Landscape Diversity as a Screening Tool to Assess Agroecosystems Sustainability; Preliminary Study in Central Italy

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Abstract

Modernization of agricultural activities has strongly modified agricultural landscapes. Intensive agriculture, with the increased use of inorganic fertiliser and density of livestock, affects water quality discharging nutrients such as nitrogen and phosphorus in water bodies. Nutrients in rivers, subsequently, are excellent indicators to assess sustainability/land-use intensity in agroecosystems. Landscape, however, is a dynamic system and is the product of interaction amongst the natural environment and human activities, including farming which is a main driving force. At present not much has been investigated on the predictive role of landscape on land-use intensity. Aim of this study is to determine if, in Italian agroecosystem, landscape complexity can be related to land-use intensity. Indexes of landscape complexity (i.e. edge density, number of patches, Shannon's diversity index, Interspersion-Juxtaposition index) derived by processing Corine Land Cover data (level IV, 1:25.000) of Lazio Region, were related with land-use intensity (values of compounds of nitrogen and phosphorus and other parameters found in rivers monitored in accordance to European Directives on Waste Water). Results demonstrate that some landscape indexes were related to some environment parameters. Consequently landscape complexity, with further investigation, could be an efficient screening tool, at large scale, to assess water quality and ultimately agroecosystems sustainability in the absence of monitoring stations.

Key-words: landscape, agroecosystem, diversity, corine, indicator, river basin.

1. Introduction

Monitoring environmental quality of a territory is often complex as it includes the analysis of a great number of variables. The analysis of single components of the ecosystem can be made through indicators that, with different precision, can measure directly a specific parameter and indirectly an environmental state to which the parameter is linked. An indicator is a parameter, or a set of parameters, that gives information on the state of a phenomenon or of an area. The significance goes over the property directly associated to the value of the parameter itself (OECD 1993). An indicator needs to be a concise tool but at the same time it needs to be effective in the description. The validity of an indicator can be assessed by its accuracy, meaning the capacity to detect a specific parameter and by its efficiency, meaning the capacity to easily detect the parameter.

In all those areas where human manipulation for agricultural production overlays the natural ecosystem, originating the agroecosystem (Caporali, 2000), agriculture practices can generate more or less impact according to the type of farming procedures undertaken (Altieri, 1995); the impact of the different agriculture practices on environment quality of agroecosystems is measured through different indicators. Water is one of the main renewable elements of agroecosystems, and rivers can be considered as the final basin, in time and space, of pressure and impacts of the surrounding terri-

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tory (Kristensen, 1994; Borgvang et al., 2000).

River pollution due to nitrogen compounds, such as NH_4 and NO_3, and phosphorous, P, is an effect of intensive use of fertilizers and of the abundance of livestock. The higher the pressure of the agriculture system is on the environment, the higher is the presence of nutrients in rivers. Furthermore, when the disturbance of the field's margin in correspondence with the river's bank is higher, river pollution increases; due to absence of vegetation, in fact, there is a reduced uptake of nutrients before these can reach the river (Siligardi, 1997). Consequently, values of nitrogen and phosphorous are the main indicators used to assess water quality in agroecosystems (Wascher et al., 2000). Water quality, however, of a river body can be also assessed through biotic analysis.

In Italy the Legislative Decree 152/99 made compulsory the monitoring of river bodies so to assess the Water quality. Furthermore the Framework Directive 2000/60/EU points out the necessity of an ecosystem approach of river basin monitoring. Within the agroecosystem, the different agriculture management, the vegetation and the soil use affect the transformation of the landscape/territory. Landscape itself, in fact, can be considered as a representation of the complex interactions between anthropogenic activities and the natural environment (Farina, 2001; Battisti, 2004). Complexity of landscape has been used to assess intensity of land use (Bunce et al., 1993; Roscherwitz et al., 2004, 2005) and to measure water quality (Wiens, 2002; Kearns et al., 2005; Houlahan et al., 2004). Furthermore, many reports and guidelines suggest the use of landscape metrics to measure environmental quality (AA.VV., 2000; Wascher et al., 2000; OECD, 2003 and 2004; EEA report, 2005).

Aim of this preliminary study is to assess whether, in Italian agroecosystems, landscape metric can be associated directly to values of nutrients and of biotic indexes so to be used as an indirect indicator of environment quality in agricultural areas.

In particular this study aims to assess whether between landscape and the environmental quality of the water body:
– there is a "minimal area" suitable to establish a direct relationship;
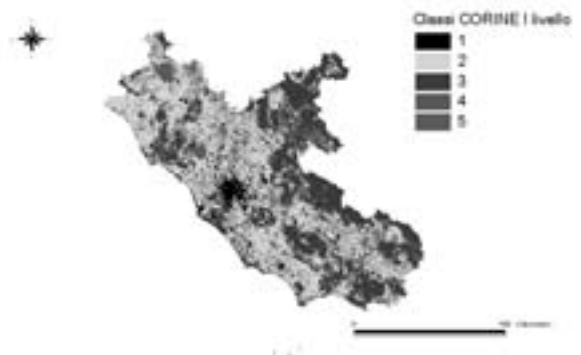– a more detailed definition of the landscape, therefore with an higher number of patch

Figure 1. CORINE Land Cover; Level 1, class II (in yellow) agricultural areas of Latium.

types, is more suitable to detect relationships;
– some landscape indexes are more suitable then others to detect relationships.

According to the answer obtained from the previous points, this study aims to verify if landscape metric can be used as an efficient indicator of environmental quality.

2. Materials and methods

Latium, in Central Italy, is the Italian Region chosen for this analysis. In Latium, agriculture is an important economic resource and most of its territory is characterised by conventional agricultural practices (Fig. 1).

Within 52 sites, located on water bodies, where there is constant monitoring, according to the D.Lgs. 152/99, we chose 24 that had in the surrounding buffer zone of 3,000 metres the higher values of agriculture areas (measured with CORINE Land Cover-CLC). These 24 sites were the areas investigated for this study (Fig. 2; Tab. 1). For each of the 24 monitoring stations, average values of chemical-physical parameters and indexes (Tab. 2) for the years 2002-2003-2004 were calculated. Analysis of landscape complexity was developed using CORINE Land Cover database (CLC) 1:25,000 of the Latium Region.

To assess the extent of a "minimum monitoring area" capable of measuring the relation between landscape and environmental quality of the water body, two different buffer areas, around the monitoring station, were analysed: one within 1,000 m and one within 3,000 m of radius.

To assess whether a more detailed definition

Table 1. Rivers and sites of the monitoring stations.

Stations location	XUTM ED50	YUTM ED50
Fiume Amaseno - Madonna del Ponte	355010	4596298
Fiume Amaseno - Mola dell'Abbadia	349702	4591481
Fiume Amaseno - Ponte alle Mole	349892	4594214
Fiume Aniene - Lunghezza	306666	4644528
Fiume Fibreno - Sora - S. Domenico	381884	4617348
Fiume Fiora - Ponte Badia	223643	4702103
Fiume Fiora - Ponte S. Agostino Vecchio	219947	4694853
Fiume Fiora - Ponte S. Pietro	221372	4713435
Fiume Liri - Le Compre	384322	4624548
Fiume Liri - Ponte Corvo - S.G. Incarico	388623	4590273
Fiume Marta - Ponte strada Litoranea	228593	4682212
Fiume Marta - Ponte strada Marta -Tuscania	245789	4706551
Fiume Marta - Ponte strada Viterbo - Tuscania	243077	4699416
Fiume Mignone - a monte conf.fiume Lenta	253713	4670129
Fiume Mignone - loc. Montericcio	231905	4684092
Fiume Mignone - Rota teleferica	253017	4671355
Fiume Sacco - V. Casilina Km 47 conf. Savo	332043	4625233
Fiume Tevere - Ponte Attigliano	276451	4709794
Fiume Tevere - Ponte di Mezzocamino	285625	4631798
Fiume Velino - Antrodoco	342108	4697830
Fiume Velino - Chiesa Nuova	321419	4699875
Fiume Velino - Ponte Ubertini	314769	4708410
Torrente Arrone - SS1 Aurelia	223380	4691381
Torrente Farfa - Ponte Sfondato	305743	4676025

Figure 2. Locations of monitoring stations.

of the landscape is more suitable to detect the relation between landscape and environmental quality of the water body, both buffers were analysed with the Level 1 and 3 of CLC.

The different landscape indexes used in this study are shown in Table 3.

Consequently, each of the 24 sites was associated with different landscape indexes and different environmental parameters and indexes. To determine which landscape parameter is more capable to detect the environmental quality of the water body, excluding the cause-effect relationship, values of landscape metric and environmental data were correlated. Validity of this approach was assessed by the numbers of correlations for each landscape index and values of correlation coefficient. Data were tested with the Pearson correlation (r) for the chemical-physical parameters that are on a continuous scale and with the Spearman correlation (rs) for the environmental indexes that are in classes. Correlation was considered medium (M) for coefficient included between $\pm$ 0.3 and $\pm$ 0.45 and high (H) with coefficient greater than $\pm$ 0.45.

3. Results

Results from the correlation between landscape indexes and environmental quality of the water bodies are shown in Table 4.

In particular, most of the correlations present were medium; the 3,000 m radius buffer had a greater number of correlation compared to the 1,000 m buffer; the 1st level CLC had slightly higher number of correlations compared to the 3rd level; the landscape indexes SDI and

Table 2. Investigated environmental data: chemical-physical parameters and indexes.

CHEMICAL PARAMETER	IT MEASURES:	IT INDICATES:	RANGE	
			Level 1: high environmental quality	Level 5: low environmental quality
NH_4^+ (mg/l)	Ammonium ion concentration in waters	It's an indicator of agricultural pollution and bacterial activity	<0,03	>1,5
NO_3^- (mg/l)	Nitrates concentration	It's an indicator of both agricultural and organic pollution	<0,3	>10,0
P Total phosphorus	Total phosphorus	It's an indicator of both urban and agricultural pollution; trophic level	<0,07	>0,6
INDEX				
LIM Macrodescriptors Pollution Level	Synthetic Index of pollution	Chemical-physical pollution	1	5
IBE Extended Biotic Index	Community structure of macroinvertebrates	Water body quality	1	5
SECA Ecological State of rivers	It's an integration of LIM and IBE	Ecological State	1	5

Table 3. Landscape indexes used in the study.

CODE	Description	Range
LSI *Landscape Shape Index*	It provides a simple measure of class aggregation or clumpiness	1 = when the *buffer* consists of a single square or maximally compact patch of the corresponding type LSI increases without limit as the patch type becomes more disaggregated (i.e., the length of edge within the landscape of the corresponding patch type increases)
SDI *Shannon's Diversity Index*	It's a measure of the number of patch types in the landscape	0 = when the *buffer* contains only 1 patch It increases as the number of different patch types increases and/or the proportional distribution of area among patch types becomes more equitable
SEI *Shannon's Evenness Index*	It's a measure of the distribution of area	0 = when the *buffer* contains only 1 patch and among different patch types in the landscape approaches 0 as the distribution of area among the different patch types becomes increasingly uneven 1 = when distribution of area among patch types is perfectly even (i.e., proportional abundances are the same)
ED *Edge density*	It reports edge length on a per unit area basis that facilitates comparison among landscapes of varying size	0 = when there is no class edge in the landscape; that is, when the entire *buffer* and *buffer* border consist of the corresponding patch type and the user specifies that none of the *buffer* boundary and background edge can be treated as edge
TE *Total Edge*	Total edge at the class level is an absolute measure of total edge length of a particular patch type or all the patches in the landscape	0 = when there is no class edge in the *buffer*; that is, when the entire *buffer* and *buffer* border consists of the corresponding patch type and the user specifies that none of the *buffer* boundary and background edge be treated as edge

(continued)

Table 3 *(continued)*

MPS *Mean Patch Size*	It equals the total class area divided by the total number of patches of the class	MPS > 0, without limit
NUMP *Number of Patches*	It equals the number of patches of the corresponding patch type.	1 = when the *buffer* contains only 1 patch of the corresponding patch type; that is, when the class consists of a single patch. It increases, without limit, as the number of patches increases
MSI *Mean Shape Index*	It measures the average patch shape for a particular patch type or for all patches in the *buffer*. It corrects for the size problem of the perimeter-area ratio index by adjusting for a square (or almost square) standard	1 = when all patches in the *buffer* are circular (vector) or square (raster); it increases without limit as the patch shapes become more irregular
AWMSI *Area Weighted Mean Shape Index*	It equals the average Shape Index of patches, weighted by patch area so that larger patches weight more than smaller ones.	1 = when all patches in the *buffer* are circular (vector) or square (raster); AWMSI increases without limit as the patch shapes become more irregular
AWMPFD *Area Weighted Mean Patch Fractal Dimension*	It equals the average patch fractal dimension of patches in the landscape, weighted by patch area.	AWMPFD approaches 1 for shapes with very simple perimeters such as circles or squares, and approaches 2 for shapes with highly convoluted, plane-filling perimeters
IJI *Interspersion Juxtaposition Index*	It is based on patch adjacencies. It rather isolates the interspersion or intermixing of patch types.	100 = when the corresponding patch type is equally adjacent to all other patch types (i.e., maximally interspersed and juxtaposed to other patch types). IJI approaches 0 when the corresponding patch type is adjacent to only 1 other patch type and the number of patch types increases
MNN *Mean Nearest-Neighbor Distance*	It equals the sum of the distance to the nearest neighboring patch of the same type.	MNN > 0, without limit. MNN approaches 0 as the distance to the nearest neighbour decreases

SEI had higher numbers of correlations in particular with NH_4, NO_3 and P.

IBE was associated only once in the 3,000 m buffer at the 1st level.

4. Discussion

As shown in other studies already mentioned in this paper, this study also shows presence of correlation (which does not imply causation) between landscape indexes such as SDI and SEI and the chemical-physical parameters such as NH_4, NO_3 and P, which are usually used as indicators of land use pressure in agroecosystems.

The indexes SDI and SEI are commonly used to characterise species diversity and evenness in biotic communities and are also used to quantify landscape diversity. The first index is a measure of relative patch diversity, or the proportional abundance of each patch type within the landscape, while the latter is a measure of patch distribution and abundance, or the measurement of the distribution of areas among patch types within the landscape.

In river bodies within agroecosystems, large values of chemical-physical parameters are associated with large values of SDI and SEI. The analysis of other landscape indexes (such as NUMP, TE and ED) showed that the presence of many small patches was associated with environmental parameters. A 1,000 m-radius buffer is not sufficient to detect solid relationship between landscape and the environmental

Table 4. Correlation r and rs between environmental data and landscape indexes; M medium, H high correlation coefficent.

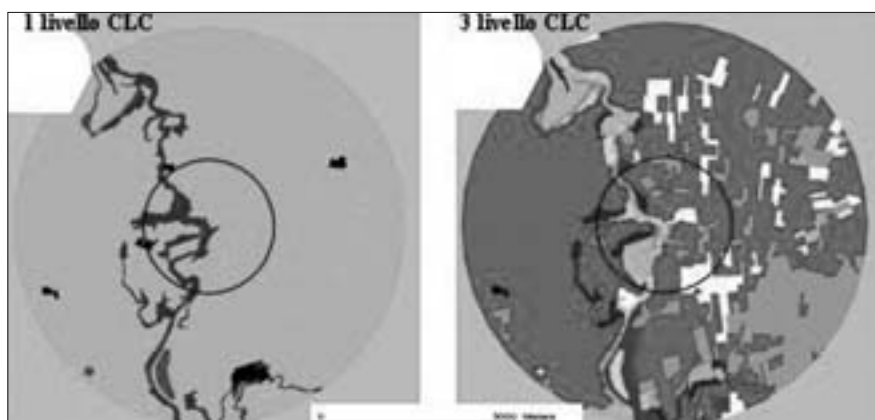| Level	Buffer	Environmental data	Landscape indexes											
			MNN	IJI	NUMP	MPS	TE	ED	MSI	AWMSI	AWMPFD	SDI	SEI	LSI
3rd level	1000 m	N-NH$_4$ mg l^{-1}					M					M		
		N-NO$_3$ mg l^{-1}			H		H	H						H
		P tot mg l^{-1}					M							
		LIM												
		IBE												
		SECA												
	3000 m	N-NH$_4$ mg l^{-1}										M	M	
		N-NO$_3$ mg l^{-1}			M	-M	M	M				M	H	M
		P tot mg l^{-1}										H	M	
		LIM								-M	-M			
		IBE												
		SECA												
1st level	1000 m	N-NH$_4$ mg l^{-1}			M		M	M				M		M
		N-NO$_3$ mg l^{-1}										M		
		P tot mg l^{-1}										M	M	
		LIM		M										
		IBE												
		SECA												
	3000 m	N-NH$_4$ mg l^{-1}			H									
		N-NO$_3$ mg l^{-1}	-H			-M	H	M		H	H	M	H	M
		P tot mg l^{-1}			M							H	M	
		LIM												
		IBE			M							M	M	
		SECA												

Figure 3. Level 1 and 3 of CLC and 1,000 m and 3,000 m buffers.

quality of the water body while there is no need of a detailed definition of the landscape as analysis of the 1st level of CLC is sufficient to detect possible relationships.

Numbers of correlations and values of coefficient remain however low, and this could be due to the fact that, due to the absence of long-term monitoring, an average of only 3 years of monitoring may not be sufficient to properly represent the water quality. Furthermore, values of monthly monitoring could easily be influenced by the seasonal flows. According to our preliminary study, at present, landscape metrics only partially can efficently describe water quality within agroecosystems and could just be useful as an initial screening tool in the absence of

monitoring stations. "[…] however there are areas – and landscape is one of them – for which the definition of operational indicators remains a major challenge" (AA.VV. 2000).

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