Chapter 4
Landscape Assessment: The Ecological Profile

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Abstract In recent decades, Landscape Ecology has consolidated a broad set of indicators to analyse and quantify the significant correlations between the morphological structure of a landscape mosaic and its ecosystem functions. These correlations define the principles of landscape organization on different scales space-time. This contribution proposes a review of some of these indicators, identifying those that the empirical evidence proved to be most effective in an ecologically oriented planning. The review concludes with the selection of two indexes, that for the high information content and for the wealth of experiments conducted on a national and international level, are particularly significant: *Evenness* and *Biological territorial capacity* (Btc). The technical requirements and the reliability at different scales of these indexes are detailed, with particular regard to the Piemonte territory.

Keywords Diversity • Connectivity • Patch • Richness • Scale

4.1 Principles and Definitions

When considering Landscape ecology indicators and indexes, first and foremost we must take a look at the theories and principles these instruments are based on, which condition the method of application and the interpretation of results.

Landscape ecology defines a landscape as a system of ecologically different interrelated spatial units, in other words as a system of ecosystems, or meta-ecosystem (Forman and Godron 1986; Ingegnoli 1993). This is characterised by many space-time scale hierarchical domains and represents a specific level of biological organisation, immediately above the ecosystem.

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This definition embodies the entire innovative character of the discipline: it reveals the fundamental principles that govern the field of action, and the notable theoretical and applicative implications.

Firstly, the definition of landscape as a system means we must adopt a paradigm of analysis in which both the relations between the elements of the system, and its principles of organisation can emerge. From their interaction, in fact, we can obtain the global properties of the system, different to those of the single elements (principle of emergent properties). A landscape, and its environmental system, is always more complex than the sum of its parts, and each part has different characteristics on the basis of how it interacts with its surroundings.

This, in operative terms, means we have to emphasize the reciprocal correlations between the *structure* and *functions* of the environmental systems which, as intrinsic aspects of the same phenomenon, define the configuration of a landscape on the basis of various space-time scales (O'Neill et al. 1986, 1989; Turner 1990).

Secondly, when defining landscape as a biological system we must implicitly refer to a hierarchical organisation model, where the interactions between components of the lower level are controlled by slower interactions at higher levels.

Landscape ecology emphasizes the influence of scale on ecological phenomena (Turner et al. 1989), an influence with significant implications also on the application of control indexes, as we shall see.

In operative terms, using a hierarchical type organisation means acknowledging that the properties of a landscape mosaic can only be comprehended in a more all-encompassing context. While the ecology of ecosystems was based on the *vertical* study of homogeneous and all but autonomous spatial units, Landscape ecology on the other hand leans towards a *chorological* study, which analyses the horizontal relations between separate and non-homogeneous spatial units. The heterogeneity of the environment is no longer merely background noise of secondary importance (Blondel 1986).

Finally, it must be said that Landscape ecology has made it possible to go beyond the man/environment opposition which traditionally characterizes most biological and natural disciplines, creating a new integration between natural and human domains. Landscape is, in fact, an expression of both natural and anthropic dynamism, the expression of a continuous superimposition and interpenetration of the two domains (Ingegnoli 1993).

Therefore, anthropic ecosystems, their disturbances and their influence on the environment, are an integral part of landscape and subject to more intense study in order to harmonize human requirements with those of nature and the environment.

4.2 Landscape Ecology Indicators

The notable progress in the theoretical Landscape ecology models, and the numerous experiments in the field, have established and consolidated several types of different indicators which we can divide, from a merely instrumental point of view, into two main macrocategories:

- structural control or pattern indexes;
- functional control or process indexes.

This group of indexes is measured on the basis of the different kinds of land use in the territory in question. The above information is integrated, using methods that vary for each single index, with data on the morphological structure of the different patches in the landscape mosaic (surfaces, perimeters, longitudinal and transversal axes, …) and with data on their reciprocal relations (distances between neighbouring patches, distances between patches of the same type, …).

Therefore the characteristics of the geographical context define the matrix with which the ecological processes are analysed and compared. Landscape ecology operates within this context, defining the meeting point of ecosystemic functions and chorological patterns (Farina 2001).

This structure derives from the theoretical and cultural paradigms that have contributed to establishing the discipline. The first experimentations in Landscape ecology were done in Central-Northern Europe (Germany, Holland, Denmark) and in Eastern Europe (Czechoslovakia, Poland, the Baltic countries), and while establishing the common ground for epistemological theories, models and approaches, they were in fact related to human landscapes (natural landscapes long since modified by anthropic activities) and were solidly based on both geographical and geomorphological disciplines.

In the 1980s, the main movers of the European school took their ideas overseas with the resulting development in American ecological schools, where large-scale ecosystems, found only in this continent, became the main focus of attention. This new approach concentrated in particular on the problems associated with the correct management of vast natural areas and their relations with neighbouring agroecosystems, where the complexity of the places is almost always synonymous of diversity and richness.

The influence of the European approach (focused on the human component of landscape mosaics and its geographical dimension) and the American approach (more focused on the complexity of large natural and seminatural areas) and vice versa, consolidated and enriched the Landscape ecology disciplinary body, favouring also the creation of useful operative tools, including a rich set of indicators and indexes.

The widespread diffusion of these indexes made it necessary to review them, selecting the more reliable, and this review referred not only to the various and diversified applications, sometimes uncontrolled and incorrect, but also to the authors who first proposed the experimentation for ecological planning (Tables 4.1 and 4.2). Furthermore, an attempt was made to emphasize the theoretical references that consolidated content and applicative methods.

4.2.1 Structural Control Indexes

Structural control indexes measure in quantitative terms some salient characteristics of the structure of an ecomosaic or, in some cases, of its organisational cell:

Table 4.1 List of indicators

		Indicator	DPSIR	Source
Structural indexes		*Spatial indexes*		
	1.	*Elongation index* Measures the elongation of a patch considered as a suitable topological condition for favouring the exchange of organisms, biological energy and matter in a landscape mosaic	S	Davis 1986; Forman 1995
	2.	*Circularity ratio* Measures the distance of a patch shape from the isodiametric, evaluating the greater or lesser articulation of its surfaces and therefore the greater or lesser tendency to exchange organisms, biological energy and matter with the surrounding context, through more or less defined edges	S	Stoddart 1965; Unwin 1981; Forman 1995
	3.	*Shape factor* Measures the distance of a patch shape from the isodiametric, assessing the greater or lesser articulation of its surfaces and therefore the greater or lesser tendency to exchange organisms, biological energy and matter with the surrounding context, through more or less defined edges	S	Davis 1986; Forman 1995
	4.	*Grain index* Measures patches size in a landscape mosaic in relation to the density of the same	S	Forman 1995
	5.	*Isolation of patches* Considering a landscape mosaic represented on a cartesian plane of coordinates x and y, this index measures the isolation level of the patches in the same as a sum of the patches variation in relation to axes x and y of said plane	S	Lowe and Moryadas 1975; Forman and Godron 1986; Forman 1995
	6.	*Dispersion of patches* Measures the dispersion level of the single landscape element types in a particular environmental system, differentiating between compact groups and discrete distributions of elements of the same type with no connection between each other	S	Pielou 1977; Forman and Godron 1986; O'Neill et al. 1988
		Numeric indexes		
	7.	*Relative richness* Measures the richness of a landscape mosaic as a percentage based on a ratio of the number of patch types measured and the maximum possible	S	Romme 1982; Turner 1989; Forman 1995
	8.	*Margalef richness* Measures the richness of a landscape mosaic relating the number of landscape element types to the logarithm of the overall number of patches	S	Margalef 1958; Farina 2001, 2004

Table 4.1 (continued)

		Indicator	DPSIR	Source
Structural indexes (*cont.*)		*Numeric indexes* (*cont.*)		
	9.	*Menhinick richness* Measures the richness of a landscape mosaic relating the number of landscape element types to the square root of the overall number of patches	S	Menhinick 1964; Rossaro 1998
	10.	*McIntosh diversity* Measures the ratio between the different element types of a landscape, assessing the position of the same in a space of n-dimensions, where n is the number of landscape element types. The position of any kind of element is determined by its entity and it is measured as the distance from the origin along its axis. The distance average is equal to the diversity of the landscape pattern analysed	S	McIntosh 1967
	11.	*Hill diversity* Measures the dominance of a precise number of landscape element types in a landscape mosaic. The index varies from 0 to the total number of types considered	S	Hill 1973; Farina 2004
	12.	*Shannon diversity* Measures the diversity of a landscape mosaic on the basis of both the number of patch types present, and their relative abundance in the mosaic	S	O'Neill et al. 1988; Turner 1989; Forman 1995
	13.	*Evenness* (Pielou) Assesses the ecological diversity, in other words the richness of the landscape element types (biotopes) that characterise a landscape mosaic. Ratio between the real diversity of a landscape mosaic obtained with the Shannon formula (H) and the maximum possible (H_{max})	S	Pielou 1977; Romme 1982; Turner 1989; Forman 1995
	14.	*Simpson dominance* Measures the prevalence of a few patch types in an environmental system, based on the application of the Simpson formula (1949)	S	Simpson 1949; Farina 2001, 2004
	15.	*O'Neill and Turner dominance* Measures the prevalence of a few patch types in an environmental system, based on the application of the Shannon formula (1949)	S	O'Neill et al. 1988; Turner 1989; Forman 1995
	16.	*Contagion index* Assesses both the composition, and the configuration of a landscape mosaic, measuring the level of aggregation of each single patch category	S	O'Neill et al. 1988; Turner 1989; Li and Reynolds 1993; Forman 1995
Functional Indexes	17.	*Gamma index of network connectivity* Indicates the connection level of a landscape system represented schematically in a planar graph, consisting of nodes and connections along which the flows of organisms, matter and energy move. It is measured by comparing the number of existing connections with the maximum number of possible connections	S	Forman and Godron 1986

Table 4.1 (continued)

		Indicator	DPSIR	Source
Functional Indexes (*cont.*)	18.	*Alpha index of network circuitry* Indicates the efficiency level of the connections in a landscape system represented schematically in a planar graph. It is measured by comparing the number of existing independent circuits to the maximum possible	S	Forman and Godron 1986
	19.	*Percolation index* Analyses the possibility of movement of a species or of an organism in a territory, through the application of percolation theory. In general, it describes the connection level of an environmental system	S	Gardner et al. 1987a, b, 1989; Turner and Gardner 1990; Farina 1993
	20.	*Biological Territorial Capacity* (Btc) Magnitude of the metabolism of the ecosystems in a territory and of its homeostatic and homeoretic capacity (for self/re-equilibrium), which measures the equilibrium level of an environmental system. It is defined by the sum of the products of surfaces with land use types, and the relevant unit biological territorial capacity value, and by the subsequent weighed average of this sum in relation to the total surfaces being studied	S	Ingegnoli 1980, 1993, 1997, 2002; Ingegnoli and Giglio 2005

Table 4.2 Formulas for the application of indicators

Elongation	
$E = \frac{\omega}{l}$	w = width of patch perpendicular to long axis l = length of the longest axis of a patch
Circularity ratio	
$C = \frac{A}{A_c}$	A = area of patch A_c = area of smallest circle enclosing a patch
Shape factor	
$SF = \frac{p_c}{p}$	p_c = perimeter of circle having same area as patch p = perimeter of patch
Grain index	
$G = \frac{A}{n}$	A = area of the landscape mosaic n = number of patches in the landscape mosaic
Isolation of patches	
$D = \sum (\sigma_x^2 + \sigma_y^2)$	σ_x^2 = variance on the x-axis of the patches in a landscape mosaic, represented as a graph on the cartesian plane of coordinates x and y σ_y^2 = variance on the y-axis of the patches in a landscape mosaic, represented as a graph on the cartesian plane of coordinates x and y
Dispersion of patches	
$R_c = 2d_c\left(\frac{\lambda}{\pi}\right)$	d_c = average distance from a patch (its centre or centroid) to its nearest neighbouring patch λ = average density of patches
Relative richness	
$R = \frac{s}{s_{\max}} \times 100$	s = number of landscape element types $s_{\max}$ = maximum possible number of landscape element types
Margalef richness	
$R = \frac{s}{\ln (n)}$	s = number of landscape element types n = total number of landscape elements
Menhinick richness	
$R = \frac{s}{\sqrt{n}}$	s = number of landscape element types n = total number of landscape elements
Shannon diversity	
$H = -\sum_{K=1}^{s} (p_k) \ln (p_k)$	p_k = percentage presence of a K type element in the ecomosaic (percentage in terms of surfaces) s = number of landscape element types
Evenness (Pielou)	
$E = \frac{H}{H_{\max}} = \frac{H}{\ln (s)}$	H = Shannon diversity $H_{\max}$ = ln (s) = maximum possible diversity s = number of landscape element types
Simpson dominance	
$D = \sum_{i=1}^{s} \left(\frac{n_i}{N}\right)^2$	n_i = number of landscape elements in the i-esima category N = total number of landscape elements s = number of landscape element types
O'Neill and Turner dominance	
$D = H_{\max} + \sum_{K=1}^{s} (p_k) \ln (p_k)$	$H_{\max}$ = ln (s) = maximum possible diversity p_k = percentage presence of a K type element in the ecomosaic s = number of landscape element types

Table 4.2 (continued)

Contagion	
$C = 2s \log s + \sum_{i=1}^{s} \sum_{j=1}^{s} q_{i,j} \log q_{i,j}$	s = number of landscape element types $q_{i,j}$ = probability of landscape element i being adjacent to landscape element j
Gamma index of network connectivity	
$\gamma = \frac{L}{L_{\max}} = \frac{L}{3\,(V-2)}$	L = number of connections in a planar graph V = number of nodes in a planar graph L_{max} = maximum possible number of connections in a planar graph
Alpha index of network circuitry	
$\alpha = \frac{(L-V+1)}{C_{\max}} = \frac{(L-V+1)}{(2V-5)}$	L = number of connections in a planar graph V = number of nodes in a planar graph C_{max} = maximum possible number of circuits in a planar graph
Biological Territorial Capacity – (Btc) [Mcal/m^2/year]	
$Btc_i = \frac{1}{2}(a_i + b_i) \times R$	$a_i = (R/PG)_i/(R/PG)_{max}$ $b_i = (ds/S)_{min}/(ds/S)_i$ R = respiration PG = gross primary production *ds/S* = R/B = structure maintenance ratio B = biomass i = principal ecosystems of the biosphere

the landscape patch (Forman and Godron 1981). As the morphological structure of a certain landscape influences the ecological function, conditioning the relations between the single components of the system, obviously the analysis of the same discloses and supports the assessment of the ecological processes in act.

To get a better idea of the peculiarities and purposes, it may be useful to make a further distinction between spatial indexes and numeric indexes. Spatial indexes describe the characteristics of the components of a landscape mosaic on the basis of both a topological approach (shape and size), and a chorological approach (position of a component in relation to other components or of a different type). Numeric indexes, which derive from the Ecology of ecosystems, are mathematical expressions that can be used to measure the information implicit in the complexity of a landscape mosaic.

4.2.1.1 Spatial Indexes

Spatial indexes include both indexes that focus on a single patch, and indexes that assess the structural characteristics of a mosaic of patches as a whole.

Of the former, Forman (1995) indicates the *elongation index* (Davis 1986), the *circularity ratio* (Stoddart 1965; Unwin 1981) and the *shape factor* (Davis 1986), which measure the distance of the shape of a patch from the isodiametric, using different criteria. In other words, these indexes assess the greater or lesser articulation of the surfaces considered and therefore the greater or lesser disposition to exchange organisms, biological energy and matter with the surrounding context, through more or less developed edges. The *shape factor* in particular is built so the range of its values is always between 0 and 1. Values near 0 indicate a high convolution of the margins; values near 1 indicate an increasing compactness of the area in question.

Of the indexes that assess the characters of a complex system of patches, the same author (1995) indicates the *grain index*, the *isolation of patches* (Lowe and Moryadas 1975; Forman and Godron 1986) and the *dispersion of patches* (Pielou 1977; Forman and Godron 1986; O'Neill et al. 1988).

The *grain index* measures the size of the patches in a landscape mosaic in relation to their density, and can therefore be used to size new patches correctly.

The *isolation of patches* measures the reciprocal position of the patches in a landscape pattern, therefore their degree of isolation, or vice versa clustering, in an ecologically non-neutral matrix, which is resistant to the movement of species. Considering a landscape mosaic represented on a cartesian plane by coordinates x and y, the degree of isolation of patches is determined by the sum of the patch variance in relation to axes x and y of said plane.

The *dispersion of patches* establishes the degree of dispersion of the single landscape element types in the environment, differentiating between compact groups (for example a compact portion of woodland) and discrete distributions of unrelated elements of the same type (groups of trees). This index measures the relationship between the number of interruptions in landscape elements of the same or type, or functionally homogeneous, and the overall surfaces of the same elements. For want of an internal connection between natural and seminatural patches, it can represent a good stepping stone indicator.

4.2.1.2 Numeric Indexes

There is a rich set of indexes to use in the Ecology of ecosystems and communities which, by sampling the presence of animal or vegetable species, measure the degree of heterogeneity in a biological community. Landscape ecology, instead of sampling species, samples landscape element types (ecotopes, biotopes, patches, …), making some of these indexes ideal for measuring the heterogeneity and complexity in an environmental system of a particular landscape (Bernini and Padoa-Schioppa 2002).

Some of the most commonly used and consolidated indexes include richness, diversity, dominance and evenness, applied at an ecomosaic level.

Romme (1982) and Turner (1989) were the first to measure the heterogeneity of a landscape mosaic using the *relative richness index*, which calculates the percentage ratio between the number of patch types (habitats) in a landscape system, and the maximum possible.

The *Margalef index* (Margalef 1958; Farina 2001) and the *Menhinick index* (Menhinick 1964; Rossaro 1998) are two more sophisticated variations of the relative richness index. These indexes compare the number of element types with the effective number of patches in a landscape mosaic, in consideration of the fact that the first term increases as the area in question increases.

The richness of a landscape mosaic, as can be imagined, is significantly influenced by the dimensions of the sample analysed. Therefore, we must use corrective factors to increase the margin of variation in the results induced by the weight of the dimensional factor.

For this purpose, the number of element types in the landscape is compared to the logarithm of the overall number of patches in the landscape mosaic in the Margalef richness index, and to the square root in the Menhinick index.

Diversity is a complex figure. It is influenced by the dimensions of the sample in question, and therefore by the number of landscape element types, as well as by their quantitative distribution. Therefore, results are more reliable and exhaustive when measuring diversity using indexes of ecosystemic diversity which consider, not only the richness of the element types in the landscape mosaic, but also the quantitative distribution (the relative weight) of the single types in the mosaic. In other words these indexes, along with the number of types present, also consider their relative abundance, without indicating a value for the single types. Each single element is only considered in relation to its presence and abundance.

A complete review of diversity indexes can be found in the Environmental Impact Assessment Manual published by the Association of Environmental Analysts (Colombo and Malcevschi 1999; Malcevschi and Poli 2008) in the "Indicators of terrestrial ecosystems". These include the *McIntosh index* (1967), the *Hill index* (1973) and the *Shannon index* (1949).

Shannon diversity is based on information theory (Shannon and Weaver 1949) and was first applied to Landscape ecology by O'Neill et al. (1988) and Turner (1989).

The Shannon formula measures the mean degree of uncertainty in the prediction that an object, chosen at random from a group, will belong to a certain category. This uncertainty increases with the number of categories and the equal distribution of the same. Applying this type of calculation to Landscape ecology means that the greater the value of the index—adimensional index which varies from 0 and infinite—the greater the landscape diversity.

Furthermore, in terms of diversity, note that a conspicuous number of landscape element types is a necessary condition, but insufficient on its own to guarantee a high level of ecological diversity in a certain geographical context. For this to be the case, these types must all tend to be equally represented. Diversity depends not only on the overall number of landscape element types, but also on their reciprocal balance ratio.

In operative terms it can be very useful to compare the real diversity of a landscape mosaic with the maximum possible, which represents the equitability or equal distribution, seen as the possibility that the different elements of the landscape are found in the same quantity.

Evenness or *equitability* (Pielou 1975, 1977)—equal to the ratio between the value of the real diversity and the maximum possible (H_{max})—measures the distribution of the relative abundances of landscape element types in a landscape mosaic. If this ratio tends towards 1 then the real diversity tends to coincide with the maximum possible, and the ecomosaic being examined will be characterised by many elements of a similar relative weight. On the other hand, when this ratio tends towards 0, the landscape mosaic will be dominated by one single, widespread and interlinked element, which acts as a matrix. In other words, comparing H and H_{max} lets we calculate how far the real value of ecological diversity departs from the maximum possible value which represents the optimal situation in terms of ecological functionality.

Shannon diversity and evenness, as mentioned in Sect. 2.2 are included in a group of indicators proposed in recent European documents for landscape assessment and monitoring.

The EnRisk project (*Environmental Risk Assessment for European Agriculture*) of the European Centre for Nature Conservation (Delbaere 2003), with the aim of identifying indicators to monitor European agro-environmental policies and the landscape dimension of rural territories, includes these indexes in the tools suitable to establish the status and vulnerability of European landscapes, in relation to processes of transformation dictated by the use of farmland (identification of sensitive zones with environmental risks). With similar aims, the PAIS project (*Proposal on Agri-Environmental Indicators*) (Landsis et al. 2002) indicates Shannon diversity as one of the indicators on "formal landscape features", and lists it with the "landscape configuration" indexes, used to assess the properties in the structural pattern of a landscape (*structural arrangement of landscape elements*).

The ELCAI project (*European Landscape Character Assessment Initiative*) (Wascher 2005), part of the 5th Framework Programme for the Environment, with the aim of selecting suitable indicators for highlighting the distinctive character of a landscape (*Landscape Character Assessment*), proposes Shannon diversity as the ideal instrument for estimating both landscape diversity (*Spatial structure landscape*), and habitat diversity (*Biodiversity*).

Dominance indexes have an opposite trend to evenness and measure the prevalence of a few elements in an environmental system. A high value in these indexes means that in the territory in question, a few landscape types have a monopoly on resources.

Several authors have proposed the *Simpson index* (1949) to calculate dominance, the first index used for this purpose in the Ecology of ecosystems. The value obtained with the Simpson formula, which varies from 0 to 1, measures the probability that two objects chosen at random in a group, belong to the same category. If a category is abundant, the probability that this condition occurs is high, and therefore the global diversity of the system will be quite low.

O'Neill et al. (1988) and Turner (1989) however, calculate dominance as the difference between the maximum possible diversity (H_{max}) and Shannon diversity. The higher the difference between the two terms, the greater the dominance, in this case seen as the complementary of diversity.

Of the indicators derived from the Ecology of ecosystems, the *contagion index* (O'Neill et al. 1988; Turner 1989, revised by Li and Reynolds 1993; Hunsaker et al. 1994; Riitters et al. 1996) is widely used, simultaneously indicating the composition and the configuration of a landscape mosaic, measuring the level of aggregation of each single patch category.

When the contagion value is low, all the patches are equally adjacent to each other, and the landscape system will consist of many small patches; vice versa, if the value is high, we will have the maximum possible aggregation of patches and the system will be characterized by a few large patches.

Forman (1995) includes this index, along with dispersion of patches and isolation of patches, in the tools used to measure the overall pattern of the landscape mosaic (*All-patch pattern measures*), differentiating it from indexes focused on the assessment of single patches (*Patch-centred measures*) such as isolation of patch or accessibility of a patch. Farina, in a similar way, classifies the index in "indexes of spatial organisation", in other words indexes that measure the relationship between the single patches of an ecomosaic on the basis of their reciprocal position.

4.2.2 Functional Control Indexes

Functional control indexes assess the resistance of the fundamental processes that the stability of the landscape environmental system is based on, analysing the functional relations between its components. These indexes also measure the interference of anthropic disturbance for these processes, establishing the ranges within the variables, the processes are based on, can oscillate without causing breakage or degeneration.

The most widely used functional control indexes (process indexes) both in planning and environmental assessment, are the gamma index of network connectivity, the alpha index of network circuitry, the percolation index and the biological territorial capacity.

The stability of an environmental system—in other words its capacity to maintain a constant structure and function—depends on the efficiency of the flows of organisms, biological energy and matter which, by traversing the landscape help to conserve it intact (Forman and Godron 1986), and therefore the stability of an environmental system also depends on the availability of functional paths for said flows. These paths, in our current landscape situation, are becoming more and more compromised and reduced by the progressive fragmentation and insularization of the territory, in particular due to the indiscriminate and often auto-referential growth of anthropic settlements.

Therefore, in order to calculate the ecological function of an environmental system, we must identify the connections between the single components of the landscape structure, along which organisms, matter and energy flow, and the barriers that obstruct and interrupt these flows.

Gamma index of network connectivity and alpha index of network circuitry (Forman and Godron 1986) meet these requirements. Based on graph theory, these have been widely used for some time, both in the study of Landscape ecology, and in the specific study of ecological networks.

Their use involves the construction of a planar graph that indicates the connections between the different patches of the landscape mosaic analysed, and the connections to re-establish or reconstruct. Therefore, the application of these graphs implies simplification of landscape elements into nodes and superimposed connections for areas without connective functions.

The *gamma index* shows the level of connection between the nodes of a graph and provides an indication of the number of existing connections in relation to the maximum possible number of connections. The *alpha index* measures the level of efficiency and is expressed by the relationship between the number of independent circuits in a graph and the maximum possible. Globally, these indexes define the level of complexity of a network.

The *percolation index* (Gardner et al. 1987a, b, 1989; Turner and Gardner 1990; Farina 1993) has similar aims to gamma and alpha indexes and lets us analyse and quantify the possibility of movement of a species or of an organism in the territory, and in general describes its level of connection.

In physics, the percolation theory (Stauffer 1985) studies the dynamics of fluids in an aggregated medium; in Landscape ecology this doctrine is used as a theoretical base for creating neutral models to describe and explain different patterns which can be observed, on different scales, in an environmental mosaic, and to provide approximate forecasts of its suitability to support focal species.

Considering a matrix $m \times m$, the probability that a fluid, and in the same way a species, expands and crosses the entire matrix is established by the critical probability (*cp*), calculated experimentally, as equal to 0.59275.

If the cells of the matrix, which in a landscape mosaic coincide with patches suitable for supporting the movement of a particular species, reach the critical threshold[1], in other words a coverage of 59%, we have percolation. It is highly probable that the species in question can transit throughout the entire mosaic, occupying the majority of the cells. The landscape mosaic, in relation to the requirements of said species, is linked.

Near the critical value (*cp*), the behaviour of the system is very unpredictable, and even the smallest change in the abundance of a certain object, whether land use or vegetation, can result in significant modifications in system organisation and also in the behaviour of the species that inhabit it.

Biological territorial capacity (Btc) (Ingegnoli 1980, 1993, 1997, 2002; Ingegnoli and Giglio 2005) is a status function that measures the latent auto-equilibrium capacity of a landscape system.

Landscape, being a living system, is a complex adaptable structure, in continuous evolution, characterised by a dynamic metastable equilibrium, in other words by a specific condition of precarious stationariness, liable to evolve into a more organised status, or vice versa deteriorate.

The levels of landscape system organisation and order depend on its capacity to incorporate disturbances (events that produce significant modifications in the structure and function of the system) and always represent the point of equilibrium between the forces that encourage change and those that oppose it.

Within a range of ordinary disturbances a landscape mosaic, using and optimising the energy flows that cross the same, fluctuates with subtle variations, remaining within its own field of metastability. If the disturbance exceeds the limit of this range, the system recalibrates its functions to meet the new conditions. This means reach-

[1] The threshold value *pc* is a theoretical value which must be increased or decreased in relation to the species in question. Each species, in fact, has a specific perception of the contiguity of a specific environment.

ing a threshold of metastability, beyond which the landscape type in question will change, and tends to be replaced by a new one. If the metamorphosis is incompatible with a landscape on a greater scale, or it is unable to incorporate the local regime of disturbance, the entire system will deteriorate and reclamation will be necessary.

Large-scale transformations are usually hard to measure, and in many cases it is impossible to assess, a priori, what effect the changes will have on the ecological stability of the landscape system.

With this in mind, it can be useful to measure the metastability of the system analysed, in other words the tendency to maintain the functional processes and its own structure constant, while modifying, due to the disturbances, its point of equilibrium (homeoretic type mechanisms), or vice versa its tendency to recover its original functional level (homeostatic mechanisms) after a disturbance.

Biological territorial capacity (Btc) was established to provide a synthetic parameter to assess the metastability threshold of a landscape system: to assess, in the case of environmental stress, the limit beyond which it is impossible for the ecosystems to maintain the conditions necessary for survival. This index estimates[2] the energy flow that a landscape system must reintegrate to maintain its level of order and metastability, and it is a magnitude related to the degree of organisation of the same system and to the metabolic capacity of its main ecosystems. The Btc of a landscape system is therefore closely related to the presence of vegetable biomass and its capacity to assimilate and transform solar energy[3].

Btc associates high values with ecosystems that have a high resistance to disturbances, but a slow capacity for recovery (high metastability), and low values with ecosystems that have scarce resistance to disturbances, but a fast capacity for recovery (low metastability).

4.2.3 Scale of Application: Characteristic

The indexes considered in the previous paragraph can, in general, be applied on a large, medium or small scale, and produce reliable results at various scale resolutions[4].

It must be said however that the biological spectrum, of which landscape is a specific organisational level, is characterised by an evident principle of integration, corollary of the more important principle of emergent properties (Lorenz 1980; Kirk 1980). On the basis of this principle, the properties that characterise a certain level of biological organisation are essential in order to comprehend processes at higher

[2] Btc represents a magnitude which can be precisely measured but, as the result requires considerable expenditure in terms of time and instrumentation, an estimate is often more practical.

[3] The processes that enable a landscape to self-perpetuate, in other words to renew its fundamental components, are closely associated with the presence of vegetation, an element which plays a crucial role in the ecological functionality of the landscape system. In reality, the useful energy for the entire biosphere depends on photosynthesis and is subject to the action of autotrophic organisms.

[4] The information content of the index/indicator depends on the detail of the base data used for the calculation. The vaster the area in question, the more probable it becomes that the information acquired with the indicator will be of a general nature, as it is harder to obtain uniform in-depth data.

levels, but never enough to explain them in exhaustive terms. This means that no landscape mosaic can be fully studied at one single scale or organisational level.

Therefore, the correct use of ecological control indexes dictates that these instruments are applied at least to three different levels of analysis—interest level, higher level and lower level—which define the same number of spatial scales.

The interest level, which reflects the level of organisation of the landscape system analysed, defines the most suitable spatial size for the analysis, which will produce the most information with the greatest efficiency, in other words with the lowest margin of error. The higher level lets us comprehend the actual role of the mosaic in question in a vaster territorial structure, providing information on the limits to which it is subject. The lower scale level explains the processes that develop as emergent properties at the level of interest, and at the same time lets us highlight phenomena that can be hidden at a higher level by compensatory processes, using more detailed and disaggregated information.

On a timescale, the more complete and correct applications adopt a process type approach, applying these indexes to several historical frames, to show evolutive dynamics, and clarify and verify possible scenarios of intervention.

4.3 Proposal for Landscape Ecology Indicators

Of the above indicators, the indexes of evenness and biological territorial capacity (Btc), for the information content, the wide range of experiments and the reliable and standardized methods of application, are particularly significant (Tables 4.3 and 4.4).

Evenness—calculated with the Shannon formula—is currently the most suitable instrument for measuring the ecological diversity of a territory, in other words the variety of the patterns that distinguish an ecomosaic and control its evolution. This is extremely useful, as ecological diversity is essential for the existence of specific and intraspecific or genetic diversity and, in a hierarchically organised system like landscape, it represents the super-ordinate level. Each habitat in fact, with its own physical-chemical conditions, supports a particular variety of life forms, and the range of species in each area depends on the size, shape, variety and dynamics of said habitat.

With the greater differentiation of the natural and seminatural elements in a territory, statistically, there will also be a greater variety of species inhabiting said territory. In other words, diversified environmental characteristics will correspond to a high number of biotopes, and therefore a high number of species will find the ideal conditions for development (ecological niches)[5].

[5] The richness of different species in the community determines an increase in the number of rings in the food chain, greater probable biocenosis stability, a more efficient energy flow and matter cycle, corresponding to, in short, higher stability of the structure and in the function of the ecosystems. Furthermore, the control of any disturbances which could arise in a territory is closely related to ecological diversity. A disturbance of a certain size in a landscape with a low index of diversity, with just a few elements or just one, can cause changes of such a magnitude they cause the landscape to collapse. The same disturbance in a landscape with a high index of diversity, may be irrelevant. In fact, not all its elements react in the same way to the same disturbance, so the risk

Table 4.3 Evenness

Indicator	Evenness (E)
Definition	Assesses ecological diversity, as the richness of the landscape element types (biotopes) that characterise a landscape mosaic
Description	Ratio between the real diversity of a landscape mosaic obtained with the Shannon formula (H) and the maximum possible (H_{max})
Category	Ecology
Aims pursuant to landscape	Acknowledgement, assessment
Status/Process	Status
DPSIR category	Status
Typology	Index
Component variables (if index)	Total number of different landscape element types Relative percentage of the surfaces for each landscape element type
Unit of measure	Adimensional index
Territorial scale of reference	Municipal/provincial/regional
Time scale of reference	Year
Characteristics of use	Technical-scientific analysis, monitoring, environmental assessment
Availability of data source	Cartographic layers on land use
Method of representation	Theme maps Diagrams if applied to time grid
Other explanatory notes	The range of the index varies from 0 to 1 Values near 0 indicate landscape mosaics dominated by one single, widespread and interlinked element, which acts as a matrix Values near 1 indicate landscape mosaics characterized by many elements with a similar relative weight The index can be used to compare the values of different landscape units, highlighting the different conditions of equilibrium and the role in the environmental system
Fields/works in which it was used	EIA, SEA, Plans and projects on various scales, monitoring

The analysis and assessment of ecological diversity are therefore absolute priorities in ecologically-oriented planning with the fundamental goal of maintaining and improving the environmental stability of a landscape mosaic.

In short, evenness solves the problem of assessing biodiversity at a cognitive level which is more pertinent to the planning scale. The planned strategies establish the morphological pattern of a territory, and therefore condition the level of biodiversity with direct and immediate repercussions. In other words, evenness lets us assess the impact of anthropic transformation processes in the landscape on the ecological diversity and, indirectly, on the overall biodiversity of the environmental system.

Biological territorial capacity (Btc) provides a high information content. Unlike other functional indexes, which merely assess specific phenomena (connec-

of collapse is almost equal to zero, and the probability that the environmental system as a whole will survive is high. Protecting and guaranteeing a higher level of ecological diversity therefore means increasing the environmental stability of a landscape.

Table 4.4 Biological territorial capacity (Btc)

Indicator	Biological territorial capacity (Btc)
Definition	Magnitude of the metabolism of the ecosystems in a territory and of its homeostatic and homeoretic capacity (for self/re-equilibrium), which measures the level of equilibrium of an environmental system
Description	It is defined by the sum of the products of surfaces with different land use types, and the relevant unit biological territorial capacity value, and by the subsequent weighed average of this sum in relation to the total surfaces being studied
Category	Ecology
Aims pursuant to landscape	Acknowledgement, assessment
Status/Process	Status
DPSIR category	Status
Typology	Index
Component variables (if index)	Metabolic data of the ecosystems in a territory: R = respiration PG = gross primary production B = stable biomass Metabolic data of the main types of ecosystems in the biosphere
Unit of measure	Mcal/m^2/year
Territorial scale of reference	Municipal/provincial/regional
Time scale of reference	Year
Characteristics of use	Technical-scientific analysis, monitoring, environmental assessment
Availability of data source	Cartographic layers on land use, phytosociological and physiognomic-structural analysis of the vegetation Table estimating the values of unit biological territorial capacity for land use categories (Ingegnoli 1993)
Method of representation	Theme maps Diagrams if applied to time grid
Other explanatory notes	The range of the index in temperate and boreal environment ecosystems is from 0 to 13.2 [Mcal/m^2/year] It is structured in standard classes of magnitude, corresponding to a precise ecological meaning The index can be used to compare the values of different landscape units, highlighting the different conditions of equilibrium and the role in the environmental system
Fields/works in which it was used	EIA, SEA, plans and projects on various scales, monitoring

tion, fragmentation, carrying capacity, …), Btc is an important synthetic index as it indirectly assesses the environmental quality of a landscape. This index provides a synthesis of the equilibrium configurations in a landscape system, and therefore its tendency for environmental stability, incorporating and recapitulating the status of a territory, determined by the reciprocal interaction of diversified processes.

When planning vast areas, Btc lets us assess the degree of stability in a landscape system and its evolutional trend, when applied to subsequent time thresholds (Gibelli 1999).

For monitoring, both indexes give us evolutive projections, to qualitatively and quantitatively evaluate the scenarios planned in landscape-territorial policies, measuring the impact of the transformations envisaged, both on the preservation/destruction of habitats essential for maintaining high levels of biodiversity, and on the functional and structural stability of the landscape system.

Further confirmation of the chosen proposal comes from the fact that both the indexes in question are characterised by threshold values with which we can compare the results of the applications.

The range of biological territorial capacity, which in ecosystems in a temperate and boreal environment varies from 0 to 13.2 [Mcal/m^2/year], was listed by Ingegnoli and Giglio (2005) in 7 standard non-homogeneous classes of magnitude, corresponding to a precise ecological meaning. Evenness, as mentioned above, is always standardized between 0 and 1.

In short, the existence of reference values—as well as there being numerous and consolidated applications for the validation of the results obtained by comparing similar territorial or temporal situations—make these indexes trustworthy and reliable tools.

Box 4.1 Application of *Evenness* and *Biological Territorial Capacity* in the Piemonte Context: Technical Supports, Past Experiences and Future Prospects The application of evenness and biological territorial capacity (Btc) is based on suitable knowledge of the different land use types in the territory in question, defining the matrix within which we can analyse and compare the ecological processes.

The various land use forms are, from an ecological point of view, seen as patches of an ecomosaic or biotopes, where the presence or vice versa the absence of natural, seminatural or anthropic elements indirectly indicates the level of disturbance induced by man on the stable component of the environmental system. The ecomosaic, which can be considered as the projection on the territory of a certain system of functional and structural relations, represents the most significant configuration of juxtaposed landscape elements, to use as a basic reference in the ecological study of a landscape. The ecomosaic map of a specific territory therefore, represents the essential propaedeutic tool for the application of the above indexes: a tool used to reveal how much and in what ways man has had an impact on the environmental system, and to what extent we have altered its structure and function. In other words, the elaboration of the indexes considered envisages an evolution from the cartographic distribution of the various biotopes to obtain a synthetic mean value for the overall area being studied or the defined sub-fields of the same.

In Piemonte, *Regional Land Cover* provides a suitable source of data for said purpose: an "information layer on land use and coverage[6]" which paints an

[6] Land coverage concerns the physical characteristics of earth surface such as the distribution of vegetation, water, glaciers, … and the physical characteristics induced by human activities. Land use however refers to the utilization and strategies for the management of certain land coverage by man.

in-depth cognitive picture of the territory status and provides detailed information which can easily be used to meet these ecological analysis requirements.

The *Land Cover Piemonte* (LCP) project, implemented in 2002 by the Piemonte Regional Authority (Strategic Planning, Territorial and Building Policies Department, formerly Territorial and Town Planning Department), in collaboration with the Institute for Wood Producing Plants and the Environment (IPLA S.p.A.) and Piemonte CSI (Information Systems Consortium), has the fundamental goal of creating a homogeneous geographical database, for total regional coverage, establishing a wealth of territorial information which is easily accessible and constantly updated, for the Public Administration and for other subjects[7].

The greater part of this geographical layer derives from the standardization and integration of different information levels[8] set up by various Public Administration subjects, completed and verified by traditional photo-interpretation.

The sources considered make it possible to distinguish 33 exhaustive land use/coverage entries, for three primary classes: territories modelled artificially, farmland territories, woodland territories and seminatural environments[9].

In particular, the entries relevant to woodland territories, established by the Territorial Forestry Plans (TFP), are very high definite: this guarantees the objective adherence of the selected index value to the phenomena analysed. In other words, it is possible to reduce the margin of uncertainty in the estimate, improving reliability, significance and the information content of the same indexes.

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[7] With the implementation of the INSPIRE Directive (Directive 2007/2/EC) which establishes the Territorial Information Infrastructure (TII) of the European Union, the diffusion and the transversal shared use of territorial data by the public administration bodies has assumed a more and more fundamental role in the field of Geographical Information.

[8] The following data was used to draw up the LCP:

- *Register of Farms:* containing information on regional farmland use acquired at a cadastral parcel level, updated annually and geo-referenced with AGEA cadastral source data;
- *Forestry paper* of the Territorial Forestry Plans (TFP): containing detailed information on woodland surfaces and seminatural environments (grazing land, open grassland, stabile meadows, grazing meadows, …) in Piemonte, which refers to period 2001–2005;
- *Report on the Status of the Territory* (RST) and *Numeric Regional Technical Paper* (NRTP) with the limits of the urban surfaces updated at 2001–2005;
- *Plurimodal regional transportation graph:* with continuous integrations and updates, reproduces the road network (motorways, A-road, regional roads, provincial roads and urban roads), the railway network (lines in use or disuse) and service footpaths of the previous types, summarizing them on the basis of the specifications of European standard GDF2 (Geographic Data Files) for the construction of topographical databases.

[9] The LCP classification, in the same way as for the CORINE Land Cover Project, is organized in hierarchical levels. The first three levels have currently been defined and organized. The third, the one with the highest definition, identifies 33 land use/coverage classes.

The woodland system is organized into 21 forestry categories[10] which, especially in the mountain territories, characterised by a high degree of naturalness and the general absence of significant anthropic activities, let us determine the effective value of evenness and biological territorial capacity, established on the basis of the simultaneous presence of different forestry categories rather than the variety of land use types.

Furthermore, one of the fundamental aims of the *Land Cover Piemonte* project is to create an information layer which is constantly updated: not a rigid cartography fossilized in time, but rather a dynamic instrument for the systematic acquisition of territorial transformations. The Piemonte Regional Authority is therefore striving to establish a method for updating the information levels relevant to land use/coverage "in real time"; using both data from ordinary activities in various sectors, entered in the regional geographical databases on a regular basis, and the information gathered in projects for the analysis and assessment of the transformations in act (Diegoli et al. 2007).

The continuously updated knowledge of the territory and its transformations, will therefore be the ideal support for monitoring the proposed indexes.

As mentioned above, both evenness and biological territorial capacity are status indexes, in other words functional interpretative models which simply provide a picture of the condition of a territory at a certain time. To establish the evolutionary trend of an environmental system, or to verify the scenarios programmed by landscape-territorial planning policies, these indexes must be applied on the basis of a process type approach, with subsequent elaborations corresponding to different time frames.

The frequency with which the proposed indexes are updated must vary in relation to the entity of the actual transformations and the size of the territory in question. While on a large scale an update every ten years may be sufficient, on a local scale more frequent revisions of the indexes must be envisaged. The same source of impact will usually have a more or less marked effect on the environmental system in relation to the size of the territory analysed. On a large scale, the variation in the synthesis value of the indexes will be diminished by the compensation processes between the more natural and stable ecosystems and the more artificial ecosystems; processes which are unlikely to be found on a local scale, where the same source will produce a more intense impact, with faster and more significant transformations.

[10] The forestry categories correspond to physiognomical units defined on the basis of the dominance of one or more developing arboreal species.

Box 4.2 Application on a Regional Scale: The Strategic Environmental Assessment of the Piemonte Regional Landscape Plan In the framework of new territorial government process implemented by the Piemonte Regional Authority in 2005, the first Landscape Plan, drawn up in accordance with the Cultural Heritage and Landscape Code (Legislative Decree 42/2004 and subsequent modifications and integrations) and the European Landscape Convention (Council of Europe Treaty Series no. 176, Florence, 20.10.2000), is a fundamental instrument for establishing the sustainable development of the entire regional territory based on the quality of landscape and the environment.

As can be inferred from the system of strategies and the general and specific goals that characterize the same, the principal aims of the Plan are the protection and development of the Piemonte landscape and environmental system. It considers various levels of focus ranging from themes specifically dedicated to the protection and development of the historical-cultural heritage and of its identity, to themes more closely associated with the protection of the environmental system (conservation, development of the ecological range, protection of fragile ecosystems, reduction of the risks associated with abandoning the protection of the territory or vice versa with the banalization and homologation that derive from its intensive exploitation).

On these themes the Strategic Environmental Assessment (SEA) (Directive 2001/42/CE of the European Parliament and Council), which has supported and integrated the planning process, identifies a set of indexes, firstly to synthesize the level of quality/criticality of the Piemonte environmental and landscape system within which the Plan operates, and secondly to monitor the effectiveness of the lines of intervention envisaged by the Plan, measuring the transformation dynamics involved. Overall, these indexes focus on the functionality of the environmental component in the Piemonte territory, emphasizing the actual status in relation to the principal pressures on the more natural contexts, and those which are highly anthropic. Evenness (ecological diversity) and biological territorial capacity (Btc) are two of these indexes (Figs. 4.1, 4.2, and 4.3).

In operative terms both indexes have been applied in the 76 Landscape territorial ambits into which the regional territory is divided, in accordance with Art. 135 of the Cultural Heritage and Landscape Code. The value of the same was estimated using the map of the regional ecomosaic drawn up with Land Cover Piemonte data.

Therefore, it was possible to assess both the different conditions of ecological diversity, and the richness in terms of habitat for each territorial ambit, as well as the different degrees of ecological equilibrium, in other words their role in relation to the ecological stability of the Piemonte territory, identifying

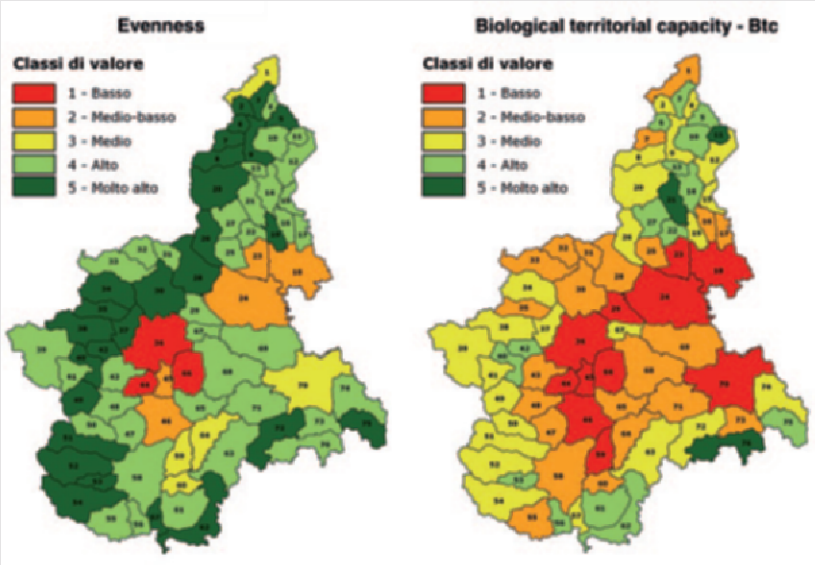

Fig. 4.1 Evenness and biological territorial capacity (Btc). The cartograms illustrate the results of the applications of the two indexes in the Landscape territorial ambits defined by the first Piemonte Regional Landscape Plan. (Piemonte Regional Authority, Strategic Planning, Territorial and Building Policies Department, *Regional Landscape Plan*. *Environmental report and non-technical synthesis*, July 2009) (Regional Council Resolution n. 53-11975—4/8/2009)

the territorial ambits which may still have a strategic role for the functionality of the regional landscape-environmental system.

The integration of this information with that of the application of the other indexes, envisaged in the SEA process, made it possible to measure the environmental and landscape status of each single territorial ambit, and to establish the status of the entire regional territory on the basis of the summary of the results. In the Landscape territorial ambits, where the indexes showed high critical thresholds, the plans for implementing the indications of the Regional Landscape Plan must envisage specific actions for requalification based on the Regulations for the Implementation of the Plan.

The Environmental report (Directive 2001/42/CE, Art. 5, Enclosure I) of the SEA contains a paper with in-depth information on the ontological and methodological content of each index and with illustrations of the results of their application. This paper includes: a detailed description of the index, the reason for which the index was used in the SEA process, an explanation of the method of construction and calculation and of any units of measure used, a brief description of the classes in which its range can be developed, a table

Fig. 4.2 Map of the Piemonte ecomosaic. (Piemonte Regional Authority, Strategic Planning, Territorial and Building Policies Department, Regional Landscape Plan, *Report*, July 2009) (Regional Council Resolution n. 53-11975—4/8/2009). The creation of the ecomosaic map and the quantification of the surfaces relevant to its landscape element types represent the propaedeutic tools for the application of evenness and biological territorial capacity. The various patches of the landscape mosaic, established by the Land Cover Piemonte project, were organized into four main types (natural, seminatural, anthropical agricultural and anthropical urbanized components) in relation to the level of naturalness, and the origin and type of energy supporting the ecosystemic function (solar energy or substitutive energy)

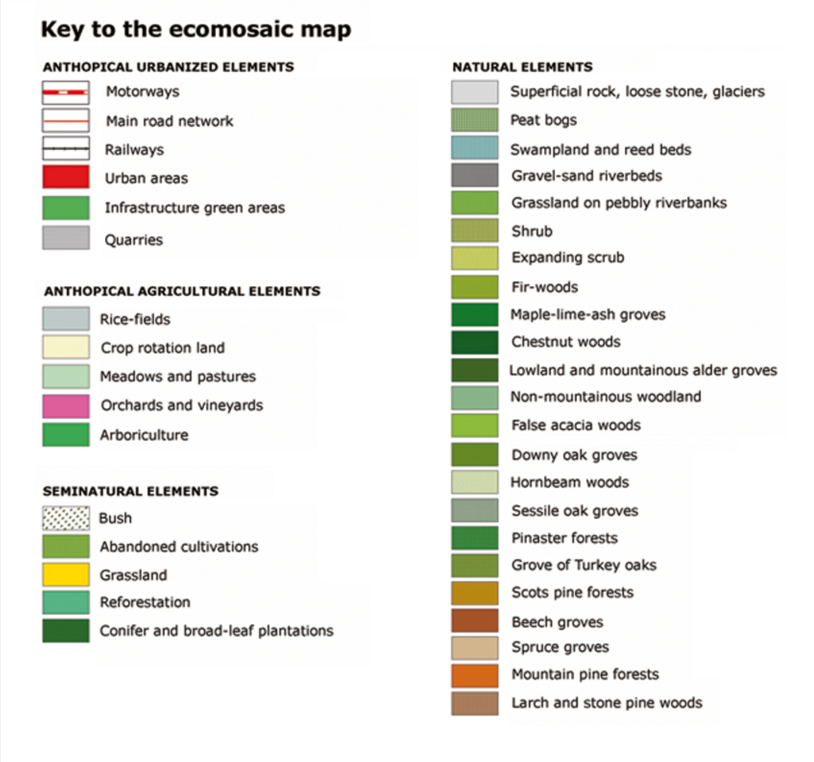

Fig. 4.3 Key to the ecomosaic map. (Piemonte Regional Authority Strategic Planning, Territorial and Building Policies Department, Regional Landscape Plan, *Report*, July 2009) (Regional Council Resolution n. 53-11975—4/8/2009)

with the results obtained at a Landscape territorial ambit level, also with an explanatory cartogram and, finally, a short summary of the conditions that can be found at regional level.

The index set used by the SEA (including evenness and biological territorial capacity) is not only the tool for monitoring and assessing landscape-territorial policies and the consequent environmental repercussions of the Plan, but it is also a reference for the assessment of the plans and programmes regulated by the Regional Landscape Plan.

Box 4.3 Application on a Local Scale: The Pinerolo District in the Research "Constructed Environment and Natural Environment in the History, the Rural Tradition and the Future of Turin and Its Province (Figs. 4.4 and 4.5)"

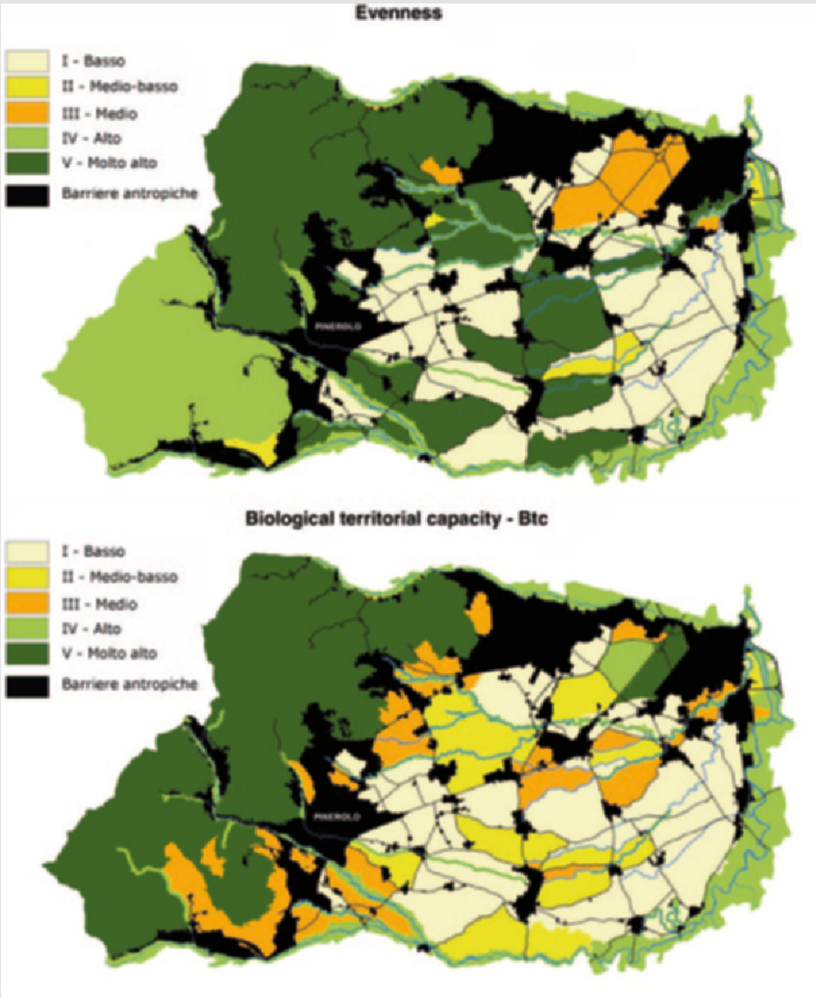

Fig. 4.4 Evenness and biological territorial capacity (Btc). The cartograms show the results of the application of the two indexes to the Pinerolo district territory in the research "Constructed environment and natural environment in the history, the rural tradition and the future of Turin and its Province", by the Inter-University Department of Territorial Studies (Polytechnic and University of Turin (Diter) in 2004 under contract to Diter—Provincial federation of direct cultivators of Turin (Coldiretti) with the contribution of the CRT Foundation—Scientific coordinator: A. Peano. This study, using an interpretative matrix of the provincial landscapes consisting of four inter-related approaches (geographical and social-economic, historical, ecological, town planning-building), establishes guidelines for rural development based on the development of the landscape. The author's cartographic elaboration

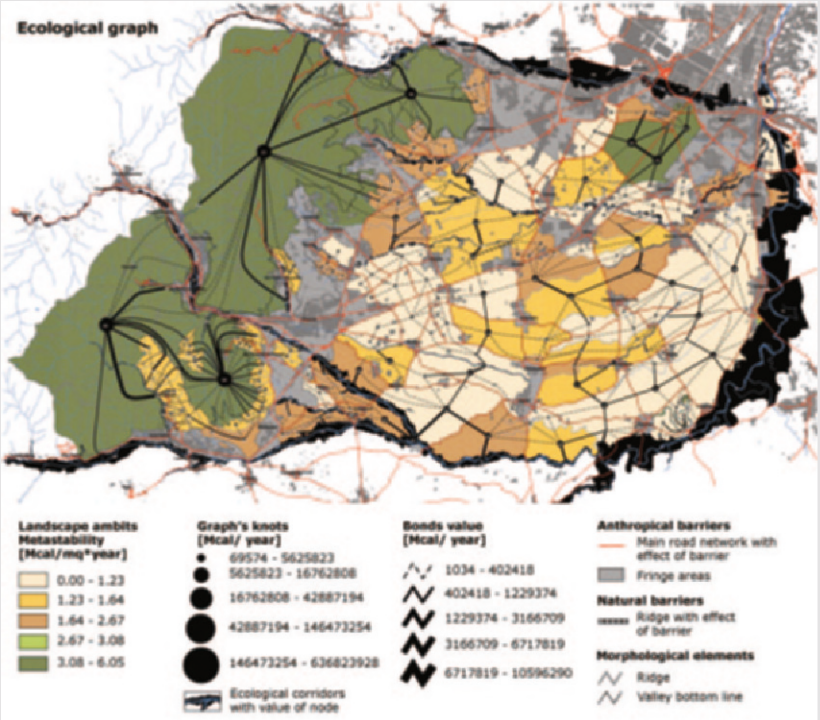

Fig. 4.5 Pinerolo district ecological graph

In the field of research, evenness and biological territorial capacity have been used to draw up the *ecological graph* (Cantwell and Forman 1993; Fabbri 2003, 2007; Fabbri and Finotto 2007), to assess the level of fragmentation in an environmental system. This model is based on the premise that an environmental system can be organized into different *ecological sectors* separated by natural or anthropic barriers, which can have different degrees of permeability, or be impermeable to the passage of biological energy and matter. The stability of the environmental system, in other words its capacity to maintain a constant structure and function, depends on the efficiency of these flows and therefore on the availability of functional paths for said flows.

The ecological graph model, quantifying and relating the values of biological territorial capacity of the various ecological sectors of an environmental system to their structural characteristics (in this case with reference to evenness) and to the permeability of their barriers, lets us analyze and assess rural and natural areas as interacting components of a single system or *virtual ecological network*. The graph considers both the intrinsic value of each single element of the environmental system, and the value of said element in relation to the other components of the same system in terms of potential exchange in the flows of biological energy and matter. Therefore, the ecological graph establishes a synthetic functional model which lets us reproduce, with an excellent degree of clarity, the network of energy flows that support the landscape organisation, also highlighting the level of ecological effectiveness of all its elements (Finotto 2006)

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ECNC European Centre for Nature Conservation. http://www.ecnc.nl/
EEA European Environmental Agency. http://www.eea.europa.eu/
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