Natura 2000 areas are not strictly protected reserves

where human activities are excluded; Habitat Directive aims to ensure nature protection taking account of economic, social and cultural requirements and regional and local characteristics (Art.2). Private individuals may be owners of Natura 2000 sites, ensuring an ecologically and economically sustainable management. The Directive recognizes the value of all those areas where the secular human presence and its traditional activities has enabled the maintenance of the balance between anthropic activities and nature. Agricultural areas, for instance, are linked to numerous rare or endangered animal and vegetal species, which survival is threatened and it is necessary the continuation of the enhancement of traditional activities, such as grazing and non-intensive agriculture. On the very title of the Directive, it is specified the aim of conserving not only natural habitats but also semi-natural ones (as the traditional agriculture areas, wood, grazing land, etc.). Another innovative aspect is the recognition of the importance of certain landscape features, which play a connection role for wild flora and fauna (Art.10). Member States are encouraged to preserve or develop these features to improve the ecological coherence at Nature 2000 network. In Italy, SCI, SAC, and SPA all together, cover the 19% of the national land territory and almost the 4% of the marine one.

It is interesting to notice how Nature 2000 is described as an instrument of "widespread ecological network throughout the EU territories", insisting in a definitional imprecision that has been dragging on for more than twenty years, and that was often, also authoritatively, criticized by many (Battisti, 2011).
Here, we are not going to explain again the constitutional details of ecological networks, referring to a multitude of much quoted scientific works (Linehan *et alii*, 1995; Forman, 1995; Jongman, 1995; Bennett, 1999; Fahrig, 2003; Battisti, 2003; Crooks e Sanjayan, 2006; Boitani *et alii*, 2007; Gibelli and Santolini, 2015). However, it should be emphasized, solely for introductory purposes of this work, the conceptual unstitching between the shared model of ecological network and geographical configuration of Nature 2000 sites, particularly to the ones belonging to the Sites of Community Importance (SCIs). Italy has almost 2.000 sites (Tab. 1), with an average size of about 1600 ha, placed at widely varying distances between them: from a few hundred meters to tens of kilometers. Undoubtedly, many of these elements constitute the focal point of local ecological networks for species conservation importance, but their functionality depends on equally undoubtedly by the presence of ecologically permeable matrices that enable the biotic flows dynamics. The scientific knowledge on Nature 2000 sites has been scrupulously examined during the last decade, thanks to a substantial provision of economic resources from the Regions. On the contrary, the knowledge on territories eco-functional prerogatives, which contain the sites themselves, is very limited. On these territories there have been carried out a settlement and transformative pressure, without special precautions, responding to the same economical-political-social criteria that have always driven it, well before "Habitat" Directive was enacted and effective.
Even if it is possible to see multiple signals for approach variations from European bodies, currently much more careful to improve the ecological coherence of Nature 2000 network, taking actions directed on the agricultural picture and on the settlement diffusion (Bonnin *et alii*, 2007; EEA, 2010; CE, 2012; CE, 2016), it still remains an unsolved issue the Italian terrestrial SCIs' objective ecological fragmentation. These last ones are distributed with a 10 ha/km^2 ratio (Tab. 1), inside an area where the settlement presents the same average density

(about 7% urbanized surface and 3% suburban road surface) and an high population density (almost 200 inhabitants/km^2), with multiple disturbance effects now well explained by a vast scientific production on this subject (Bierwagen, 2005; Girvetz *et alii*, 2008; EEA, 2011; Romano *et alii*, 2014; Fiorini *et alii*, 2016; Zullo *et alii*, 2016). SCIs' eco-functional solution has to be provided by the ecological networks, considered as Regional institutional layers. The Italian Regions where a local "designed" ecological network has become part of ordinary regulations regarding the urban transformations supervision, are very few (Umbria, Lombardia, Emilia Romagna, Toscana e Marche). On the rest of the Italian territory, the environmental matrices that contain Nature 2000 sites continue to face settlement evolutions, solely driven by the municipal urban planning tools, which, not even rarely, show sensibility toward the ecological connections subject, but that are still episodic and random (Montanari *et alii*, 2010; Lombardi *et alii*, 2014; Frontoni *et alii*, 2014; Ragni, 2009; Malcevschi e Lazzarini, 2013).

REGION	Regional Area (ha)	Terrestrial SCIs/SCZ			
		Number	Area (ha)	% region	Mean Area (ha)
Abruzzo	1082699,34	53	232707,00	21,5%	4390,70
Basilicata	1007279,56	41	38672,00	3,8%	943,22
Calabria	1522338,44	178	70197,00	4,6%	394,37
Campania	1360917,22	93	321391,00	23,6%	3455,82
Emilia-Romagna	2218436,81	71	78064,00	3,5%	1099,49
Friuli-Venezia Giulia	785992,83	55	75302,00	9,6%	1369,13
Lazio	1722149,03	161	98526,00	5,7%	611,96
Liguria	540594,93	126	138067,00	25,5%	1095,77
Lombardy	2386118,81	175	204430,00	8,6%	1168,17
Marche	974954,49	68	94488,00	9,7%	1389,53
Molise	446103,32	76	65607,00	14,7%	863,25
Piedmont	2538879,38	95	119548,00	4,7%	1258,40
Puglia	1953385,64	73	232618,00	11,9%	3186,55
Sardinia	2392007,60	87	269333,00	11,3%	3095,78
Sicily	2555398,17	208	360735,00	14,1%	1734,30
Tuscany	2268095,74	90	207770,00	9,2%	2308,56
Trentino-Alto Adige	1360076,94	146	158679,00	11,7%	1086,84
Umbria	846107,82	97	103212,00	12,2%	1064,04
Valle d'Aosta	326092,95	25	25926,00	8,0%	1037,04
Veneto	1842399,67	63	198871,00	10,8%	3156,68
Total	**30130028,68**	**1981**	**3094143,00**	**10,3%**	**1561,91**

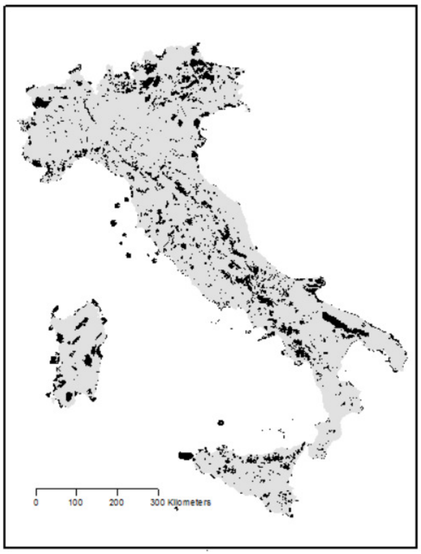


Table 1 – Terrestrial SCIs and SCA (Special Conservation Areas) distribution and consistency by Region (Data processed by http://www.minambiente.it/pagina/sic-zsc-e-zps-italia - gennaio 2016)

What have been just stated is shown in Fig. 1: in the SCIs' immediate adjacency mileage range, during the 50s, there were 84.000 ha of urbanized areas; later on, after 2000, they became more than 300.000 ha, with an average increase of 260%, therefore, there was an important emphasis on the habitat isolation of these strategic habitats.

For the reasons given, jointly with the progress of Nature 2000 sites settling phases, that are management plans approval, SCA conversion, PAF (Prioritizing Action Frame) implementation, today it appears essential to explore the subject of their spatial and ecological fragmentation, to avoid further transformative behaviors that may seriously affect the role of biodiversity conservation that the European Directives give to Nature 2000 system.

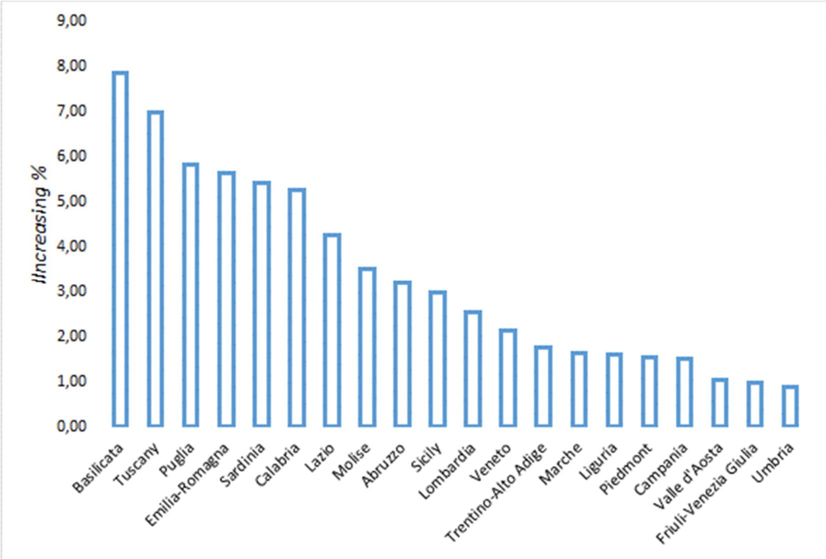


Figure 1 – Urbanized surfaces increase within 1 km buffer from Italian Nature 2000 sites.

Materials and methodologies

The Italian Regions are the subjects of this study, as an expression of homogeneous forms of territorial government and as a reference on the administrative level for the implementation of Community policies for Nature 2000 network; while the processed information come from the ministerial SCIs dataset, updated at January 2016 (Tab. 1). The method followed in the work refers to an evaluate spatial fragmentation conditions methodology, already implemented and tested in 2012, however, applying it to the Italian "bio-permeable" areas and forests, whose definitions are referred to the general guidelines (Romano and Zullo, 2012). In this work the SCIs are the evaluated patches, they have a high dispersion on the national territory, and their buffer radial step is equal to 500 m; therefore, the considered distances were: 500, 1000, 1500, 2000, 2500 m (Fig. 2). Buffer's depth, intended as the radial segment of the patch edges, it is always constant. The buffer generation surrounding the patches generates the reduction of the distances among them till the overlapping of the created buffers, that, thanks to the aggregative effect, weld together. As a result, a new configuration is formed, where the number of the resulting patches decreased. This new configuration allows us to put in relation buffer's distances and corresponding patches' numbers, until we arrive at the extreme value of n.1 patch when all the original ones result welded the one to the other. Hence, it is possible to elaborate curves that put in relation buffer's distances and patches' number (fragmentation reduction curves) as shown in Figure 2 about Umbria Region.
Afterward, from this data, fragmentation reduction curves were implemented, carrying the buffer's distance in the *x*-axis, and the Fragmentation Reduction Rate (FRR) in the *y*-axis.
Given that there is order 1 buffer and the following ones are order 1+*i*, the FRR value is:

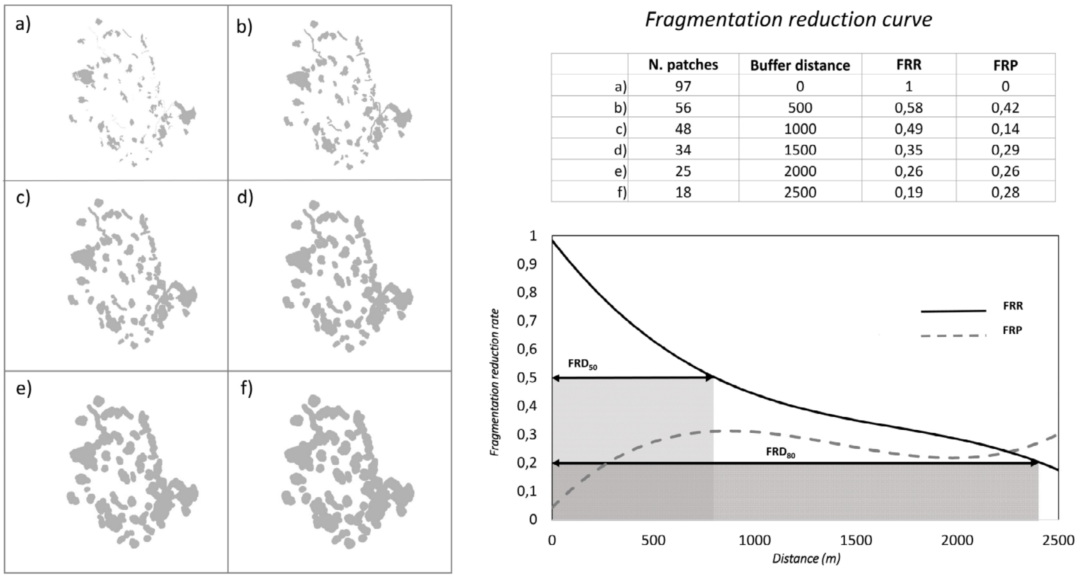
[1] $$FRR = \frac{Np_{(1+i)}}{Np_{(1)}}$$

Where:

$Np_{(1)}$= number of patches deriving from the aggregation with order 1 buffer

$Np_{(1+i)}$= number of patches deriving from the aggregation with order 1+*i* buffer

Fragmentation reduction curve shows that the greater the distance between the buffer, the more compact are the patches, with an increase of environmental continuity. From the functions that express the fragmentation curves (generally third grade polynomial), it is possible to calculate reduction distances of the fragmentation itself (FRD*x*). Where there is fragmentation reduction distances the patches partition decreases for a certain ratio: for example, FRD show the aggregation distance corresponding to a measured fragmentation reduction of 50-80%.



	N. patches	Buffer distance	FRR	FRP
a)	97	0	1	0
b)	56	500	0,58	0,42
c)	48	1000	0,49	0,14
d)	34	1500	0,35	0,29
e)	25	2000	0,26	0,26
f)	18	2500	0,19	0,28

Figure 2 – FRD indexes calculation method: buffer aggregative graphic framework with constant radial segment (500 m), following the Umbria Region example.

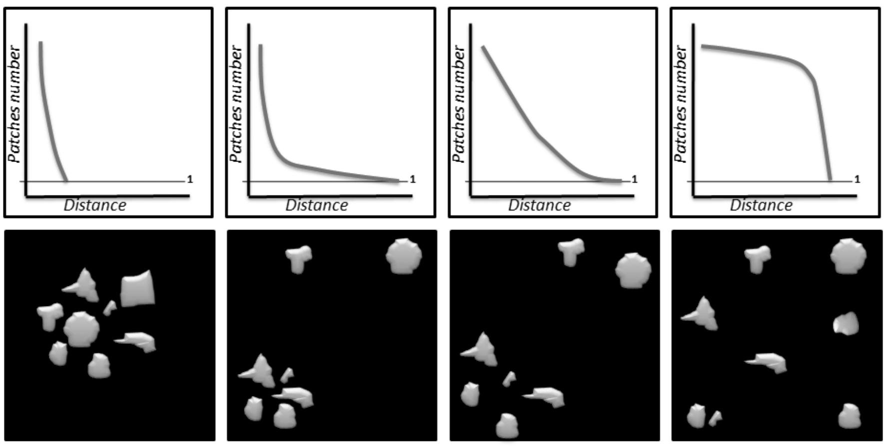


Figure 3 – Fragmentation reduction curves sampling

Fragmentation reduction curves geometry (Fig. 3) allows to classify four sampling models. A and D are the extreme cases: in the A example, it is sufficient to work on short distances to connect the patches together because they are already quite aggregated. Instead, D case is about greatly disjointed patches, and it is necessary to work on long distances. B and C are the intermediate cases. In the B case there is a group of patches very close one to the other and some other one is more distant. In the C example there is a group of patches quite close between them (environmental matrices few disaggregated) and other residual patches more isolated.

Simultaneously with the FRR and FRD, it was created another index called Fragmentation Reduction Performance (FRP), which corresponds to the aggregate patches reduction ration, while moving from one buffer to another.

Given that there is order *m* buffer and the following ones are *m*+1, the FRP value is:

[2] $$FRP = 1 - \frac{Np_{(m+1)}}{Np_{(m)}}$$

Where:

$Np_{(m)}$= number of patches deriving from the aggregation with order m buffer

$Np_{(m+1)}$ = number of patches deriving from the aggregation with order m+i buffer

This index shows buffer's welding distance where there is the higher level of aggregation. It appears to be a more convenient distance where to invest plan and project resources, to obtain as a result continuity among the Nature 2000 sites.

Results

In the last half century, one of the major effects on the urban conversion was the spatial and ecological habitat isolation of the most important Italian natural areas for the bio-diversity conservation. Fig. 4 highlights the drastic reduction of territorial sections, happened in 2000 (organized on a 5x5km plot), with low urban density (DU<2%) compared to the existing situation during the '50s. It is not clear that exists a link between the latitudinal belts and the phenomenon analysed in this work, which it appears to be mainly related to local dynamics. However, developing this information separately for each of the three Italian geographic areas, it is evident how the parameter doubled in the Northern Italian regions and more than tripled in the Centre and Southern Italy.

With the Italian SCIs' habitat isolation study, conducted following the previously stated method, we can see that (Fig. 5) more than a half of the Regions (11 out of 20) show a situation close to the Fig. 3 C model, with slightly concentrated and rather far sites, with very progressive patches welding and very high FRD_{50} (exceeding 1km).

Only in Molise and Campania are found similar situations close to B model, being most of the SCIs very concentrated and having a very high FRD_{50} (within a 500m range). Hybrid C and D models concern most of the Regions including Marche, Umbria, and Sicily, with a part of the SCIs' highly concentrated and the other part very scattered, with an FRD_{50} included between 500 m and 1 km, but with an FRD_{80} far superior to 2 km. The only case which appears to be clearly belonging to the D model is the Abruzzo's one, while Sardinia is the Region with more distant and more scattered sites, which generate the highest FRD_{50} and FRD_{80} values, both far superior to 2 km (Fig. 6).

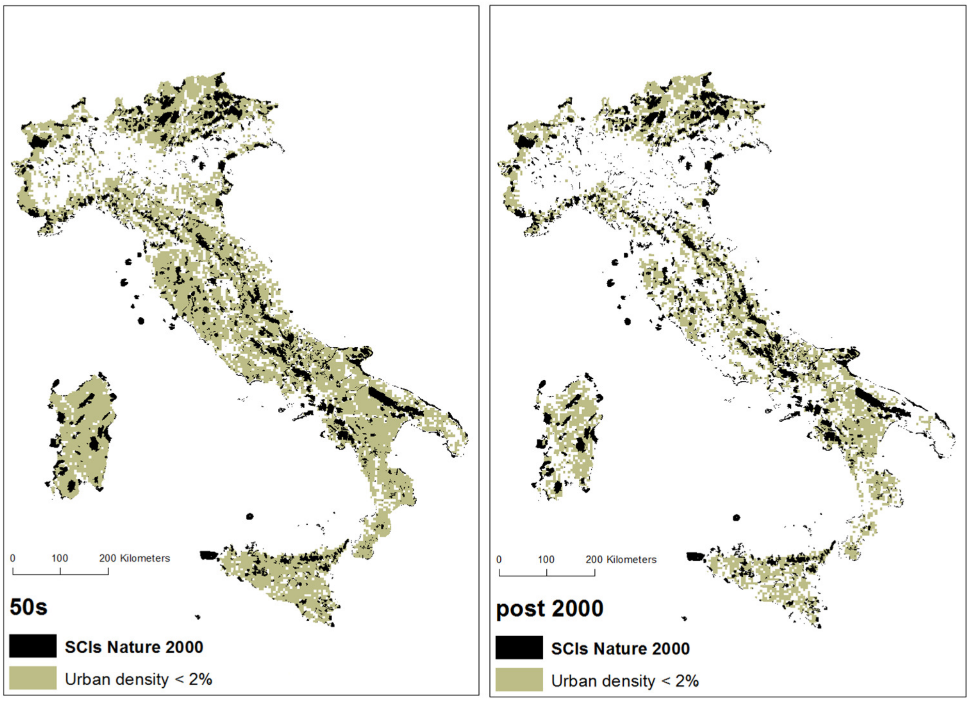


Figure 4 - Last 50 years' reduction of low urban density territorial sections (5x5km plots) in Italy.

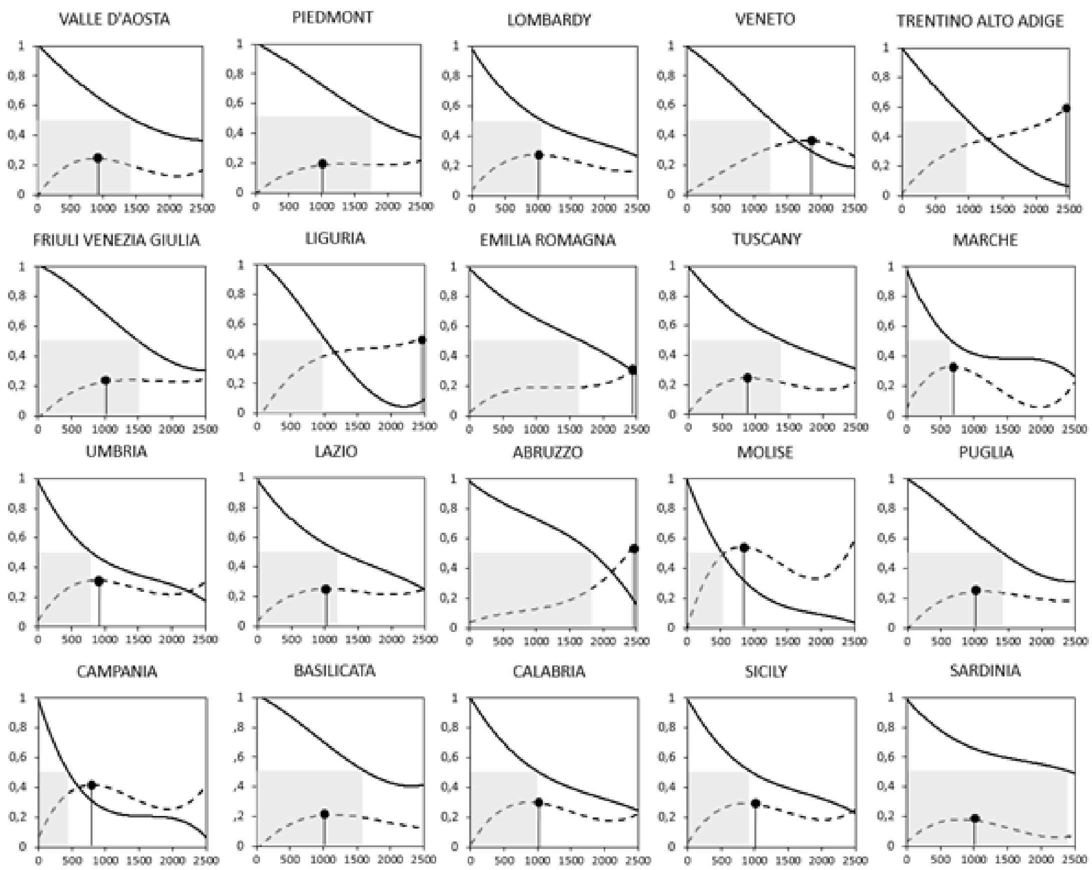


Figure 5 –SCIs' fragmentation reductions curves in the Italian Regions (on the *y*-axis FRR values, on the *x*-axis buffers' distances. FRD_{50} values are in grey, while FRP_{max} (Fragmentation Reduction Performance) curve is dashed).

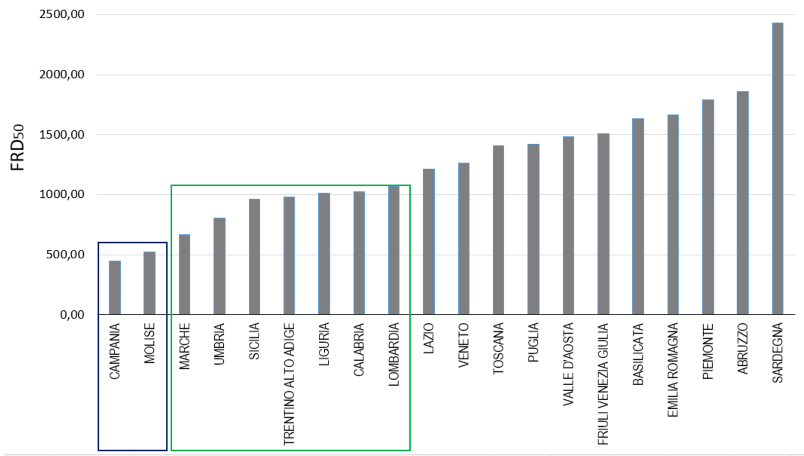


Figure 6 – FRD_{50} values for the Italian Regions with group of regions with an index inferior to 500 m and 1 km.

According to Fig. 5 and Fig. 6 indications, it appears quite clear that suppose an, even partial (up to 50%), Italian SCIs' welding it is an extremely hard operation because it should be considered that the implementation of conservation and protection norms and regulations should cover average distances that are too long for a territory with a very high level of urban sprawl. As already pointed out, national average urbanization density is equal to 7%, with Regional peaks of 14%; without including the very dense infrastructural network, whose spatial incidence is calculable to be in a 3% incremental. In most of the Regions, not even a reduction of 20% would be readily achievable, considering that FRD_{20} sometimes are inferior to 200-300 m (Fig. 6). Regarding efficiency (performance), it has to be noticed that 15 out of 20 Regions show maximum values (FRP_{max}) around 1000 m (Fig. 5). For six Regions, (Lombardy, Marche, Umbria, Lazio, Calabria and Sicily) FRP_{max} also coincide with FRD_{50}, meaning that the most convenient intervention on 1000 m produce also the aggregation of half of Nature 2000 sites surfaces.

Only in the case of Molise and Campania, the most efficient intervention on 1000 m would produce aggregation results superior to 50%.

In this sense, it could be assumed that a few hundred meters fragmentations can be mitigated within the urban projects setting, therefore taking actions for the design and the organization of the residential complexes, local road networks and private and public green areas. Instead, in order to restore ecological continuity lines on average distances superior to 1 km, which seems to be the average distance for almost all the regions, it will be necessary to resort to planning and territorial rules instruments, incurring in far more complex issues like removing and lightening the barriers, which in any case, will last for many years.

Thus, considering SCIs' separation pattern, expressed by calculated FRD_x indexes, it results clearly the second stated condition. However, SCIs' are partially absorbed by semi-natural matrices that are infiltrated in urbanized contexts and maintain high environmental quality residual grades. These are the already defined bio-permeable spaces, which would allow reaching higher connectivity grades, surpassing very close separation distances.

In fact, Figure 7 shows how, calculated on bio-permeable matrices, FDR_{50} values (Romano e Zullo, 2012) sharply contract for all the Regions with values always below 600 m, and that only in two cases, for the FRD_{80} (Lombardy and Puglia) they exceed one kilometer. These are

spatial dimensions that are more feasible for urban projects and plans, for whose application, with a general role of ecologic connection, it could be sufficient implement norms of protection, also limited, compatible with many productive ordinary human activities.
The problem lies in the progressive erosion of bio-permeable surfaces, caused by settlement activities, which are carried out with inadequate controls on the environmental consequences, outside the highly controlled perimeters.
For this purpose, it has been conducted an analysis on the Italian SCIs' habitat isolation by region (Fig. 8), that well point out the high pressure on the hinterlands, provoked by the increase of urban surfaces in the surrounding areas, either close than far.

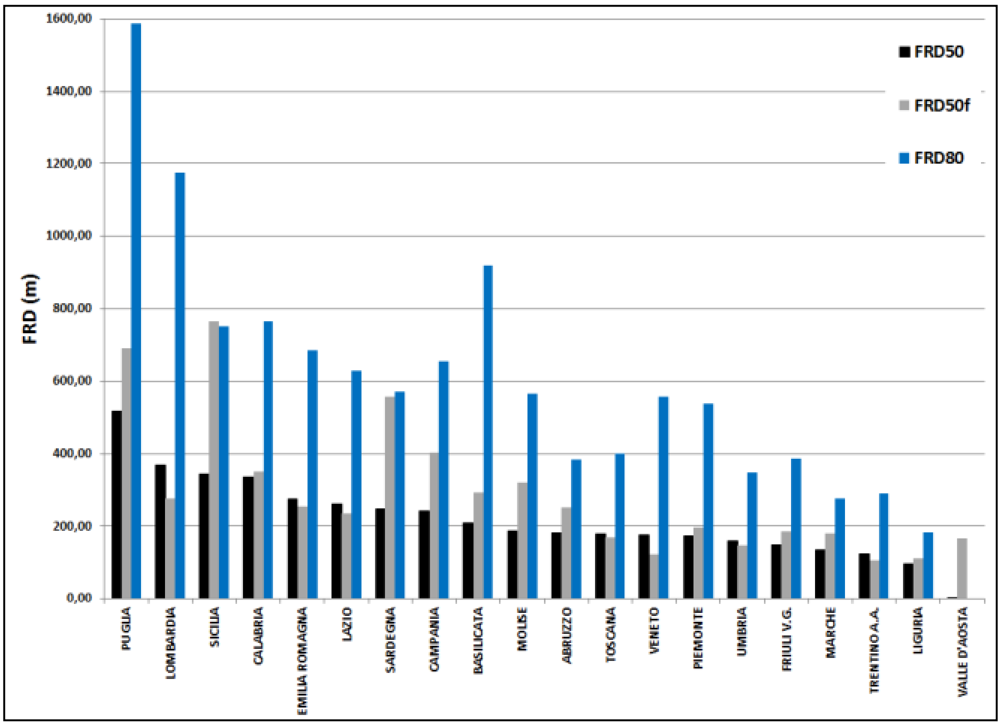


Fig.7 – FRD_x index values in the Italian regions regarding the bio-permeable (FRD_{50} and FRD_{80}) and forestall areas (FDR_{50f}) (Source: Romano and Zullo, 2012).

The method here applied is always based on the spatial gradient expressed by progressive buffers with a 1 km pace (from 1 to 5) consecutive to the single SCI. The urbanization density is calculated within the buffers using artificial surfaces deriving from the local database, and based on these data, through tendency lines, variation curves, that describes the previously stated densities, are constructed. As showed in Fig. 8 this methodology allows us to obtain a clear indication of the major or minor presence of urban surfaces within the kilometric rings that surround Nature 2000 sites, and therefore, where and how far from these locations there are more pronounced disorders linked to land use and intensive anthropic attendance. If the available data allow it, habitat isolation curves can also be calculated for different time sections, in this way it is possible to notice the changes occurred over time, or also considering the local urban tools (PRG) expansive contents, highlight PRG full execution potentially expressible pressures. In the following case, regarding Umbria region, these data were indeed available, so there have been drawn diachronic curves for all the SCAs.

A weak spot of this methodology is that calculated settlement pressures do not take into account urban densification directionality and thus the possible presence of sectors totally free from any disturbs, which are more suitable for biotic transitions. In this sense, a methodological integration is under development.

The difference between calculated habitat isolation curves in the '50s and after 2000 (Fig. 9) shows clearly where and in what region the fragmentations, due to high settlement densification, were more evident. In Piedmont, Lombardy, Veneto, Friuli, Liguria, Emilia Romagna, Lazio, Campania, Puglia, Sicily and also Sardinia the values that emerge are quite high for the urban densities either within the proximity buffers (1-2 km), or in the medium distances buffers, similar to the national average 7%. Certainly, the index is much higher in the Northern Italy big industrialized regions (up to 10-15% of the value of immediate proximity within the first kilometric buffer in Piedmont, Lombardy, Veneto, and Friuli). However, in 12 out of 20 regions the SCIs' matrices are highly urbanized (exceeding the 7%) is a significant data that shows, statistically, the fragmentation condition that Italian habitats endure, and of which we have already discussed above. In these circumstances, it is extremely hard to create those ecological networks that, despite being considered by the European Community and most of the regions, should provide a decisive contribution to national bio-diversity conservation. If the situation is evaluated on a regional scale, it could appear better for those regions morphologically more articulated and with mountain or hilly agricultural economies, such as Valle d'Aosta, Trentino A.A., Marche, Umbria, Abruzzo, Molise and Basilicata.

On the average regional scale these phenomena look much less uninformed, but, considering singularly every SCAs, they appear to be more pronounced. In Fig. 10 there is an analysis of Umbria SCAs' habitat isolation that also used the local urban tools in force (PRG) dataset which made possible to have a typological classification of 5 models that covers the entire regional 97 SCAs records.

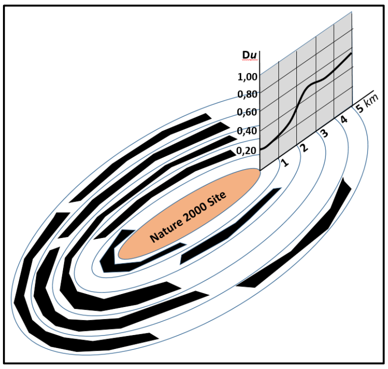


Fig.8 – Habitat insularization curves processing method framework

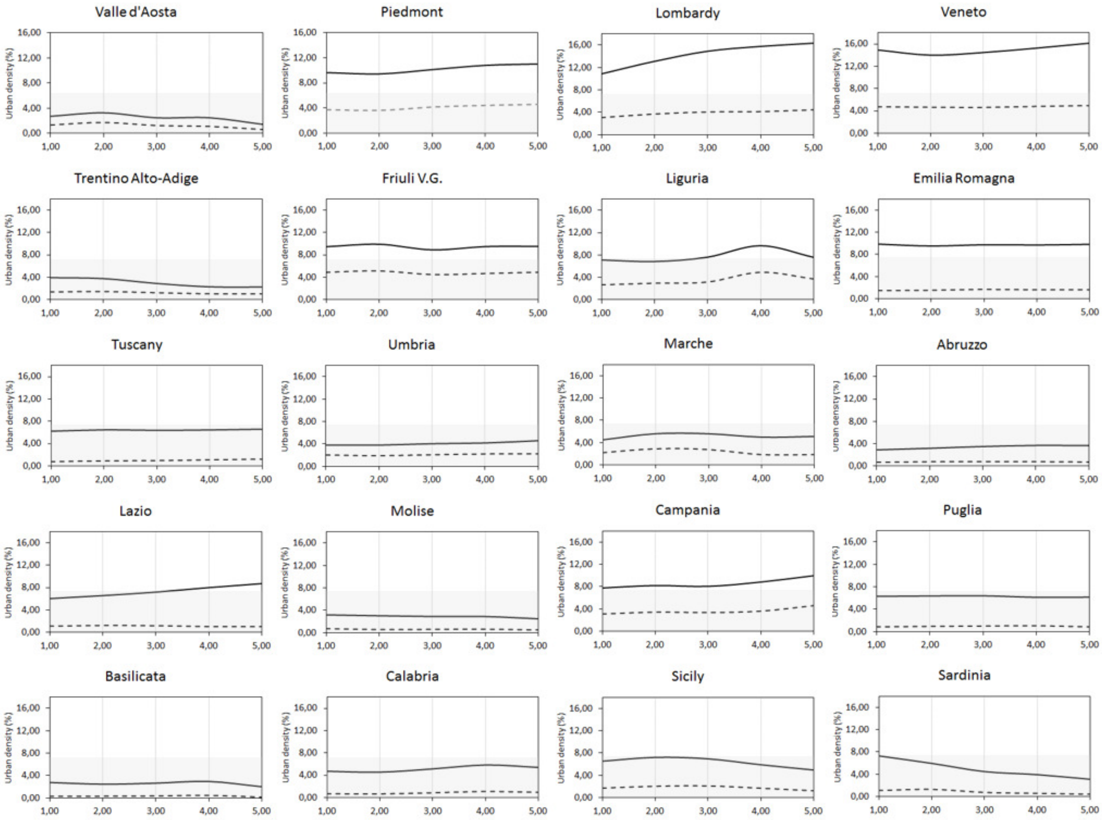


Fig.9 – Italian SCIs habitat isolation curves on regional aggregation level: in black, density in 2000; in dashed, density in the '50s and in grey average national density (7%). On the *x*-axis there are the buffer distances evaluated.

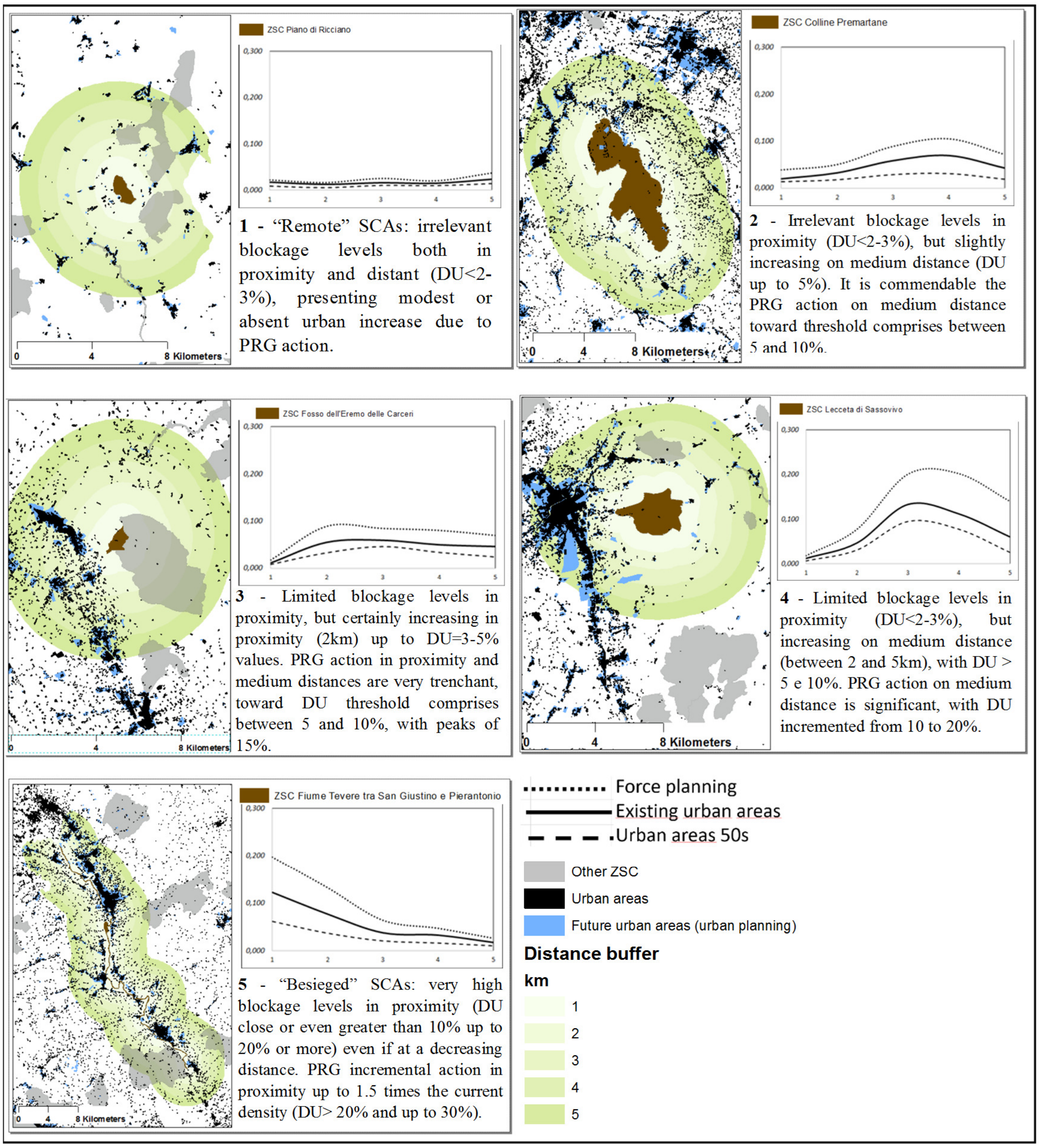


Figure 10 – Umbria SCAs' habitat isolation curves prototypes.

Conclusions

This research has been conducted to show how the central issue of habitat and species conservation is still currently the fragmentation provoked by mobility infrastructures and urban planning. As advanced and sophisticated the Nature 2000 sites management and protection measures could be, the results of biodiversity conservation will never be stabilized over time if there will not be enforced extended matrices transformations control policies. It is indeed a very complex issue because it has to involve the entire regional local urban planning, either the municipalities include Nature 2000 sites or protected areas, or they are very far from them. The current Italian administrative and technical capacity is not sensible, except for some dozens cases, to the environmental continuity issue. Or at least it not sensible to such an extent that one municipality can influences the decisions made by its PRG for reasons linked to some sites ecological functionality, located few kilometers within its borders.

Connect together the whole territory, from an environmental perspective, is up to the Ecologic Networks, considered as the superordinate planning structure in this sector; but, as mentioned before, only few Italian regions have networks integrated in their legislative frameworks, having the actual competence to influence municipalities urbanistic planning activities.
The indexes presented in this text have highlighted how it is almost impossible to obtain Nature 2000 sites connectivity efficient results without get all the administrative levels involved in it. In all the Italian regions (Fig. 6) to reduce by 50% the current SCIs/SCAs habitat insularization, it is needed to exceed distances (FRD_{50}) never lower than 500 m and well beyond one kilometer (up to almost 3 km). As already pointed out, these distances are manageable only through norms and planning tools. On the contrary, aggregation distances, calculated on the territorial bio-permeability (Fig. 7), are on average correspondent to some hundreds of meters, therefore, are quite easily manageable by local urban projects planning offices, provided that there are adequate guidelines for the private and public workers. Thus, it emerges the importance of implementation of ecological networks designs in all the regions. These designs have to evaluate every soil section connectivity quality, especially in a country where the settlements main feature is the extreme dispersion, penetrating every area, even the most remote, following a quite peculiar pattern that has been defined as "sprinkling" by the recent scientific literature (Romano *et alii*, 2017).
Undoubtedly, there are many gaps that must be filled in the fragmentation field, which is becoming strategic for the conservation of global biological values species that are in Italy. Further researches and specific interventions are needed on the "efficient" ecological networks, to consider real gaps to potential biotic fluxes through infrastructural lines and urban plots, conducting large scale maps studies. For example, these kind of studies conducted in Umbria have shown how alongside the 134 km of the E45 route (Valle del Tevere) there are only 17 significant gaps, for an overall development lower than 4 km, with the arterial road transversal permeability equal to 2,6%. Numbers and situations of this entity are verifiable all over the national road network, even though the majority of those are not acknowledged due to lack of investigations on ecological occlusion of the infrastructures (Henle *et alii*, 1997; Jaeger *et alii*, 2007; Romano *et alii*, 2012), which there are only in very few regional cases.
The present work is now redirecting toward a methodological approach of habitat insularization curves (Fig. 8 and 9), to implement directional evaluation techniques of occlusions caused by urbanization and the road network, in order to provide support to network ecological corridors and stepping stones identification studies.

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