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Integrated Assessment of the Anthropic Pressure Level on Natural Water Bodies: The Case Study of the Noce River (Basilicata, Italy)

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Abstract. Fragmentation is a phenomenon that involves the transformation of large patches of natural habitats into smaller ones (fragments) that tend to be isolated from the originals. In this case, the degree of environmental fragmentation of the Noce River in the Basilicata region (Italy) will be analysed. Following the installation of hydroelectric plants, the river has undergone such alterations that it has been classified as a Heavily Modified Water Body (HMWB). Environmental fragmentation is caused not only by soil sealing, which causes the loss and subsequent fragmentation of natural patches, but can also be caused by major changes in natural patches. In the case of a territory crossed by a watercourse, these patches may be subject to changes in the natural course of the river or in the vegetation present close to it. The aim of this work is to calculate, through GIS applications, the level of fragmentation of the adjacent area surrounding the water body along which there are several hydroelectric plants. Through a change detection in 2006, 2013 and 2018, metric and biodiversity indicators will be calculated to define the level of anthropic pressure of the water body. The results reveal that the variation of the calculated indices, both for landscape metrics and diversity indices, concerned "natural" land use classes, whose variation caused fragmentation of natural patches by changing the shape of the water body.

Keywords: Fragmentation · River · Diversity index · Natural soil · Environmental health

1 Introduction

Anthropic action has always been a double-faced medal. On the one hand, there are benefits related to the development of buildings and infrastructure to increase the quality of life and the amount of services for the population. On the other hand, the negative effects that have an impact in different areas emerge: economic - energy, hydro-geo-pedological, physical-climatic, ecological-biological, landscape-cultural [1–4]. These

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negative effects therefore produce land take, soil sealing, fragmentation and degradation of natural habitats [5, 6]. In terms of soil sealing, human action has been strong enough to cause the natural soil to progressively reduce, speeding up the fragmentation process [7, 8]. Fragmentation is a phenomenon that involves the transformation of large patches of natural habitats into smaller ones (fragments) that tend to be isolated from the originals [9–11]. The environmental fragmentation process, in addition to being caused by soil sealing that causes the loss and subsequent fragmentation of natural patches, can also be caused by major modifications of natural patches. If we take into account a territory crossed by a waterway, these patches may undergo changes related to the natural course of the river or to the vegetation present near the waterway. Alterations caused by excessive use of water for industrial purposes, the development of hydroelectric plants and water purification treatment tanks.

The case study focuses on a section of the Noce river in the Basilicata region (Italy). Previous studies carried out by Environmental Observatory Foundation of Basilicata Region (FARBAS) [12] have shown that several sections of this river have characteristics such as to be classified as Heavily Modified Water Bodies (HMWB) under the European water directives [13, 14]. The level of environmental fragmentation of the Noce River following the recent construction of hydropower plants will be analysed through landscape metrics and diversity indexes. The analyses will be carried out in three time phases: 2006-2013-2018.

2 Materials and Methods

2.1 Study Area

The study area concerns the Noce river in the south of Italy. Originating from the Pincipe of Murge, Noce River covers a total length of 45 km, with a total surface area of 351 km^2 and flows into the Tyrrhenian Sea, in the Castrocucco Plain (about 8 km south of Maratea). The river-bed crosses three provinces in three different regions: the province of Salerno in Camapnia region, the province of Potenza in Basilicata region and the province of Cosenza in Calabria region. Noce river has a hydrological regime characterized by varied flows altered by the significant slopes of the hydro-graphic network and the small size of the basin. In terms of overall impluvium, there are sub-basins with fairly good importance and different shapes and characteristics, dictated by the tributaries of the main course. This paper will only analyse the section of the Noce river falling within the territory of the Basilicata region (Fig. 1).

Along the Noce river there are 11 hydroelectric plants and several installations of transversal works (bridles) that aim at altering the hydrological regime of the watercourse.

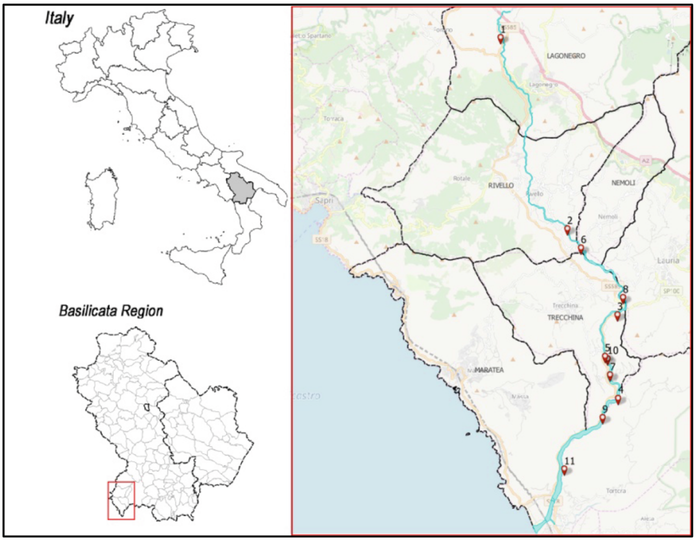

Fig. 1. Study area with indication of the stretch of the Noce river analyzed and the location of the 11 hydroelectric plants.

2.2 Data Acquisition

In order to construct spatial data sets describing the evolution of land use in the study area, several sources of information were considered. (i) The regional technical map - RTC (scale 1:5000) of the Basilicata Region at 2013, available as open data on RSDI regional map portal. (ii) The coordinates of the hydro-electric plants of the regional agency for the protection of the environment. (iii) Dataset for the sewage plants provided by the Basilicata region.

The RTC information layer has been used as a starting point for analysing the soil changes evolution as of 2006-2013-2018. From the CTR of 2013 they have built: the 2006 land use by comparison and digitalization of the 2006 ortho-photo and the 2018 land use by comparison and digitalization with Google earth satellite images.

Three layers of vector information were created on which eighteen classes of land use were identified: (a) uncultivated area, (b) green area, (c) hydroelectric base, (d) bridle, (e) urban centre, (f) crops, (g) sewage treatment plant, (h) river Noce, (i) plant, (j) hydroelectric plant, (k) industrial settlement, (l) urban settlement, (m) beach, (n) roads, (o) vegetation mixed with sand and rock, (p) scarce vegetation, (q) discontinuous vegetation, (r) industrial area, (s) street.

The vector information layers were subsequently rasterized with a pixel size of 3×3 m.

2.3 Landscape Metrics and Diversity Indexes

The purpose of this analysis concerns the calculation of diversity indexes and landscape metrics to assess the environmental fragmentation of the territory caused by the recent installation of hydroelectric plants from 2006 to nowadays.

LecoS (Landscape Ecology Statistics) [15] software has been used to calculate landscape metrics and diversity indexes, based on the land use classification. This analysis is useful to describe the structural characteristics of the landscape, to document the changes and the relationship of these indices with the occurrence of different species or groups of species [16–19]. The landscape metrics analyzed are specified following. (i) Land cover: metric expressed in number of pixels in each patch for every land use class. (ii) Landscape Proportion: defines the proportion of each land use class to the total of the analysed area; the sum of the indices for all identified land use classes will return the unit value. (iii) Edge Length expresses the number of pixels present on the patch borders for each class of land use analyzed, a sort of patch perimeter. It is useful to represent the landscape configuration in relation to habitat loss and environmental fragmentation. (iv) Edge density, (v) Patch density and (vi) Number of patches are metrics that describing the landscape structure at quantitative level [20–22].

A diversity index can be defined as the probability that two randomly taken organisms in a given community are not of the same species [23].

The Shannon-Wiener Diversity Index (H_{SH}) is a statistical index based on information theory. It represents the amount of "information" per individual or type of patch, in this specific case [24]. The SH index is expressed by formula:

$$H_{SH} = -\sum_{i=1}^{S} p_i \log_2 p_i$$

Where:

pi is the proportion of the landscape occupied by the patch type (class) *i*. Shannon's diversity index returns the sum of the proportions of each class over the total. The SH index is a type of diversity index often applied to the assessment of specific diversity and used extensively in the field of landscape ecology [25]. It has a range of values from 0 to ∞. A high value of SH indicates an equal proportion of the categories, while a low value expresses the strong dominance of one category, combined with a poor representativeness of the others.

Simpson's index [26] (H_{SI}) is expressed by the following formula:

$$H_{SI} = 1 - \sum_{i=1}^{S} p_i^2$$

Where:

$\sum_{i=1}^{S} p_i^2$ represents the probability (p) of randomly choosing two organisms of the same species (i) (any of the available S species). The maximum value is reached at $\mathrm{p_i} = \frac{1}{\mathrm{S}}$ for every i. Simpson's index varies between 0 and 1. The higher the index, the more likely it is that every two randomly designed cells will be different types of patches.

The Evenness index (E_V) - also called uniformity or equitability - describes how equal are the specific abundances between them, that is, how uniformly the individuals of a population are distributed among the species [27]. E_v is obtained from the ratio between the calculated value of H_{SH} and its maximum value with respect to the number of species present in the data sample.

Landscape metrics and diversity indexes were calculated in the study area by first considering the entire study area and then the 500-m buffers around each hydro-electric plant. This has been useful to understand how the landscape has changed following the installation of these plants.

3 Results and Discussions

The study area concerns the main course of the Noce river for a section that extends for about 45 linear km. The 500 m to the right and left of the river bed have been categorized, totalling an area of approximately 54 km^2.

The vector files of the land use to the years 2006, 2013 and 2018 were created, which were subsequently rasterized with pixels of size 3 × 3 m. Through the global area categorization it emerged that, following the recent installation of several hydro-electric plants, land use from 2006 to 2018, does not show significant changes. Analysing the variation of the various classes surfaces, it is highlighted the greatest peak near the spaces that have seen the construction of hydroelectric plants between one year of reference and the other. Between 2006 and 2013, the percentage change in the surface area of the hydro-electric plants class was +47.99%. At the same time as this increase, there was a decrease of the land use class concerning Noce river and discontinuous vegetation in the areas that were most affected by the implementation of hydro-electric plants. In fact, the class of land use concerning the Noce river, has the largest decrease in surface area on both intervals, 2006–2013 and 2013–2018, with a negative variation of 8.20%. This results in a shrinkage of the river bed.

Figure 2 shows the data concerning the landscape metrics at the three time intervals considered. The variation of landscape metrics and diversity indexes in the time intervals considered, over the whole area, does not give useful results to define if and how the construction of new plants has caused environmental fragmentation. The three diversity indexes show a negligible increase (Table 1).

	Land cover			Landscape Proportion		
Class	2006 km^2	2013 km^2	2018 km^2	2006	2013	2018
Area Incolta	17,686431	17,686431	17,684568	0,03804487	0,038041622	0,037976163
Area Verde	308,615346	308,03895	305,388387	0,663855291	0,662558852	0,65579658
Base Idroelettrica	0,192456	0,192456	0,248427	0,000413988	0,000413952	0,000533477
Briglia	0,000165375	0,000158625	0,000158625	8,54E-06	8,19E-06	8,18E-06
Centro Urbano	24,834033	24,834033	24,825123	0,053419911	0,05341535	0,053309921
Colture	34,755561	34,721703	34,860294	0,074761879	0,074682671	0,07485963
Depuratore	0,001299375	0,001299375	0,001296	6,71E-05	6,71E-05	6,68E-05
Fiume Noce	6,305526	5,788179	6,052482	0,01356367	0,012449754	0,01299721
Impianto Idroelettrico	0,000921375	0,0013635	0,00131625	4,76E-05	7,04E-05	6,78E-05
Insediamento Industriale	2,893239	2,9484	2,98242	0,006223579	0,006341693	0,006404503
Insediamento Urbano	11,44935	11,44935	11,569959	0,02462843	0,024626328	0,024845541
Spiaggia	1,968705	1,968138	2,677455	0,004234836	0,004233254	0,005749616
Strade	11,546793	11,546793	11,546793	0,024838038	0,024835917	0,024795793
Vegetazione mista a Sabb	10,908918	12,356145	15,287697	0,02346592	0,026576747	0,032829079
Vegetazione pressoché as	2,416959	2,416959	2,416959	0,005199064	0,00519862	0,005190222
Vegetazione Sporadica	29,272266	28,917	28,10133	0,06296689	0,062197376	0,060345307
Zona Industriale	1,980612	1,975752	1,952181	0,004260448	0,004249631	0,004192149
Impianto		0,000631125	0,000621		3,26E-05	3,20E-05

	Edge length			Edge density		
	2006	2013	2018	2006	2013	2018
Area Incolta	35100	35100	35100	0,000679525	0,000679467	0,000678369
Area Verde	435516	436968	422670	0,008431455	0,008458843	0,008168843
Base Idroelettrica	1680	1680	2202	3,252428025	3,252150368	4,255753384
Briglia	324	306	306	6,272539762	5,923559599	5,913989717
Centro Urbano	96480	96480	96414	0,001867823	0,001867663	0,001863371
Colture	135900	135798	135690	0,002630982	0,002628783	0,002622449
Depuratore	540	540	540	1,04542	1,045334047	1,043645244
Fiume Noce	112578	117156	115056	0,002179475	0,00226791	0,00222366
Impianto Idroelettrico	708	1020	984	1,37067	1,974519866	1,901753556
Insediamento Industriale	16596	17322	17148	0,000321293	0,00033532	0,000331415
Insediamento Urbano	82182	82182	83478	0,001591018	0,001590882	0,00161336
Spiaggia	6522	6522	10662	0,000126264	0,000126253	0,000206062
Strade	371700	371700	371700	0,007195997	0,007195383	0,007183758
Vegetazione mista a Sabb	85878	91014	92988	0,001662572	0,001761852	0,001797157
Vegetazione pressoché as	8802	8802	8802	0,000170404	0,000170389	0,000170114
Vegetazione Sporadica	95544	94506	90906	0,001849702	0,001829451	0,001756919
Zona Industriale	5412	5412	5364	0,000104775	0,000104766	0,000103669
Impianto		528	528		1,022104401	1,020453128

	Number of Patches			Patch density		
	2006	2013	2018	2006	2013	2018
Area Incolta	15	15	15	2,903953593	2,903705686	2,899014567
Area Verde	118	118	112	2,284443493	2,284248473	2,164597543
Base Idroelettrica	4	4	5	7,743876249	7,743215163	9,66338189
Briglia	1	1	1	1,935969062	1,935803791	1,932676378
Centro Urbano	69	69	68	1,335818653	1,335704616	1,314219937
Colture	143	145	143	2,768435759	2,806915496	2,763727221
Depuratore	3	3	3	5,807907187	5,807411372	5,798029134
Fiume Noce	639	727	587	1,23708	1,407329356	1,134481034
Impianto Idroelettrico	6	7	8	1,161581437	1,355062653	1,546141102
Insediamento Industriale	26	27	28	5,033519562	5,226670235	5,411493858
Insediamento Urbano	189	189	191	3,658981528	3,658669164	3,691411882
Spiaggia	2	2	3	3,871938125	3,871607581	5,798029134
Strade	325	325	325	6,291899452	6,29136232	6,281198228
Vegetazione mista a Sabb	82	81	91	1,587494631	1,56800107	1,758735504
Vegetazione pressoché as	5	5	5	9,679845311	9,679018953	9,66338189
Vegetazione Sporadica	82	81	80	1,587494631	1,56800107	1,546141102
Zona Industriale	5	5	5	9,679845311	9,679018953	9,66338189
Impianto		2	2		3,871607581	3,865352756

Fig. 2. Landscape metrics of total study area in every temporal interval considered.

In order to investigate the issue in more detail, 500-m buffers were created from hydro-electric plants. In this way, 8 areas (Buffer) around the plants along the Noce river were analysed in detail. A sample case is reported for which a variation in the diversity indexes was recorded in the time phases analysed (Hydro-electric power plant n.6 – Buffer n.6 - see Fig. 3).

Table 1. Variation of diversity indexes for total study area and single buffer areas.

Area	Year	I_{SH}	E_V	I_{SI}
Total area	2006	0.48	0.56	0.70
	2013	0.48	0.57	0.70
	2018	0.49	0.57	0.71
Buffer 1 (Hydro-electric plants n.11)	2006	0.42	0.26	0.18
	2013	0.43	0.27	0.19
	2018	0.64	0.40	0.33
Buffer 2 (Hydro-electric plants n.9)	2006	0.60	0.36	0.26
	2013	0.60	0.37	0.26
	2018	0.66	0.37	0.30
Buffer 3 (Hydro-electric plants n.4)	2006	1.42	0.52	0.64
	2013	1.45	0.56	0.66
	2018	1.34	0.57	0.67
Buffer 4 (Hydro-electric plants n.5-10-7)	2006	1.77	0.71	0.76
	2013	1.77	0.71	0.76
	2018	1.80	0.76	0.76
Buffer 5 (Hydro-electric plants n.8-3)	2006	1.49	0.65	0.70
	2013	1.49	0.65	0.70
	2018	1.49	0.65	0.70
Buffer 6 (Hydro-electric plants n.6)	2006	0.87	0.40	0.38
	2013	0.87	0.40	0.38
	2018	0.94	0.43	0.42
Buffer 7 (Hydro-electric plants n.2)	2006	1.30	0.54	0.64
	2013	1.31	0.54	0.64
	2018	1.31	0.54	0.64
Buffer 8 (Hydro-electric plants n.1)	2006	0.88	0.55	0.51
	2013	0.88	0.55	0.51
	2018	0.88	0.55	0.51

Between the two extreme time phases (2006 and 2018), the land use class corresponding to vegetation mixed with sand and rock increased at the cost of the land use class corresponding to the green area. Figure 3 show the variation of the diversity indexes in the area around the hydro-electric plant N. 6 (Buffer 6). The change in the indexes is reflected in an increase of fragmentation degree in the study area.

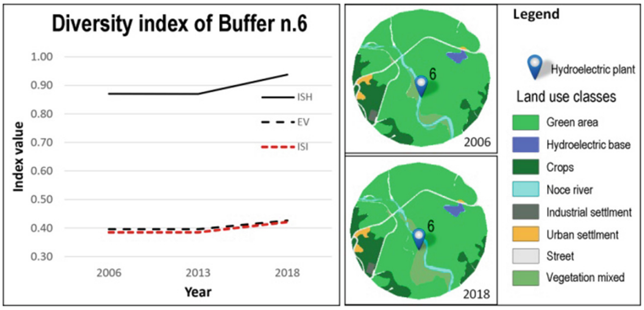

Fig. 3. The image on the left shows the graph of the indexes change and on the right the detail of hydroelectric plant n.6 to 2006 and 2018.

A particular case is that of a multi buffer (Buffer 4) in which the hydroelectric plants n.5-10-7 are concentrated. In this area, despite the concentration of three plants, there was no change in the diversity indexes, which remained stable (see Table 1). In this case, the emergence of new hydro electric plants has not led to environmental fragmentation.

4 Conclusions

No significant land-use change was identified from the analysis of the entire study area. This result can be easily related to 2 factors: (1) the hydroelectric plants on the main course of the Noce river are recent and, therefore, have not significantly influenced an area of about 50 km^2, in the time interval analyzed; (2) the plants are small, the power of the hydroelectric plants varies from a minimum of 50 kW to a maximum of 580 kW. This observation is valid when analyzing the entire area, but it varies when analyzing the area surrounding the hydroelectric plants. indeed, in certain cases, it is evident as the soil transformation undergoes fragmentation in a quickly manner in the proximity of the hydroelectric plant. However, areas with the highest concentration of installations do not necessarily correspond to those most subject to fragmentation and waterproofing. It should be noted that in all cases analyzed the variation of the calculated indexes, both with regard to landscape metrics and diversity indexes mainly concerned classes of natural land use ie. those concerning the “Noce river”, “green areas” or “vegetation mixed with sand and rock”. Their variation caused fragmentation of natural patches. Human activity, on the other hand, was almost inexistent. This means that, beyond the construction of the plants along the bed of the Noce River, human activity has been limited in compliance with the landscape regulations for the river buffer zones.

The results obtained are in accordance with the preventive study carried out by FARBAS [12] in which it was demonstrated that different sections of the Noce river have characteristics such as to result as Heavily Modified Water Bodies (HMWB).

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