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Research article

Italian landscape macrosystem (ILM) from urban pressure to a National Wildway

Bernardino Romano[1,*], Andrea Agapito Ludovici[2], Francesco Zullo[1], Alessandro Marucci[1] and Lorena Fiorini[1]

[1] University of L'Aquila-DICEAA-Via Gronchi 18 – 67100 L'Aquila - Italy
[2] WWF Italia ONLUS – Via Po 25/c – 00198 Roma - Italy

* **Correspondence:** Email: bernardino.romano@univaq.it; Tel: +390862434113.

Abstract: Thirty years after the widespread establishment of the concepts of environmental continuity in Europe and Italy, linked to the EU Habitat Directive and the Natura 2000 project, these have almost completely lost their impetus. After having fostered a very intense scientific and political/administrative/managerial period, these concepts have produced only a few virtuous examples of implementation. The study presented in this paper shows that today national environmental quality is almost entirely based on land use categories that are scarcely protected and not subject to sufficiently binding planning. Moreover, their functional structure and extension/quality depend on how the local and global market impact spatially complementary categories mostly affected by anthropic action, which instead undergo efficiently planned changes. From the fundamental paradigm of "ecological networks" the interests of the scientific world and local authorities have shifted to other fronts, losing that physical and conceptual cohesion inherent in "environmental continuity" as a value in itself. The availability of recent, very advanced data helps take stock of this issue and verify critical points on the national territory that have been unresolved for several decades, but still rife with potential for the application of models of international value.

Keywords: landscape macrosystem; urban pressure; land biopermeability; national wildways; Italian landscape

1. Introduction

This paper is part of a line of research on territorial continuity of ecosystems (biopermeability and ecological networks) that has been very active in Europe and Italy between 1995 and 2005, leading to some important results, including applications. However, before 2010, it ebbed leaving few traces still visible today. This topic has involved several scientific sectors, such as landscape ecology, forest sciences, zoology, biological sciences, plant ecology and territorial sciences, often also in an interdisciplinary perspective. Vast national and international scientific literature has been produced, to which reference should be made for a more in-depth examination of concepts and definitions [1–12] and specific departments within

government agencies and universities have been set up too. The debate in Italy has been very intense and marked by innumerable conferences, participation in European projects, funding of university research, with five regions out of 20 (Umbria, Lombardy, Emilia Romagna, Tuscany and Marche) that have also enacted targeted regulations [13–17]. The "ecoregional" approach should also be underlined, which, starting from an identification of the world's ecoregions [18], was also declined in Italy by WWF with the identification of 24 priority areas for biodiversity for the Alpine ecoregion and 36 for that of the Central Mediterranean. Although progress in research has been significant, interest has waned rather suddenly and prevented the topic from being included in a broader national strategy, in order to produce more consistent results than those achieved by a few regions. However, research on ecological networks has produced a spectrum of knowledge fuelling other areas of interest, such as greenways and ecosystem services, which even today are the scientific core business of various important Italian research centers [19–23].

The goal of this research is to review, twenty years later, the critical issues of spatial continuity in Italian territorial systems having greater biopermeability, i.e., in minimum conditions of residual naturalness or man-made changes, so as to allow at least the transit of large animal species without continuous and intense disturbance [24]. Using the data produced over the last twenty years, we intend to verify the quality of some territorial layers with respect to their potential functions of support and dissemination of high-end ecosystem qualities.

There are areas that change shape and layout as a result of market trends (e.g., agricultural areas) or abandonment (e.g., forest or semi-natural areas), outside of any established supervision and whose results can only be assessed after at least a decade. An interesting aspect is that these various systems undergo mutual interchange effects caused by different drivers, whose dynamics stop and become irreversible for those parts that become urbanized. As a result, their development ends in the only state that does not allow retrofitting and that destroys soil resources [25,26].

2. Material and methods

This study identifies two macro-types of landscape-environmental mosaics: the first includes areas with prevailing anthropogenic physiognomy that tend to be more "managed", while the second encompasses areas of higher environmental quality or in transition and much less regulated by forms of planning. These two macrosystems exchange surfaces over time, but the dynamics of transformation and mutual substitution are only sometimes regulated by planning, while in many cases they are spontaneous and influenced by the market, economic crises and local or global events lacking any specific control. Some systems, such as urbanized areas, are generally managed through local urban planning, despite weaknesses or the spread of illegal phenomena [27,28]. For other systems, there are no forms of highly binding planning, excluding any parts falling within specially regulated areas (parks or nature reserves, hydrogeological risk districts and international environmental constraints such as UNESCO or Natura 2000 sites).

To achieve the result, we used the European Corine Land Cover classification [29,30]: from 43 of the 44 land cover categories (maritime environments were excluded) six Italian Landscape Mosaics (ILMs) were extracted and then grouped into three landscape macrosystems (Table 1). The six ILMs consist of artificialized areas covered by urbanization (U), intensive agriculture (IA), extensive agriculture (EA), forests (F), natural and semi-natural areas (SN) and water bodies (W). This category has undergone the least changes in its expanse, at least since World War II. Indeed, the last reclamations that have taken important areas of water away from the territory date back to the 1960s although, until recently, waterways have been subject to significant regulation and damming that, in several cases, have altered the geography of their courses and sections. In the various historical periods, the six ILMs have frequently interchanged owing to economic, technical and social reasons, making the country assume different prevailing physiognomies over time and with varying and uneven levels of reversibility and resilience.

The six ILMs have extremely diverse levels of perceptive and eco-functional quality and the transformations that occur over time exchanging their structures produce, in parallel, landscape and ecotonal changes with effects that can be estimated over fairly long periods of time. In particular, this relates to the consequences on the expanse and types of habitats, as well as on the layout and functionality of local and sub-national ecological networks. As mentioned earlier, both topics have been studied in-depth in Italy since the mid-1990s [31–34].

As mentioned earlier, we obtained the landscape mosaics (ILM) using the CORINE Land Cover (CLC) categories that have been a standard for the whole of Europe for thirty years now. At the third level of detail, there are 44 types of land cover from satellite surveys, produced since 1990 and subsequently updated to 1996, 2000, 2006, 2012 and 2018. The data used in this paper is the one updated to 2018 and downloaded from the following website: http://groupware.sinanet.isprambiente.it/uso-copertura-e-consumo-di-suolo/library/copertura-del-suolo/corine-land-cover/clc2018_shapefile (access April 2020). The data survey techniques include a minimum mapping unit (MMU) of 25 hectares with a minimum linear element size of 100 meters, while the MMU to record changes over time (LCC) is 5 hectares (http://www.isprambiente.gov.it/it/temi/suolo-e-territorio/copertura-del-suolo/corine-land-cover).

The definition of the ILMs for clusters of CLC categories is shown in Table 1 and in most cases allocation is fairly automatic, while some specifications should be made for the inclusion of CLC categories 221, 222, 223 in the "EA" ILM. These types of land use have different connotations in the country: in some cases, they connote IA, while in others EA. Considering that IA is mainly recognizable in northern Italy, while EA forms predominate in the larger peninsular section, the latter has been used to characterize them all.

The ILM mosaics were then divided into two macrosystems: ILM^ = (U+IA+EA) and ILM* = (F+SN+W) with ILM^ including the mosaics with the greatest land artificialization (57%), and ILM* with the greatest natural parts (42%) (Table 2).

Table 1. Clusters of ILM systems and ILM^ and ILM* macrosystems from CLC categories.

ILM macrosystem	ILM System	CLC code	CLC categories
ILM^	U	111	Continuous urban fabric
		112	Discontinuous urban fabric
		121	Industrial or commercial units
		122	Road and rail networks and associated land
		123	Port areas
		124	Airports
		131	Mineral extraction sites
		132	Dump sites
		133	Construction sites
		141	Green urban areas
		142	Sport and leisure facilities
	IA	211	Non-irrigated arable land
		212	Permanently irrigated land
		213	Rice fields
		221	Vineyards
		222	Fruit trees and berry plantations
	EA	223	Olive groves
		231	Pastures
		241	Annual crops associated with permanent crops
		242	Complex cultivation patterns
		243	Land principally occupied by agriculture, with significant areas of natural vegetation
		244	Agro-forestry areas
ILM*	F	311	Broad-leaved forest
		312	Coniferous forest
		313	Mixed forest
	SN	321	Natural grasslands
		322	Moors and heathland
		323	Sclerophyllous vegetation
		324	Transitional woodland-shrub
		331	Beaches, dunes, sands
		332	Bare rocks
		333	Sparsely vegetated areas
		334	Burnt areas
		335	Glaciers and perpetual snow
	W	411	Inland marshes
		412	Peat bogs
		421	Salt marshes
		422	Salines
		423	Intertidal flats
		511	Water courses
		512	Water bodies
		521	Coastal lagoons
		522	Estuaries

In the case of Italy, even other sources of land use maps or regional technical maps (LUM) have been available for several years, with much higher levels of detail than CLC (1:10,000, 1:5,000), but they present various kinds of problems that have prevented us from using them for this study. The most significant issue concerns update dates, as they go from 2000 to the present day with uncoordinated chronological scans managed exclusively on the basis of the programs of individual Regions. Besides the difference in update dates, there are no fixed standards for synoptic categories: even if most regions tend to follow the CLC synoptic scheme, this is not generalized and can generate considerable ambiguities. Finally, there is no standardization of the survey method for elementary polygons, especially for urbanized areas, which are sometimes extracted as built-up areas and in other cases as artificialized areas. Therefore, having to produce a homogeneous survey of the whole of Italy, we decided to use CLC coverage even if the resolution is on average lower than that of LUMs.

Other layers that have been used concern Natura 2000 (N2k) sites and protected areas (PA). Natura 2000 habitats on land (SCIs and SCZs) were taken from the site of the Ministry of the Environment (https://www.minambiente.it/pagina/sic-zsc-e-zps-italia - access April 2020), with a declared area of 3,085,663 ha. Protected areas on land refer to the VI Official List of Protected Natural Areas (EUAP) (https://geodati.gov.it/resource/id/m_amte:299FN3:06c67978-18c8-4da7-ff26-443d4f700c2d - access April 2020), established under Law no. 394/91, Framework Law on protected areas. The official list currently in force is the one included in the 6th Update approved by Ministerial Decree 27/04/2010 and published in the Ordinary Supplement no. 115 to the Official Gazette no. 125 of 31/05/2010, with a declared area of 3,163,591 ha. The methodology used is summarized in the flow chart of Figure 1.

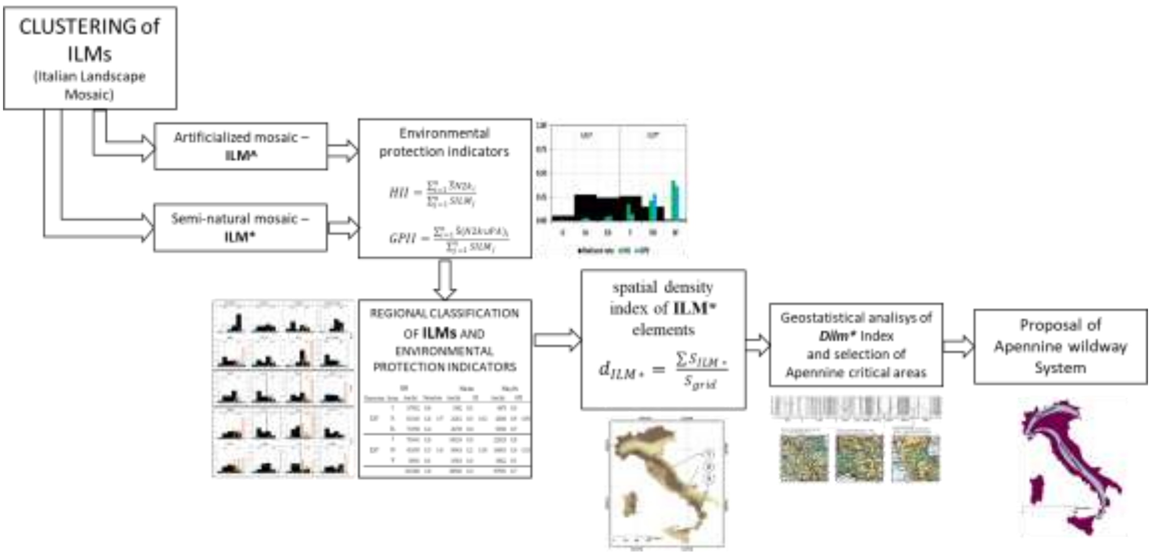

Figure 1. Methodological flow chart.

3. Results

The clustering of the 43 CLC categories in the six ILM mosaics, carried out as shown in Table 1, has led to the conclusion that three of them, intensive agriculture (IA), extensive agriculture (EA) and forest areas (F), are equally distributed at national level, with an incidence of about 25% each, covering ¾ of the country (Table 2, Figure 2). Semi-natural areas (SN) account for 15%, while water bodies (W) and urbanization (U) occupy the remaining space, 6% and 1% respectively. Table 2 also shows the two ILM^ and ILM* macromosaics covering 57% and 42% of the country respectively.

Within ILM* the most significant extension concerns forests (26%), while semi-natural areas (15%) have been greatly eroded and, as mentioned earlier, water covers a very small area. A number of considerations can be made from Figure 1 showing the nationwide distribution of the six ILMs. Urbanized areas (U) have been studied extensively in recent years. At present, they are probably the most thoroughly studied item in terms of geographical distribution and determinants of their development and therefore we refer to the considerable scientific literature on the subject [35–40].

Table 2. Values of the HII and GPII indicators for ILM systems and macrosystems.

	ILM			N2k sites				N2k U PA		
Macrosystem	System	Area(ha)	National	rate	Area (ha)	HII		Area (ha)	GPII	
ILM^	U	1679832	0.06		19682	0.01		46678	0.03	
	IA	8313463	0.28	0.57	242812	0.03	0.032	428068	0.05	0.058
	EA	7319508	0.24		284709	0.04		529386	0.07	
ILM*	F	7914441	0.26		1403234	0.18		2226128	0.28	
	SN	4516595	0.15	0.43	969416	0.21	0.198	1646910	0.36	0.318
	W	389961	0.01		165810	0.43		198822	0.51	
Total		30133800	1.00		3085663	0.10		5075991	0.17	

These areas include built-up/artificialized/sealed surfaces derived from the transformation of other land covers. Among all the mosaics identified, they are the ones with the highest level of irreversibility, at least in the mid-term. The development of this coverage throughout the country has been on the rise for seventy years [41–43]. Even the current the trend is of ongoing growth, albeit at different paces in the various historical periods. Spatial configuration is partly regulated by urban planning tools. However, especially over the last thirty years, this is left mostly to the implementation of local public-private negotiation procedures lacking any local strategic control.

As shown in Table 1 and Figure 3, intensive agriculture (IA) takes on at least 5 different physiognomies and is concentrated spatially in a few areas of the country: the Po Valley-Veneto area, the hilly coastal strip between Emilia Romagna and Marche and the enormous interregional area between Molise, Puglia, Campania and Basilicata, having an expanse equal to one third of the Po Valley-Veneto area. Other evident areas of concentration are found in the two major islands, Sicily and Sardinia, but involve larger expanses and greater spatial fragmentation. The entire Apennine belt, from Liguria to Calabria, as well as the entire eastern half of Sardinia, appear to be substantially lacking in IA areas, which are governed by local and global market trends in terms of typology and size. Extensive agriculture (EA), represented by the six CLC categories in Table 1, is marked by a radically different physiognomy. It is widely distributed at almost constant density on the pre-Alpine strip and across the country, in addition to the main islands, showing a more evident concentration only in central-southern Puglia. Excluding some territorial strips where they are totally lacking, forest areas too are distributed rather uniformly in the country, but with considerable variations in quality and structure that the CLC data do not capture. One of these (Figure 3) is the Po Valley-Veneto area, in continuity with the entire hilly Adriatic coastal strip, if we exclude a very small forest area in the Gargano promontory. A similar characteristic can be found in Sicily, where almost the entire territory has been deforested except for a small northeastern area. Forest areas can be considered governed by dedicated programs, although very partially and only in the past. At present they are essentially growing due to natural spatial recovery caused by the abandonment of EA and mainly SN, but in the past they were subject to numerous artificial reforestation initiatives. Forestry statistics from 1947 report 5.6 million hectares of forest, while currently the CLC 2018 mapping reports 8 million hectares (http://www.georgofili.info/contenuti/il-rimboschimento-naturale-in-italia/1128 - access April 2020). Historically, reforestation has been the main tool of Italian forestry and mountain policy and was promoted initially for soil protection and, since the second half of the 1970s, for wood production. Reforestation with conifers carried out in Italy from 1877 to 1983 covers an area of about 1.2 million hectares, including areas subject to forest fires [44–48].

Semi-natural areas (SN), derived from the pooling of nine CLC types (Table 1), have shrunk considerably overall, accounting for about one sixth of the country. Their highest appreciable density is found along the entire Alpine arch, Sardinia and the central Apennines, with smaller densifications in other smaller geographical areas. These territorial units include areas of extremely varying environmental quality and are subject, in part, to fluctuations over time due to the abandonment or resumption of other uses, such as farming.

Water bodies (W) have been retaining their expanse for many years, even though they are subject to considerable regulation and hydraulic control, since the last national reclamations that had impact on their spatial dimensions date back to the early 1960s. As is well known, Italy is rather lacking in water bodies (W). Apart from some large lakes, lagoon areas and rivers in the north, in central Italy there are only some lakes of volcanic/tectonic/artificial origin, in addition to the large Arno and Tiber rivers; while the whole of southern Italy and the islands lack large water bodies, although they have a rather dense hydrographic network and many artificial lakes.

Regardless of their location and concentration, ILMs differ greatly in terms of environmental quality. An indication of this has been obtained by assessing the impact on each of them of N2k habitats and the aggregation of N2k and PA habitats, using the following indicators: Habitat Incidence Index (HII) and Global Protection Incidence Index (GPII).

$$HII = \frac{\sum_{i=1}^{n} \overline{S}N2k_i}{\sum_{j=1}^{n} SILM_j} \tag{1}$$

$$GPII = \frac{\sum_{i=1}^{n} \hat{S}(N2k \cup PA)_i}{\sum_{j=1}^{n} SILM_j} \tag{2}$$

Where:

$\overline{S}N2k_i =$ Surface of the *i*-teenth sections of Natura 2000 sites falling within *j*-teenth areas of ILM macromosaics

$\hat{S}(N2k \cup PA)_i =$ Surface of the *i*-teenth sections of aggregation of N2000 and PA sites falling within *j*-teenth areas of ILM macromosaics

$SILM_j =$ Surface of the *j*-teenth areas of ILM mosaics

The decision to use the habitats surveyed by the European program Natura 2000 (SCIs and ZSCs), and then the aggregation of these habitats and protected areas, is linked to the different meanings of these two entities. The presence of habitats only indicates the eco-biological qualities of an environmental system, since European SCIs/ZCSs have been identified and their boundaries marked on the basis of specialized naturalistic knowledge. Obviously, N2k censuses carried out in the various European countries are not exhaustive of the conservation status of habitats, but the underlying logic is the one described.

Over the years, the identification and establishment of protected areas has been based and continues to be based on partially different methods. It is always true that special environmental protection is given to areas having high eco-biological values (and in fact the two systems, N2k and PA, overlap in Italy by 40%). However, perimeters also follow other historical-cultural and architectural-testimonial criteria and are often affected by complex political negotiation processes between the competent national, regional and local authorities. This aspect is also evident from the data in Table 2 and above all from Figure 2, which shows that in all ILMs PAs cover larger areas than N2k.

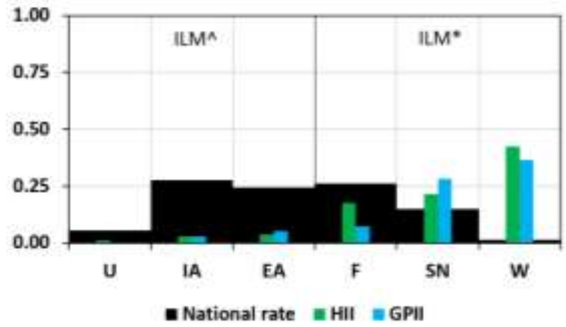

Figure 2. Values of the HII and GPII indicators for ILMs on a national scale.

Table 2 also clearly shows that, the ILM* macrosystem, accounting for just over 40% of the country overall, is encompassed in N2k habitats for a fifth of its extension and in the N2k∪PA complex for about 32%. Conversely ILM^, which occupies most of the national territory (almost 60%), is marked by almost total environmental impoverishment with HII and GPII indicators that do not exceed 0.03 and 0.06 respectively. Excluding W which, given its very small extension has both indices ranging between 0.40 – 0.50, among the six ILM categories, SN - with over 20% of its extension covered by N2k and 36% by N2k∪PA - is the most important system from the environmental point of view, more than forests that do not go beyond HII=0.18 and GPII=0.28. As shown in Table 1, SN is highly varied typologically and includes transitional woodland-shrub and burnt areas too. Therefore, it probably represents the most vulnerable areas of the country marked by considerable ambiguity of use, deriving both from the abandonment of agricultural or other activities and from primary eco-biological conditions (high altitude pastures, rocky complexes and harsh and inaccessible morphologies). If one part defends itself through morphology, another part of SN instead risks yielding to transformative activities that fail to acknowledge its environmental worth, often due to objective difficulties in perceiving it.

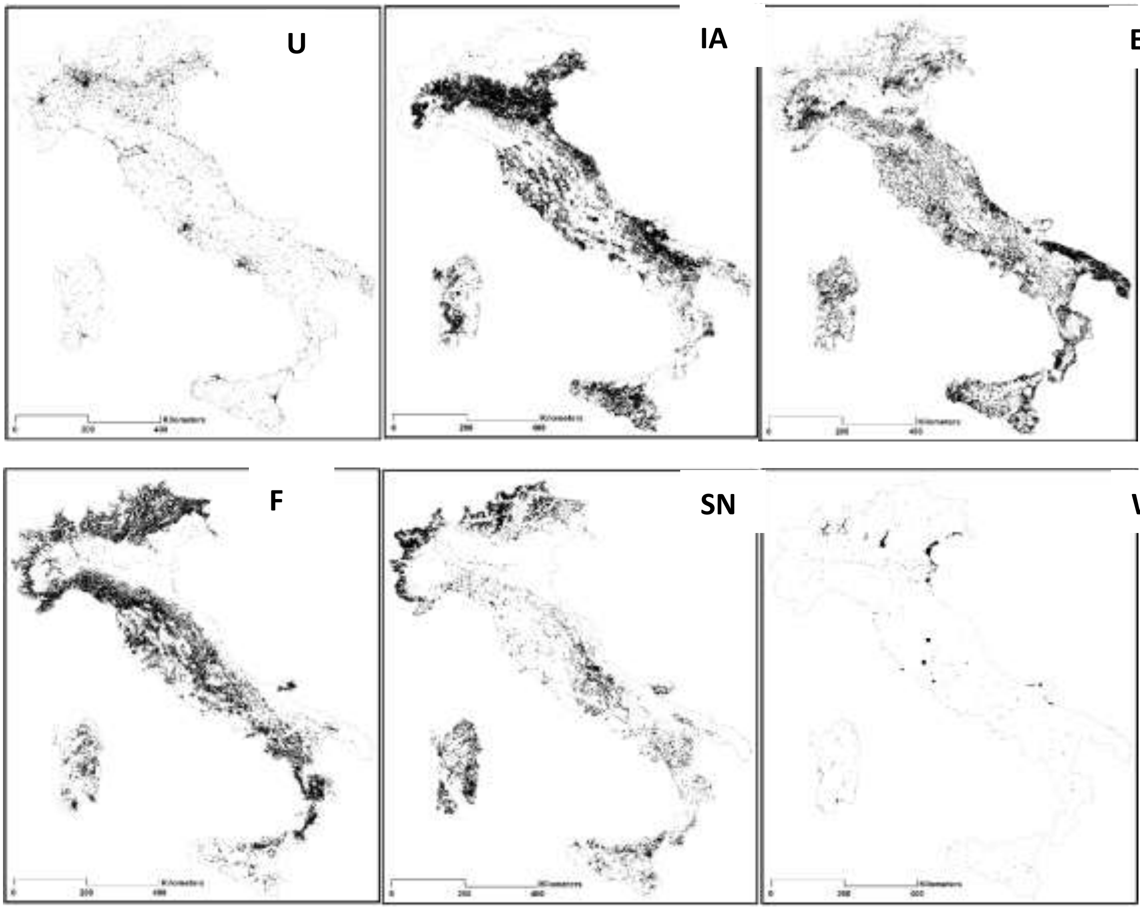

Figure 3. National geographical distribution of the six identified ILM systems.

In addition to analyzing how ILM systems are structured nationwide (Figure 3), we also performed a survey of the regions spotlighting differences among them. Figure 4 shows the outlines of the ILMs in the regions and their relationship with the national standard, together with the HII value, since we chose to highlight only the incidence of N2k habitats, deemed more significant for the reasons mentioned earlier. The national outline is particularly recognizable in Piedmont, Lazio and Abruzzo and, a little less so, in Campania, while in the remaining regions one or two prevailing systems are always found. In Valle d'Aosta, Trentino A.A, Liguria and Tuscany these are semi-natural (SN) or forest (F) systems, while in Lombardy, Emilia Romagna, Veneto, Marche, Molise and Basilicata it is the intensive agriculture system (IA). Most of the regions are below the national average urbanization threshold, except Piedmont, Friuli, Emilia, Lazio, Puglia and Campania, which are in line with the national average. Only Lombardy and Veneto exceed national average urbanization. Notwithstanding some prevailing systems, there are cases in which the ILMs are considerably below the national average threshold: this is the case, for example, of AI that has extremely lower levels in Valle d'Aosta, Trentino A.A., Liguria and, in part, Calabria. In the case of forests (F), they are particularly lacking in Puglia and Sicily, while EA is significant in Lombardy, Friuli, Trentino A.A. and again Liguria. SNs are very scanty in Emilia Romagna, Puglia and Umbria, while only Trentino A.A., Valle D'Aosta and Umbria exceed the national average.

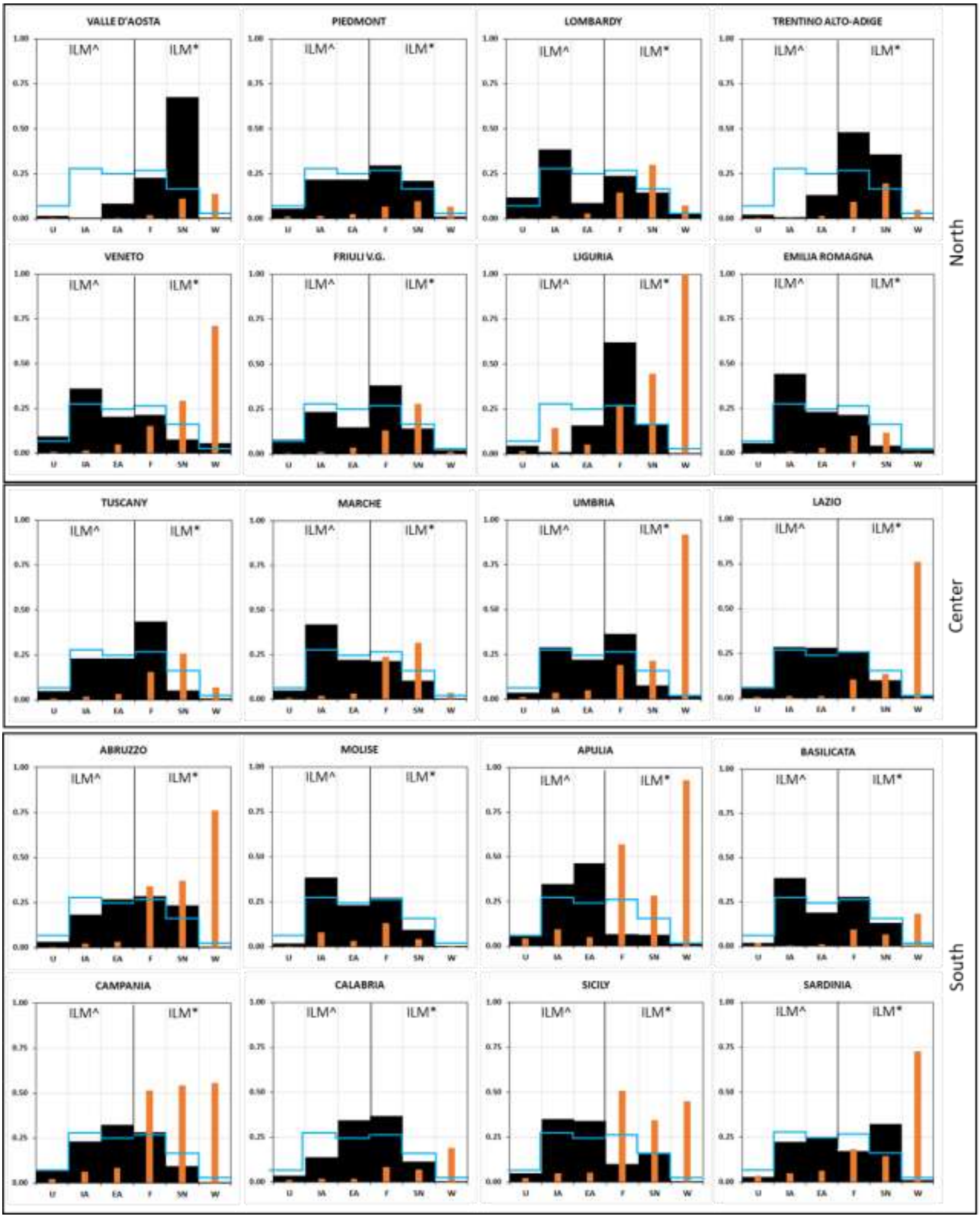

Figure 4. Regional distribution of ILMs and HII values in every subsystem.

Regarding the HII indicator, in almost all regions its significant values are all found in the ILM* macrosystem. The highest values of this indicator concern the water system that, in several cases, exceeds 50% (Veneto, Liguria, Umbria, Lazio, Abruzzo, Puglia, Campania and Sardinia) with Liguria, Umbria and Puglia nearing 100%. The prevalence of SN in central-northern regions is confirmed, if compared to F, while these two values range between 25% and 50% in some southern regions (Abruzzo, Puglia, Campania, Sicily and Sardinia).

It is interesting to note the scarce relevance of the HII indicator in all ILM categories in Valle d'Aosta, Piedmont, Emilia, Molise, Basilicata and Calabria, which is something worth investigating further.

As already shown in the national case, the irrelevant contribution of the ILM^ macrosystem to the habitat incidence (HII) indicator is also confirmed at the regional scale, excluding some limited differences in Liguria and a few southern regions (Puglia, Campania, Sicily and Sardinia).

Aside from water, SN can therefore be considered the ILM system mostly marked by environmental quality but, at the same time, the one in the most precarious state. Most territories showing high environmental quality belong to the ILM* macrosystem, which is also the one with the highest instability over time, as it is less significant and relevant than ILM^ from an economic standpoint and highly dependent on it in terms of extension and quality.

Evidence of this instability can be found by examining the changes undergone by ILM types over the years through interexchange processes. The data distributed by ISPRA on CLC time periods (http://www.sinanet.isprambiente.it/it/sia-ispra/download-mais/corine-land-cover) show that from 2000 to 2006, the areas that have changed state account for 6‰ of the national territory (approximately 180,000 ha) with a very small average size of patches, about 18 ha. The maximum expanses that have changed in these six years exceeding 500 ha are found mainly in Sardinia, with migrations within the 321–323 category (SN), while Lombardy recorded the most significant transformation into urban areas with 400 ha transitioning from 211 (IA) to 112 (U). As mentioned previously, changes that involve transitioning to the urban category have the greatest impact because they are not reversible, at least in the mid-term, unlike others.

In the following 12 years, between 2006 and 2018, this change affected 1.6% of the country, i.e., more than 500,000 ha (Table 3), with reductions concerning mainly IA and SN systems to the benefit of forest (F) and urbanized (U) areas. Confirming the established precariousness of SN in the 12 years considered, more than 72,000 ha of IA were lost, and as much as 178,000 ha of SN that become in total 156,000 ha of urban areas, 9500 ha of extensive agriculture and 86,000 hectares of forests. Of the 250,000 ha lost, 62% became urban and 30% forests. The additional urban areas and the SN lost correspond to a square of 40 km per side (circle with 22 km radius), i.e., almost 5 times the city of Rome within the ring road in just over a decade.

Table 3. Changes in the ILMs in the 2006–2018 timeframe (Data from: http://www.sinanet.isprambiente.it/it/sia-ispra/download-mais/corine-land-cover - access April 2020.

ILM		2006 (ha)	2006%	2018 (ha)	2018%	2006–2018 (ha)	square (km)
ILM^	U	1487438	0.049	1643130	0.055	155692	39.5
	IA	8401100	0.279	8329008	0.277	-72092	26.8
	EA	7326042	0.243	7335614	0.244	9572	9.8
ILM*	F	7843161	0.260	7929075	0.264	85914	29.3
	SN	4686098	0.156	4507013	0.148	-179085	42.3
	W	389961	0.013	389961	0.013	0	0.0
		30133800	1.000	30133800	1.000	0.00	

The foregoing combination of land use conversion has been ongoing in its dynamics for many decades now, involving first and foremost semi-natural (SN), and then forest (F) and urban (U) ILM systems. SN and F variations produce the most significant environmental consequences. Only 20% of SN is protected from profound alterations and changes by N2k and PA tools. So, 80% of this ILM category tends to be exposed to generalized damage without significant obstacles. This damage is caused by changes to the complementary ILM^ elements mostly influenced by the market and by local and global economies. This implies that, while theoretically assuming that protected SN sections remain unaltered over time, the actions on the rest cause significant erosion in potential ecological connections that SN and F assure among their more "noble" parts, that is to say that 20% protected for various reasons[49,50]. The case of forests (F) is different, since in general, they have increased their extension owing to agricultural abandonment, [51]. This dynamic should be considered positively given the effects on CO2 absorption, climate mitigation and the increased performance of ecosystem services associated with forest cover [52]. However, part of the scientific world is against forest expansion, considering it the cause of ecological simplification of the territory and of a decrease in ecotonal sectors that are particularly important for biodiversity [53,54]. As our analysis has shown, the ILM* macrosystem includes the highest concentration of the most important areas in terms of ecological and environmental quality and connections between ecosystems. By transferring these concentrations to 9 km^2 quadrants (3x3 km grid) through discretization, we can highlight the strategic structure of the national ecosystem (Figure 4) using a spatial density index of ILM* elements (d_{ILM*}) geostatistically calculated by means of kernel density.

$$d_{ILM*} = \frac{\sum S_{ILM*}}{S_{grid}} \tag{3}$$

Where

S_{ILM*} = surface of the systems belonging to the ILM* macrosystem contained within the 3x3km plot;

S_{grid} = surface of the 3x3 km plot forming the grid (9 km^2)

The quadrants having a $d_{ILM*} > 0.75$ cover an area of almost 13 million hectares, i.e., about 40% of the country (Table 2), but only one fifth of this area is censused as belonging to a habitat of EU importance (HII = 0.20). However, as mentioned earlier, the importance of unprotected ILM*sections is tied to their function of connecting core environmental areas found both within N2k habitats and, more generally, in protected areas and in all those other fragments of ecosystems and microecosystems that have not been officially censused, despite being sites of significant biodiversity. Kernel geostatistical estimation clearly shows (Figure 4) peak concentrations of d_{ILMs*} at national level mostly along the Alpine arc and the Apennines, with additional concentrations in the larger islands. While the spatial continuity of this considerable concentration is very significant in the Alpine area, it diminishes along the peninsular axis. There is a gradual drop in density with a latitudinal gradient from North to South, in addition to some evident interruptions in continuity ($d_{ILM*} \cong 0$), the most significant being those localized in points 1, 2 and 3 in Figure 5.

By setting a latitudinal profile of the d_{ILM*} parameter (Figure 6) along the 1,200 km of the peninsula, the two aspects described are emphasized and the points that lose magnitude are clearly the three located in Umbria, Campania and Calabria. The studies mentioned in our introduction, conducted in the mid-1990s but based on data from the mid-1970s (Geotecneco, Ministry of Public Works), showed the same weaknesses that half a century later are largely confirmed on the basis of last generation digital data. Figure 5 shows, along the d_{ILM*} distribution curve, the sequence and frequency of N2kUPA aggregate spaces that in our study were taken as a measure of ecological and environmental quality in the country. The minimum points 1, 2 and 3 are always located where there are protection vacuums, but relatively close to N2k∪PA systems.

The detailed territorial analysis of the three weaknesses shows that they are the following geographical sectors, all marked by an important concentration of infrastructural, settlement and farming elements, i.e. those that largely characterize the ILM system^: Strada Centrale Umbra-Flaminia (Umbria); Valle del Fiume-Via Appia (Campania), Valle del Fiume-Crati (Calabria).

Figure 6 shows a more detailed d_{ILM*} profile analysis and the areas falling within N2k and PA sites, highlighting their considerable territorial spread. The d_{ILM*} decline already obtained from the national profile in Figure 5 is shown in Figure 6 with a greater spatial definition highlighting that discontinuities are locally far more complex and broken down in different negative peaks (Figure 7).

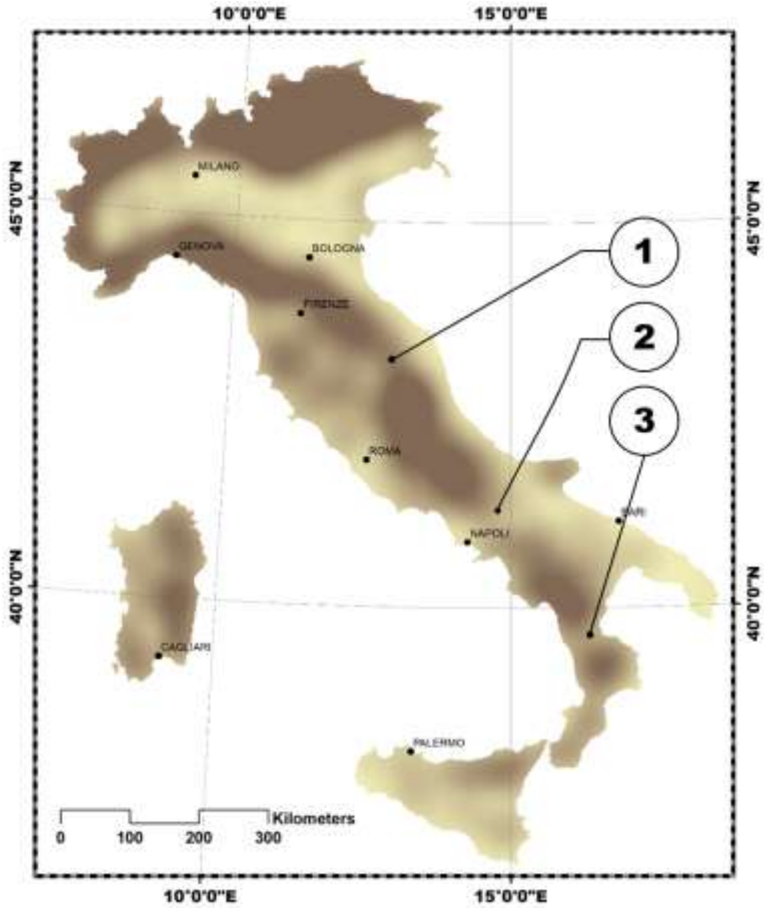

Figure 5. Geostatistical representation of the national configuration of the d_{ILM*} index represented by spatial concentration on a 9 km^2 grid. The three spots (1, 2 and 3) of interruption in latitudinal territorial continuity of d_{ILM*} are highlighted.

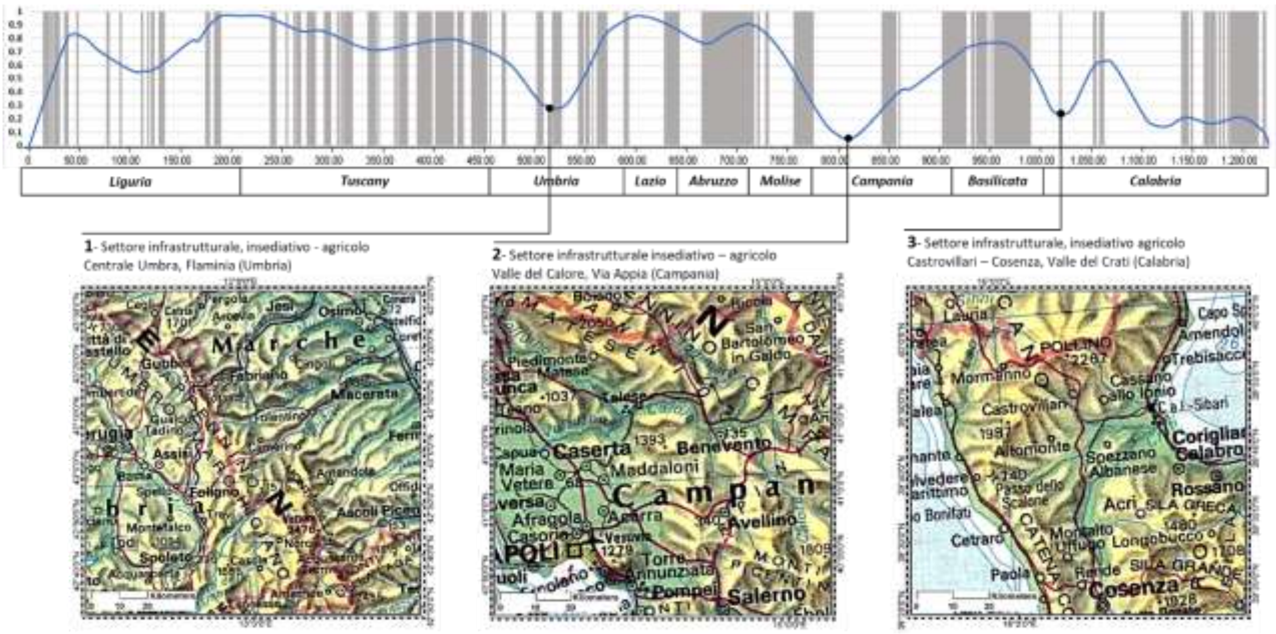

Figure 6. Figure 5 outlines the profile of the d_{ILM*} index (y axis) along the Apennines (km *x* axis) and relationship with the distribution of the N2k∪PA system and the succession of regions. In the three maps below (source: De Agostini Map) the geographical characteristics of the three sections of the national minimum d_{ILM*} are detailed.

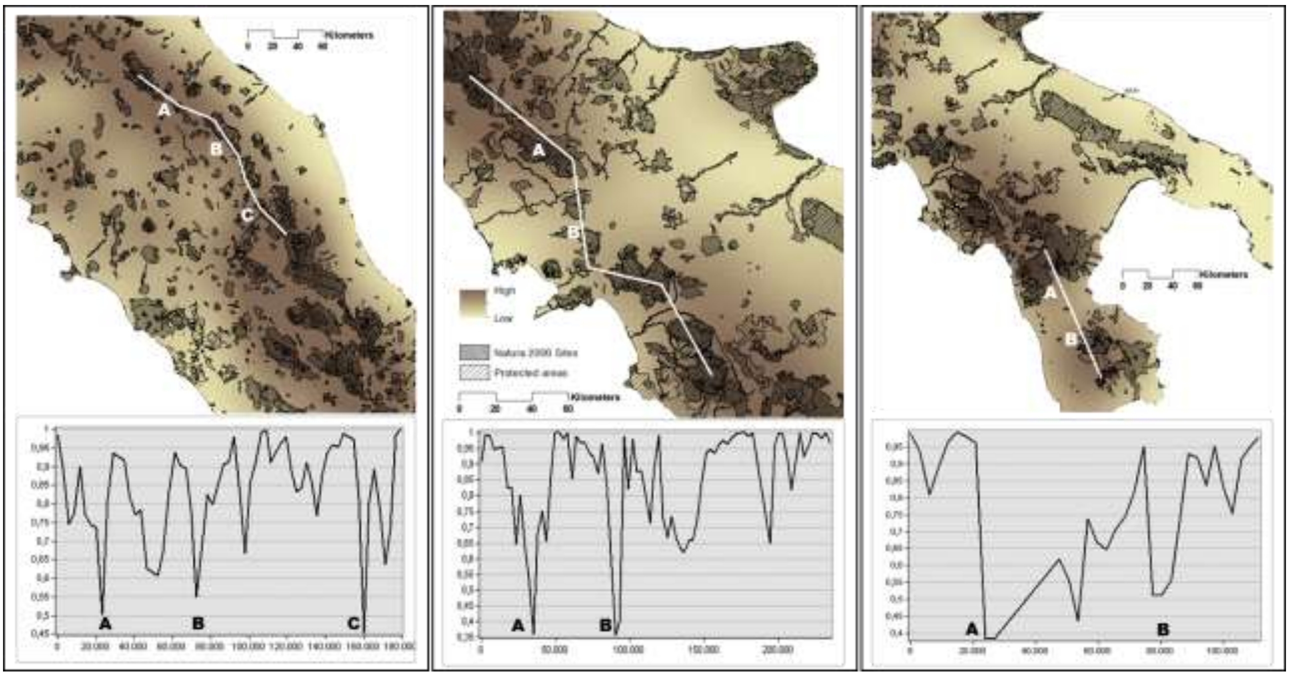

Figure 7. Tracking of the detailed profiles of the d_{ILM*} index (y axis) of the three national minimum d_{ILM*} sections (see Figure 5).

4. Discussion

This study conducted at national and regional level has highlighted the importance of ILM* systems as the key players in the environmental protection of the country with reference to historically established tools for this purpose (protected and special regime areas identified in the N2KUPA core areas) and the ecological-environmental continuity needed to ensure the best functionality of these core areas. Although with different and more ineffective methods, knowledge and conceptual expressions, this condition has been outlined since the mid-1990s. However, until the present day no impactful government actions have been planned to recognize the quality and strategic function of the ILM* system in the setting up of ecological networks. Ultimately, apart from water bodies, the SN can therefore be considered the ILM system having high average environmental quality but, at the same time, the most unstable and least managed through dedicated and binding planning tools.

Even some legislative attempts aimed at limiting, albeit indirectly, the effects of degradation and destruction of these territorial elements, such as the laws limiting land take, have been unsuccessful either at national or regional level, mainly due to pressure from lobbies against the limitation of building activities. Therefore, as stressed earlier, the extent, quality and geographical location of ILMs* are greatly influenced by movements affecting the complementary macrosystem, i.e., the ILM^. Changes in the latter are made according to market convenience and using weak forms of planning. It has been proven that, at different territorial scales, the ILM^ macrosystem is rather lacking in environmental value although, in some limited cases, some value worth protecting has been recognized, such as UNESCO sites [55,56].

In the proposals put forward in the past, and largely ignored by politicians, the establishment of a National Ecological Network was viewed as the most effective tool to draw attention to the management of the ILM* macrosystem, as several European countries have done for several decades [57–62]. Some attempts to draft a national project were made in the embryo in the 1990s within the framework of the "*Appenino Parco d'Europa - APE*" (Apennines European Park) project [63,64], but then were not implemented.

The ecological connection between natural territories, in particular subject to special forms of protection such as protected areas, constitute a very vast field of research that involves multiple scientific issues. Naturally, among the most active are those of conservation biology and ecology which have produced continuous results over time at different territorial scales, from the continental one [65–67] to the local one [68,69]. A central problem that has arisen since the beginning of the debate on the topic concerned the possibility of applying the concepts of connectivity in territorial control tools: the knowledge, although advanced, acquired in the field of biological, ecological and natural sciences has on average had a high quality, but did not manage to land effectively in projects and plans for territorial and urban transformation as they were neglected by planners and administrators. After all, the development of territorial techniques managed by architects and engineers had much more chance of passing through the rules and plan drawings, but were in general much more schematic and scientifically weak. The first appreciable results therefore emerged when the interdisciplinary dialogue between ecological sciences, planning and operational management of the territory has densified and spread in the country, but it is a process not yet settled that will require a few more years of training and above all a national regulatory framework that unifies the various regional legislative initiatives.

5. Conclusions

The calculations produced in our study show that, especially along the latitudinal line of the Apennines, there are important interruptions in continuity that tend to worsen in present conditions: in recent years settlement pressure on land take, that started in the post-World War II period, has eased, but not pressure on infrastructure, which many in the country look to anxiously, in the belief that it can play a key role in overcoming socio-economic hardships in the South [70–71]. This is potentially linked to fragmentation [72–74] and habitat erosion effects that can only cause further degradation to ecosystem quality and biodiversity, already very vulnerable although it includes wildlife species of absolute worldwide importance (among the most significant, bear, wolf, lynx, various species of ungulates including endemic ones, and numerous raptor species and by high fauna endemicity rates such as 5.12% in northern Italy and 6.9% in peninsular Italy) [75–79].An important function in the organization of territorial protection at the ILM* scale could be performed by landscape planning tools that regions in Italy have developed and are in the process of updating, initially in accordance with law no. 431/85 and later Legislative Decree no. 42 dated 22 January 2004, (Cultural Heritage and Landscape Code). However, on average these plans tend to focus only on emergencies and cultural value and less on ecological-naturalistic value.

The worth and wealth of Italian biodiversity surely deserves an ecological reconnection effort similar to the Wildlands Network of the USA shown in Figure 8 [80], https://wildlandsnetwork.org/wildways/western/. Such an effort would involve plans and projects at different scales, from national to regional to municipal and at territorial sector level, such as those indicated as negative micro-peaks in Figure 7, using previously tested techniques, such as eco-ducts, environmental regeneration of degraded areas, or public-private agreements to restore/retain ecological corridors [81–85]. However, this is merely a hope that for the time being seems to lack sufficient impetus to become more established at political government levels.

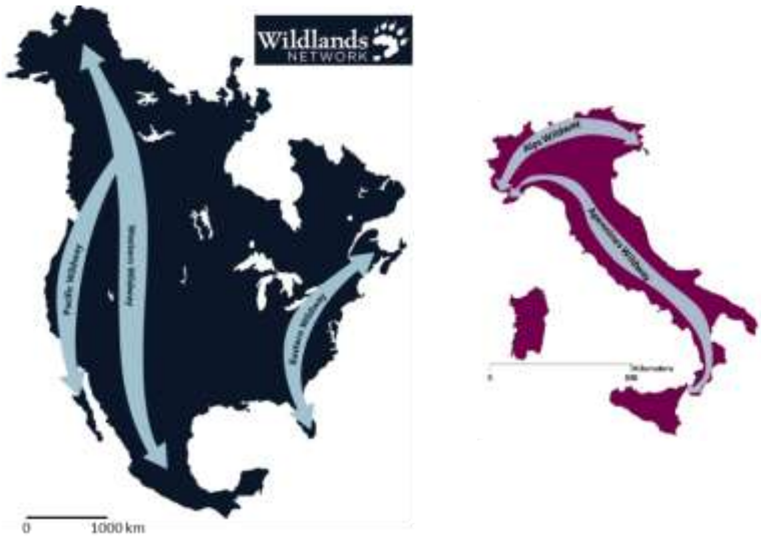

Figure 8. The configuration analogy between the USA Wildlands Network (https://wildlandsnetwork.org/about-continental-wildways/) project and a possible Italian proposal of Alpine and Apennine wildways.

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Conflict of interest

The Authors declare no conflict of interest.

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