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Non-Equilibrium Thermodynamics, Landscape Ecology and Vegetation Science

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1. Introduction

As underlined by Ingegnoli (2002), scientists have to avoid two representations of nature which tend to a world of alienation: (1) the deterministic one, with no possibility of novelty and creation, (2) the stochastic one, which leads to an absurd world with no causality principle and without any ability to forecast. Possibly, the major incentive toward a new conception of nature comes from scientists like W. Ashby (1962), Von Bertalanffy (1968), Weiss (1969), Lorenz (1978, 1980), Popper (1982, 1996) and Prigogine (1977, 1996), who observed how nature creates its most fine, sensitive and complex structures through non-reversible processes which are time oriented (time arrow). No doubt that thermodynamics becomes the most important physical discipline when complex adaptive systems exchanging energy, matter and information are involved with life processes.

Mainly starting from the System Theory and the study of complex systems, this group of scientists asserts that: (a) an organic whole is more complex than the sum of its parts (emergent properties principle) and (b) the description of the behaviour of a dynamic system presents more solutions than the classical ones. Therefore, they reach the conclusion that "life is only possible in a Universe far away from equilibrium" and that "indeterminacy is compatible with reality". The self-organising properties of non-equilibrium dissipative structures and the basic feature of indeterminacy show the real nature of our universe.

Following these scientific paradigms we can focalise a new course of Landscape Ecology[1], related to a new definition of landscape. The need of a widening foundation of this discipline brought to the school of Biological Integrated Landscape Ecology (Ingegnoli, 2002), recently named Landscape Bionomics (Ingegnoli, 2010, 2011). All these premises allow to understand the extant scientific situation in vegetation science, in which phytosociology presents serious limitations, especially in landscape evaluation.

A theoretical revision of life organisation characters and basic transformation processes of ecological systems open this chapter, leading to consider more advanced transformation and metastability processes in vegetation (from community dynamics to biological territorial capacity of vegetated units). This more theoretical and critical section is followed by an innovative section, proposing new criteria to overcome deterministic concepts (e.g. potential vegetation) in the study of vegetation and landscape. The first statements by Braun-Blanquet

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[1] The discipline of Landscape Ecology has been defined as "a study of the structure, functions and change in a heterogeneous land area composed of interacting ecosystems" (Forman & Godron, 1986).

(1928) maintain their significance as basic concepts in studying vegetation, but are in need to be integrated in new scientific theories (Naveh, 1984, 1990; Pignatti, 1994; Pignatti, Box & Fujiwara 2002; Ingegnoli, 1997, 2002; Ingegnoli & Giglio, 2005; Ingegnoli & Pignatti, 2007).

We will see that, following scientific paradigms like thermodynamics, it is possible to relate the landscape equilibrium to the concept of metastability, that is the state of a system oscillating around a central position (steady or stationary state), but susceptible to being diverted to another equilibrium state. Therefore different types of landscapes (or their parts) may be correlated with diverse levels of metastability. This statement has a very important dynamic significance, because it allows knowledge of the transformation modalities of a landscape and consequently (as we will see further) allows the diagnosis of its healthy state.

Trying to evaluate the metastability of a landscape, one has to refer to the concept of biodiversity (i.e. landscape diversity) and to the concept of latent capacity of homeostasis of an ecocoenotope (or tessera). Referring to a vegetation ecocoenotope, it has been possible to define a magnitude, named *biological territorial capacity* or BTC (Ingegnoli 1991, 2002; Ingegnoli and Giglio 1999, 2005, Ingegnoli and Pignatti, 2007), which represents the flux of energy that an ecocoenotope must dissipate to maintain its proper level of order and metastability. Therefore, the linkage of vegetation science with landscape ecology and with thermodynamics becomes more effective. An example of application of the discipline on the territory of Mori (Trento, Italy) is shown at the end of this chapter.

2. Main characters of biological systems

Between life and its environment we can discover strict relationships, exchange of matter and information and *a priori* knowledge. Energy can be transformed in matter or information, depending on different codifications of the Chronotope[2].

In the frame of the Theory of Relativity (Einstein) not only energy and mass are transmutable, but even space and time. Therefore the Chronotope shows 4 dimensions. Energy can be organized as matter or information, depending on different codifications of the chronotope. When energy is transformed in matter it assumes 3 spatial dimensions (x, y, z) plus one temporal dimension (t); while, if energy is transformed in information it assumes 2 spatial dimensions (e.g. plane wave) and 2 temporal dimensions (t_1, t_2). We have to underline these concepts, because the development of neg-entropy is needed in the evolution of natural systems, like landscapes and vegetation ones.

As expressed by P. Manzelli (1994, 1999), professor at the University of Florence, when the visible light frequencies cross a transparent medium, the associated plane wave remains dimensioned as information (2 spatial and 2 temporal dimensions); on the contrary, when the wave encounters the retina, the photochemical reaction is done through the conversion into a particle of the plane wave, which assumes a form available to interact with the three-dimensional structure of the matter.

It is important to underline these facts, because every transformation between energy and matter needs a catalisys through an information system, to increase the neg-entropy and to proceed toward ordered forms. We know that the exchanges energy-matter-information, which allowed the emergence of life on Earth, are of the maximum importance and changed completely the evolution of the entire Planet. A mutual interaction and an information

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[2] Chronotope (literally: space-time), term used both in science (Einstein's Relativity) and literature (Baktin on Novels).

exchange are present between life and his environment: a sort of "*a priori*" knowledge. As Karl Popper (1994) underlined: "From the beginning, life must have been equipped with a general knowledge, the one which we usually name 'knowledge of the natural lows'". Note that the current definition of adaptation is Darwinian, but it must be changed, because it is not seen as a form of *a priori* knowledge.

In facts, the definition of life contains both biological systems *and* their environment: therefore every living system follows life processes and exhibits systemic attributes.

Life is a complex self-organising system, operating with continuous exchange of matter and energy with the outside; the system is able to perceive, process and transfer information, to reach a target, reproduce itself, have an history and participate in the process of evolution. In an evolutionary view, structure and function become complementary aspects of the same evolving whole. Consequently life can not exist without its environment: both are the necessary components of the system, because life depends on exchange of matter and energy between a concrete entity, like an organism, and its environment (Ingegnoli and Pignatti 1996; Pignatti and Trezza, 2000; Ingegnoli, 2002). That is the reason why the concept of life is not limited to a single organism or to a group of species, and therefore life organisation can be described in hierarchic levels.

The world around life is made also by life itself; so the integration reaches again new levels. This is another reason why biological levels can not be limited to cell, organism, population, communities and their life support systems: life also includes ecological systems such as ecocoenotopes (Ingegnoli 2002), landscapes, ecoregions, and the entire ecosphere.

A short exposition of the main modern scientific paradigms (from hierarchic structure to non-equilibrium thermodynamics) and the new importance of history is necessary to better understand these characters of living systems and to update ecology.

2.1 Hierarchic and dynamic systems

The central concept of the hierarchical System Theory (Pattee,1973; Allen & Starr, 1982; O'Neill et al. 1986) is that the organisation of a system results from differences in process rates, which change with the scale. Levels within the hierarchy are isolated from each other because they operate at distinctly different rates. Boundaries, which are not only the physical ones, separate the set of processes from components in the rest of the system. As an example, for the investigation of a woodland, the first approximation will be to study in what kind of vegetational landscape it is growing, what are the climatic constraints, etc.; then this woodland has to be investigated on even a more detailed scale, e.g. single trees, if the interest shifts to the components of the plant association and the reason of their existence Note that one of the most important consequences of the hierarchical structure of systems is the concept of *constraint*, deriving from the complex interaction of several factors: it is more correct than the concept of limiting factor, i.e., a single negative action producing a linear reaction. Constraints affect the behaviour of an ecological system though the behaviour of its components and with environmental bonds imposed by superior levels of organisation. Remember that there is a linkage between constraint and information.

The System Theory states that an evolving system is first of all defined as *dynamic*. In consequence, the output (y) depends on the *history* of the system, not linearly on the input (*a*). A third element has to be introduced: the *state*, which includes information on the past, present and potential evolution of the whole. The value *x (t),* assumed by the state at the

instant t, must be sufficient to determine the value of output in the same instant: knowing the values of $x (t_1)$ and $a (t_1, t_2)$, the state (then the output) in the instant t_2 can be calculated. The couple state-time (x, t) has great significance because the set X, T is the set of events, the *history* of the system. The space containing the points corresponding to the states of the system is called the 'space of the phases'. Once an instant t, an initial state $x (t_0)$, an input function $a (.)$ are fixed, the transition function $f [t, t_0, x (t_0), a (.)]$ is univocally determined, and named "movement" of the system:

$$x (t) = f [t, t_0, x (t_0), a(.)] \tag{1}$$

A function of output transformation $u [t, x(t)]$ brings to:

$$y(t) = u [t, x(t)] \tag{2}$$

Thus, a dynamic system can be described using 6 sets of variables, correlated by 2 functions.

2.2 Dissipative systems

Systems which experience dynamic changes consume energy, therefore the photosynthesis (or chemio-synthesis in primeval systems) becomes necessary.

Photosynthetic processes have the main responsibility of energy transfer in biological systems. This is possible because living systems are open systems, otherwise, the free energy F would not be available. In open systems, variations of entropy can be the consequence of different processes: $d_e S$, is the entropy exchanged with the environment, and $d_i S$, is the entropy variation due to irreversible processes within the system. The second term is clearly positive, but the first term does not have a definite sign. So the inequality of Clausius-Carnot becomes:

$$dS = d_e S + d_i S \quad (being \ d_i S > 0) \tag{3}$$

In a period in which the system is stationary $(dS = 0)$, thus

$$d_e S + d_i S = 0 \quad and \quad d_e S < 0 \quad (being \ d_e S = - d_i S) \tag{4}$$

In evolutionary processes, when the system reaches a state of lower entropy (new stationary state) $S (t_1) < S (t_0)$, it is able to maintain it in balance by "pumping out" the disorder. But this is possible only in non-equilibrium conditions of *dissipative* systems: a dissipation of energy into heat is necessary to maintain the system far from equilibrium and to create order, as can be observed in thermodynamics, but also in the mediterranean vegetation (Pignatti, 1979; Naveh & Lieberman, 1984). The amount of entropy "pumped out" is indicated as negentropy.

An energy dissipation, which allows work to be done, has to be coupled, for instance, with the transformation of the system from state A_0 to state A_1. The process able to perform this transformation is an example of *operator* (Op), a *rule* of action on a given function. If we express it in the form $A_1 = (Op) A_0$, the complete transformation process is

$$A_1 = [(Op) \ A_0] \cup (e_w \rightarrow e_d) \tag{5}$$

where: e_w = available energy, e_d = dissipated energy.

If the state of the system becomes an auto-function for a certain operator (i.e. a function able to remain as before when applied to an Op) the system does not undergo further changes.

This state is called a *fixed point* of the system, and it may represent a stationary state or an *attractor*.

2.3 Self-organisation and chaos

Complex interacting systems in which cycling, structuring and auto-regulation are realised from the inside, may be called *self-organising* systems. In living systems the capacity to maintain a dynamic equilibrium as a whole is called *homeostasis*. It is ensured by a large number of closely interrelating cybernetic feedback mechanisms, hierarchically ordered. These biological and ecological processes of auto-regulation can be active also at the landscape level.

Auto-regulation needs information, deriving from biological and technological processes, which can be carried out both in energetic and/ or in material way: that is, energy structures itself with the help of information. Positive and negative feedbacks coupling are fundamental, too. Their dynamics can be synthetically expressed by:

$$x_t = f(x_0, t, \lambda), \tag{6}$$

where x_t is the state of the system at time t, x_0 is the state of the system at time 0, λ is a specific parameter for the examined system indicating the acquisition of energy and matter from outside.

Depending on the parameter λ and its values (Pignatti & Trezza, 2000), X may tend toward a temporary stationary state (*metastable* state) or a chaotic one. Note that the *uncertainty* given by *chaos* does not depend on complexity: in fact, even a simple deterministic system can be chaotic.

A system is chaotic when it amplifies *initial* conditions, thus magnifying small differences, for instance between two trajectories. It is impossible to shorten the description of a chaotic system because of its unpredictable behaviour due to branching possibilities of evolution, thus to a manifold of attractors.

Highly chaotic webs are so disordered that the control of complex behaviours is impossible, while highly ordered webs are so rigid that they can not express a complex behaviour. But if "frozen" components begin to melt, it is possible to have more complex dynamic behaviours leading to a complex co-ordination of activities within the system. Thus, the maximum complexity is reached in a "liquid" transition between solid and gaseous states, where the best capacity of evolution is expressed. For instance, it is possible to see a similar situation in DNA and its capacity to maintain a ordered structure but also to change by mutations. As shown by Prigogine (1996), if we consider the Bernoulli equation:

$$x_{n+1} = 2 x_n (Mod\ 1) \tag{7}$$

where: *Mod 1* = numbers between 0 and 1, it is easy to see that very short differences of the initial conditions can brought to very different trajectories, as shown in Fig. 1.

The threshold between order and chaos seems to be an essential requisite of complex adaptive self-organising systems (order at the edge of chaos). As these systems are dissipative, an order through fluctuations is effective in working between the above mentioned conditions.
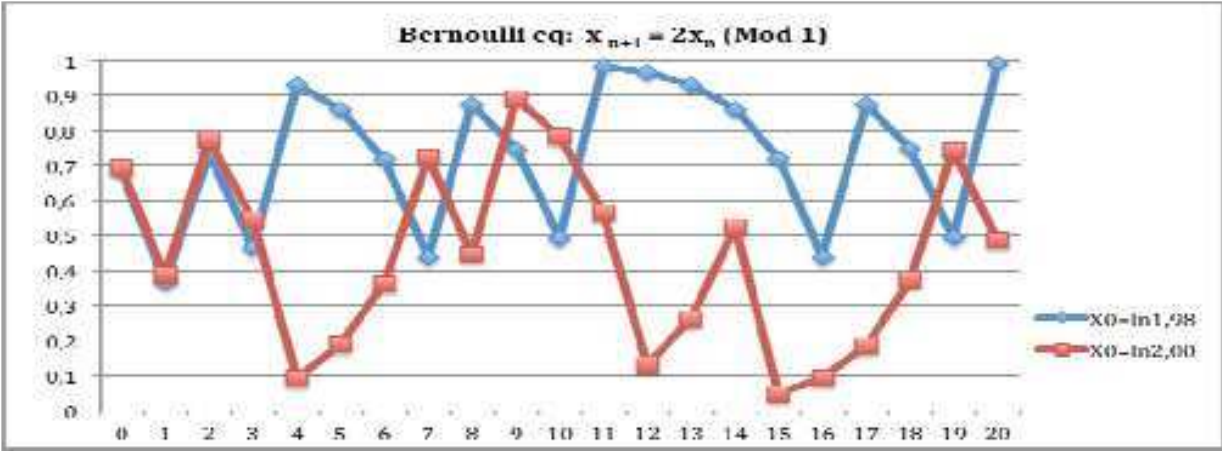
Fig. 1. An example of deterministic chaos. Starting from two very similar initial conditions ($x_0 = \ln 1.98$, $x_0 = \ln 2.00$) the Bernoulli equation (7) shows very different trajectories, after time 3. Note that these lines may represent the projection of 2 possible movements of a dynamic system within the field of the states of the system itself.

3. Non-equilibrium thermodynamic and metastability in ecological systems

A self-organised living system is able to capture intense energy fluxes and to utilise its neg-entropic input to produce new structures. Prigogine showed (1972) that even simple physical systems present processes of order.

Figure 2 shows the concentration of the intermediate product X in a chemical reaction: going further on the stable thermodynamic branch, the intermediate product enters a field of instability with the appearance of subsequent bifurcations.
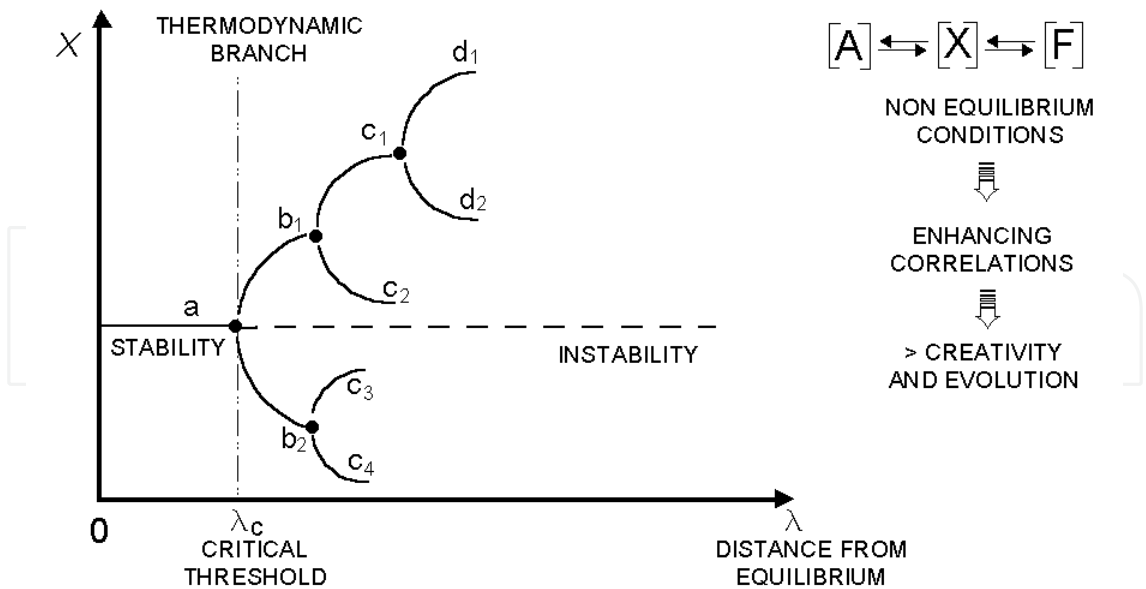

Fig. 2. Consecutive bifurcations in a non-equilibrium system. Going further on the stable thermodynamic branch, the intermediate product enters a field of instability with the appearance of subsequent bifurcations. Note that the point d_2 can be reached through the path $a\text{-}b_1\text{-}c_1\text{-}d_2$ but also $a\text{-}b_1\text{-}c_2\text{-}d_2$. So, an historical behaviour is shown in this process (from Ingegnoli, 2002).

Therefore, the result cannot be deterministic: when a system arrives at a branching point, disturbances, like fluctuations or strange attractors, become important, allowing the system to choose one of the two branches of new relative stability. So, the evolution of this kind of system has an *historic* criterion in itself.

The fluctuation-dissipation sequence can be viewed as a feedback process. A macro-fluctuation, due to a change of disturbances, produces instabilities leading to an increased dissipation of energy and the system becomes more difficult to maintain. When a threshold is reached, characterised by the prevailing of new structures over the former ones, a new organisational state results. That is why the Prigogine statement is "order through fluctuations". Ecological conditions are important for a system at a branching point, enabling it to choose one of the two branches of new relative stability (*metastability*).
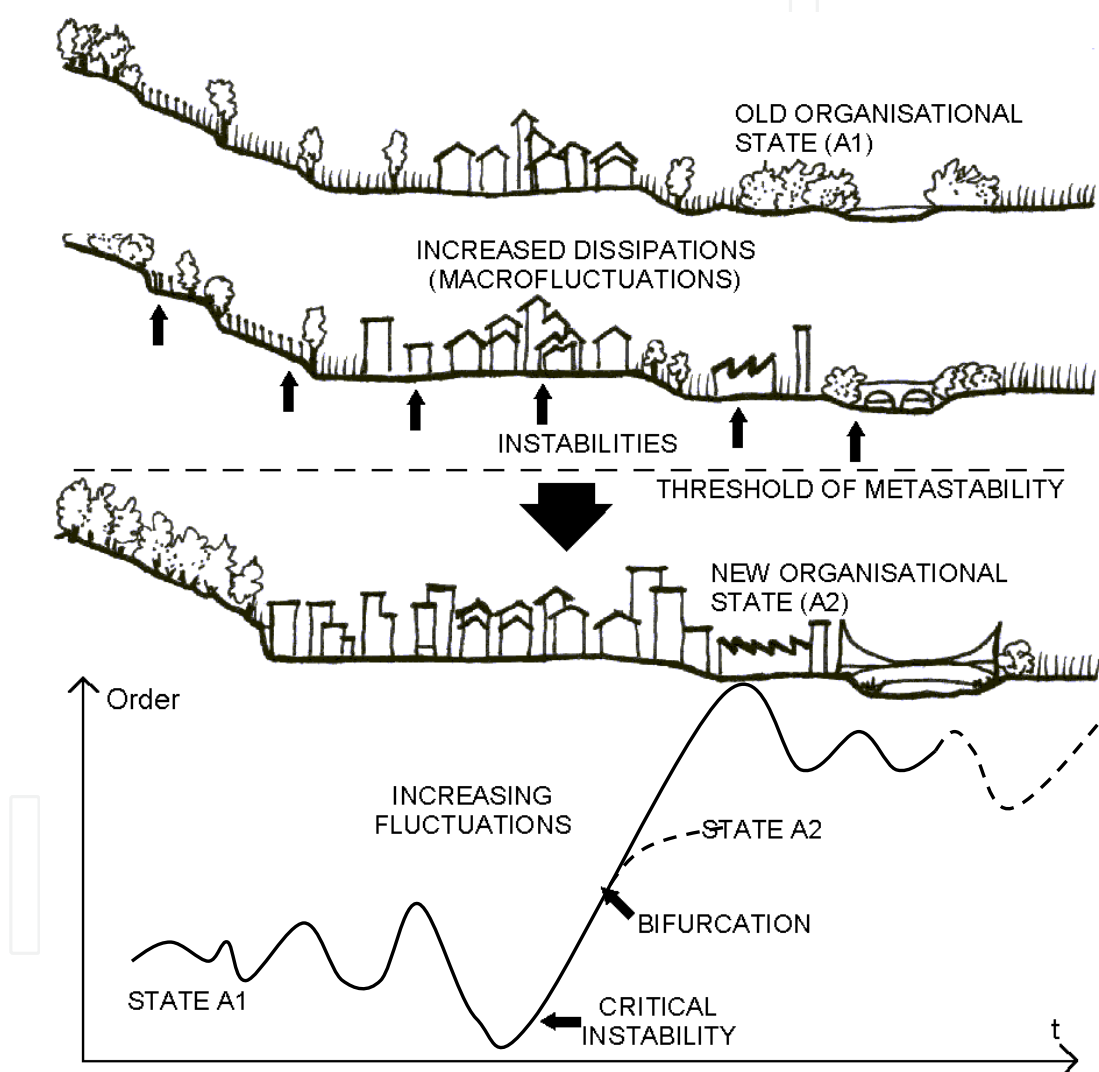

Fig. 3. Landscape transformation. From a state *A1* of lower order through increasing dissipation, a system reaches a critical threshold and, after a branching point, it arrives at the state *A2* of higher order. The old organisational state is a rural landscape; an increased flux of energy produces macro fluctuations of the local organisation and then some instabilities. These instabilities cause an increased dissipation of energy, the system becomes difficult to maintain: when a threshold is reached (e.g. a prevailing of urban structures over the former rural ones) a new organisational state results (from Ingegnoli, 2002).

Under these conditions, mutual relations of large range occur among the components. The matter acquires new properties, a new sensitivity of matter to itself, to information and its environment takes place, associated with dissipative and not reversible processes. The system, in the far from equilibrium condition, is able to self-organise through intrinsic probabilities, exploring its structure and realising one among the possible structures, but not a random one. This process takes place from cell proteins formation to the vegetation and the landscape transformation.

Let us show an example of landscape transformation (Fig. 3). From a state *A1* of lower order through increasing dissipation, a system reaches a critical threshold and, after a branching point, it arrives at the state *A2* of higher order. In this case, the old organisational state is an agricultural landscape. An increased flux of energy (e.g. agricultural improvement and social-economic richness) produces macro fluctuations of the local organisation and then some instabilities (i.e. land abandonment, use of the fluvial valley, building of the first industries, and so on). These instabilities lead to an increased dissipation of energy, the system becomes more difficult to maintain: when a threshold is reached, characterised by the dominance of urbanised structures over the previous rural ones, a new organisational state results, that needs a different kind of management.

When a system is oscillating around a steady attractor, but may even move toward another attractor, it presents the condition of *metastability* (Godron 1984; Naveh and Lieberman 1984; Forman and Godron 1986). Note that the concept of metastability is not a compromise between a form of stability and one of instability. Higher or lower metastability depends on the distance from the position of maximum stability and on the height of the thresholds of local (far from equilibrium) stability.

Ecological systems with low metastability have a low resistance, but a high resilience to disturbances. By contrast, high metastability systems have high resistance to disturbances. For example, a prairie patch has a higher resilience than a forest one. Note that the concept of metastability allows the traditional concept of ecological equilibrium to be updated: "equilibrium" does not stay around 0, but it identifies various stationary or equilibrium states far from 0. A system reaches a new organisation after instabilities and the passage to a new metastable level.

Remembering the hierarchic theory of systems, we know that some limitations on the dynamic of an ecological system come from inferior levels of scale and are due to the biological potential of its components. Other limits are imposed by superior levels as environmental constraints (Cfr. 2.1). Therefore, a wide range of conditions emerges for every kind of ecological system, for instance a vegetation complex in a landscape, and can be expressed as the *constraints field* or optimum set of existence.

Note that, in many cases, the majority of disturbances can be *incorporated* into ecological systems. The mentioned constraint field of an ecological system is based on a resistance strategy to a current regime of perturbations. Therefore, we can speak of 'disturbance incorporation' when the system organisation exerts control over some environmental aspects that are impossible to be controlled at a lower level of organisation. This process may limit possible alterations to its stationary state; meanwhile it may utilise perturbations as structuring forces.

3.1 The importance of history

Remembering the importance of the concept of time after the theories of Albert Einstein, this should be extended to all the modern science. As formerly mentioned, the state of a system

is fundamental to understand the movement of the system itself; consequently, in the "order through fluctuation" process the evolution of a system presents an historic criterion in itself. Therefore, history assumes a new crucial importance even in ecological studies. Note that history (*historia* in Latin) derives from the Greek 'ιστωρ' which means "cognition and research" but today history is intended mainly in humanistic sense and -if not- in deterministic sense.

Fig. 4. Synthetic maps of the Venice lagoon, showing the distribution and the extension of the salt marsh prairies (green), called "barene". Note the sharp difference between 1930 (left) and 1998 (plots from CVN-Technital, 2002). Note the presence of a large harbour with an industrial area (west to Venice). In the last century (1900-2000) the barene formations decreased dramatically, from 13.2% to 4.6%.

In humanistic sense, history is the understanding on the human past. Without the presence of some cultural artefact, no natural system can be studied properly in historical way. A landscape is seen only as a "cultural product", thus a forest, for instance, can not be studied as an historical subject. In deterministic sense, history is the description of naturalistic frames from which being able to deduce temporal changes according to some typologies following some laws. A landscape, in this way, is studied considering its territory as a subject containing all its own determination parameters, in a way that will not be questioned.

Hence, the humanistic sense of history is obviously too limited. In deterministic sense history forces natural changes into mechanical succession schemes. For instance, some Author presumes to evaluate the ecological state of a landscape measuring the distance of the present vegetation from the potential one: a nonsense, as we will see later on.

These limited definitions of history may bring to severe methodological errors which depend on obsolete scientific paradigms. We have to remember that the real world is transforming itself following the time arrow, in a non-finalistic evolution and in a creative way. That is why history has becoming indispensable. Without it, it is simply impossible to understand properly the right sense of the events.

Related to time irreversibility the natural processes may be variant or invariant, anyway they form real systems the behaviour of which does not accept a full determinism. So, history is the research on the evolution occurred in natural systems, that is on the happening of the phenomena in a previous time (Zanzi, 1998) (Fig.4).

4. Landscape bionomics

In the last thirty years, following an increasing consciousness related to environmental problems, some scientists of different Countries (Naveh & Lieberman, 1984, 1990; Forman & Godron, 1986, 1995; Ingegnoli, 1980, 1991; Noss, 1983, 1997) identified the biological hierarchic level of the "system of ecosystems" -that is the landscape level- as the most suitable and sensible for studies on relations between man and his environment and on "positive and negative effects of men actions on nature". Thus, a new level of ecological studies was founded, named Landscape Ecology.

At present, the discipline of landscape ecology needs a revision according to the new scientific paradigms we enhanced before. That is why Ingegnoli (2002) tried to better focalize landscape ecological elements and processes, in order to widen the foundation of landscape ecology, as expressed through his Biological Integrated School. Indeed, to advance landscape ecological theory, a widening foundation must be able to relocate in a deeper biological vision the different approaches, first of all those by Naveh (1984) and Forman (1986). The term "ecology" is today both inflated and degraded. So, the discipline of Biological Integrated Landscape Ecology has been recently named "Landscape Bionomics" (Ingegnoli, 2002, 2010, 2011).

4.1 The new school of biological integrated landscape ecology, or landscape bionomics

First of all, it is necessary to reach a manifold but unique definition of landscape and also to recognise what is important about landscapes. In this framework, it is useful to understand that:

a.   the landscape, as a level of hierarchical organisation of the life on Earth, *is a proper biological system;*

b.   thus, the landscape is a complex, adaptive, dynamic, self-organising, hierarchical system;

c.   its complex structural model can be based on the concept of tissue, thus being named *ecotissue* (Ingegnoli, 1993, 2002) (related concept: ecocoenotope);

d.   we have to consider landscape bionomics (ecology) as a discipline like medicine, biologically based and transdisciplinary. Remember that we have to study the landscape pathologies, but also their influence on human health, which may be dangerous even in absence of pollution.[3]

e.   Even *culture does not implicate the subjection of nature to the dominance of man*; we may demonstrate that in many cases cultural changes of landscapes express natural needs.

Being the landscape a biological level, it is the physiology (ecology)/ pathology ratio which permits a clinical diagnosis of the landscape, after a good analysis and anamnesis. No doubt that landscape bionomics has its own predictive theory, nevertheless, it is necessary to

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[3] The environmental stress brings to lower 24h mean cortisol excretion and to partial inhibition of feedback mechanisms.

develop this discipline not as a simple predictive science, but also as a prescriptive one – again just like medicine.
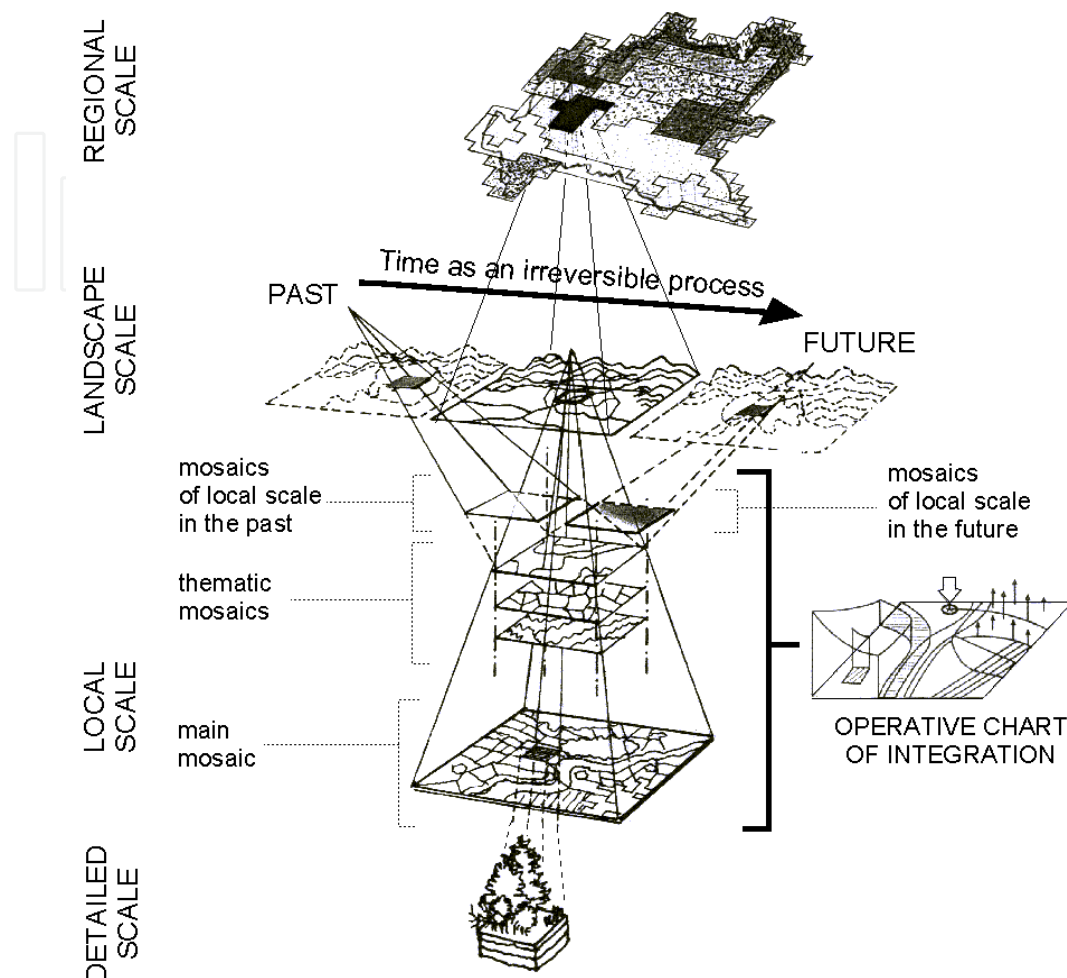

Fig. 5. The landscape ecotissue: the basic mosaic is generally the vegetation one. The complex structure of a landscape has to integrate diverse components: temporal, spatial, thematic. An operative chart of integration could be necessary to elaborate plans. Note that the integrations are intrinsic, that means they have to follow integration functions derived from the intrinsic characters of that level of life organisation (from Ingegnoli, 2002).

- Subsequent, it is necessary to define the ecocoenotope and the ecotissue, as follow:
- the *ecocoenotope* is an ecological system, composed by the *community* (biotic view), the *ecosystem* (functional view) and the *microchore* (spatial contiguity characters), while
- the *ecotissue* concept (or ecological tissue) represents a complex *multidimensional* structure built up by a main mosaic (generally formed by the vegetation *coenosis*) and a hierarchic set of mosaics and information of different temporal and spatial scales, correlated and integrated, constituting the *landscape structural model* (Fig.5).

In add, the mentioned school proposes:
- new complex integrated functions (e.g. biological and territorial capacity of vegetation; human habitat capacity evaluation, etc.),
- new methods and new applications (e.g. new evaluation of human habitat, new survey of vegetation, etc.).

4.2 BTC: The Biological Territorial Capacity of vegetation

Vegetation, as the most important component of the landscape, has to be related with the concept of metastability. The use of metastability concept enables (i) to study vegetation through new perspectives and (ii) to evaluate landscape transformation in a proper way. The evaluation of metastability in vegetation, implies the concept of landscape biodiversity (i.e. main types of vegetation communities) and the concept of latent capacity of homeostasis of an ecocoenotope (i.e. vegetation *tessera*[4]).

The *biological territorial capacity* or BTC (Ingegnoli 1991, 1993, 1999; Ingegnoli and Giglio 1999, Ingegnoli 2002; Ingegnoli & Pignatti, 2007), is referred to to vegetation tesserae, and it is a synthetic function defined on the basis of: (i) the concept of resistance stability ; (ii) the principal types of vegetation communities of the ecosphere ; (iii) their metabolic data (biomass, gross primary production, respiration, B, R/ GP, R/ B). Two coefficients can be elaborated:

$$a_i = (R/GP)_i / (R/GP)_{max} \qquad (8)$$

$$b_i = (dS/S)_{min} / (dS/S)_I \qquad (9)$$

where: R is the respiration, GP is the gross production, dS/S is equal to R/B and is the maintenance/ structure ratio (or a thermodynamic order function, Odum 1971, 1983) and i are the principal ecosystems of the ecosphere.

The factor a_i measures the degree of the relative metabolic capacity of principal vegetation communities; b_i measures the degree of the relative antithermic (i.e. order) maintenance of the same main vegetation communities. The degree of homeostatic capacity of an ecocoenotope is proportional to its respiration (Odum 1971, 1983). So the a_i and b_i coefficients, even related in the simplest way, give a measure which is a function of this capacity:

$$BTC_i = (a_i + b_i)\, R_i\; w \qquad (10)$$

where w is a variable necessary to consider the emergent property principle and to compensate the environmental constraints. Putting $\Omega = (a_i + b_i)\, R_i$, the value of w results: $w = 0.89 - 0.0054\,\Omega$, consequently:

$$BTC_i = 0.89\,\Omega - 0.0054\,\Omega^2 \ (Mcal/m^2/year) \qquad (11)$$

Reference values of BTC have been calculated on the 30 main types of zonal vegetation of the ecosphere, as shown in Ingegnoli (2002): note that both natural and anthropogenic vegetation have been considered. Moreover, the BTC function becomes an ecological index which allows the recognition of regional thresholds of landscape replacement (i.e. metastability thresholds) during time, and especially the transformation modalities controlling landscape changes, even under human influence. This index is available even to measure the functional biodiversity of a landscape.

Remember that the concept of biodiversity, as defined by U.S. Office of Technology Assessment (1986), depends on two aspects: (1) the diversity of the components of ecological

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[4] The name "*tessera*" (latin: component of a mosaic configuration) can be correlated with the delimitations of the principal types of ecosystems (i.e. biogeocenosis or, better, *ecocoenotopes*) constituting a sort of geographic map, some times apparently similar to the "land use" maps of the human territory, but with an ecological sense.

systems and (2) the diversity of their relations in the organisation of these systems (other 2 aspects: (2.1) *local* and (2.2) *context*). Biodiversity is also an attribute of an entire ecological system.

Therefore, to reach a better understanding of the ecological state of a forest, we have to check:

(1) species diversity (e.g. α, γ and β; Whittaker,1975) and landscape elements diversity (ψ, τ; Ingegnoli & Giglio, 2005);

(2.1) ecosystem-community diversity (e.g. tesserae) and

(2.2) landscape diversity (e.g. landscape unit), measuring the levels of their ecological organisation.

A better use of the BTC index derives from its very good correlation with the measure of human habitat (HH), which can be defined as areas where human populations live or manage permanently, limiting or strongly influencing the self-regulation capability of natural systems. As shown in Fig. 6, the polynomial line derived from about 50 case study of landscape units (LU) in the North of Italy (mainly in Lombardy, Trentino-Alto Adige, but even in Austria and Germany) presents a high R^2 , so that the equation:

$$BTC = 0.0007\,x^2 - 0.152\,x + 0.86 \qquad\qquad (12)$$

(where BTC is referred to the examined landscape unit and $x = HH$) may be used in the evaluation of the ecological state of the landscape. HH is expressed in % of the surface extension of the landscape unit.
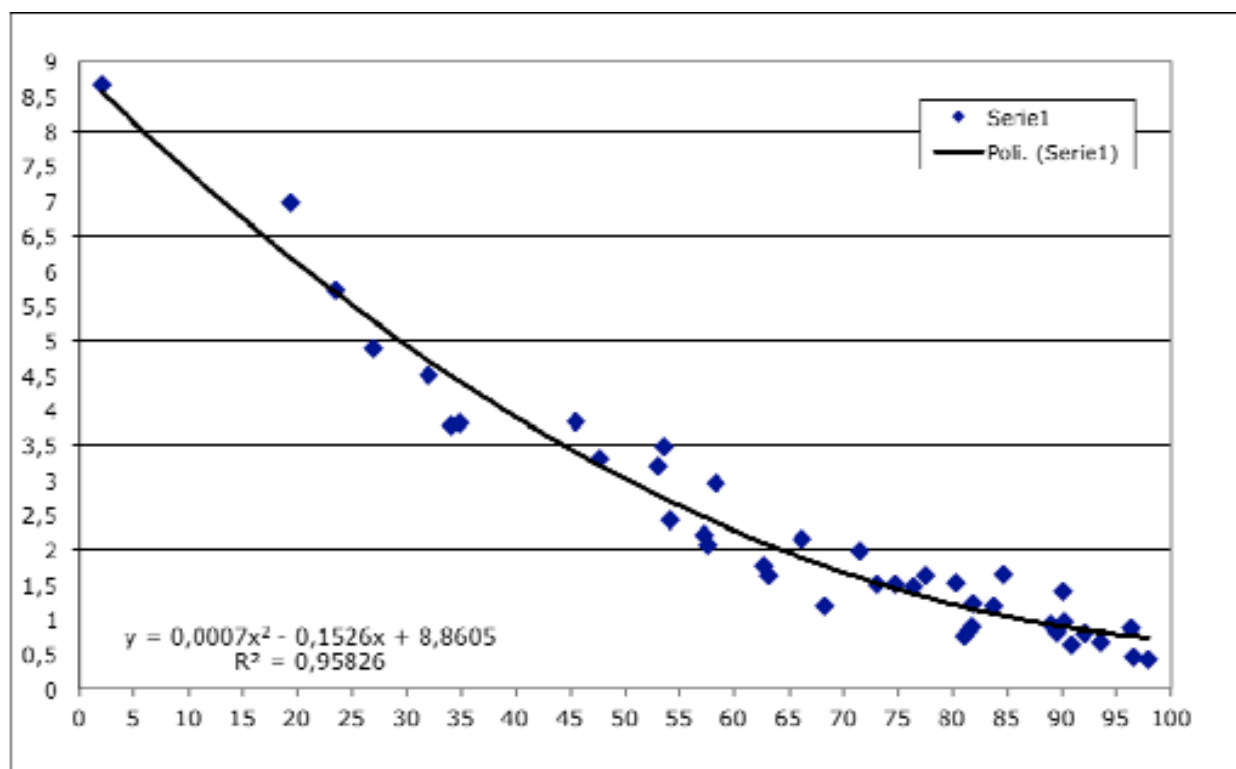

Fig. 6. Correlation between the BTC index (Mcal/ m2/ yr; Y axis) and the human habitat in about 50 case study of landscape units in central Europe (X axis : HH as %LU). Note the importance to utilise the equation (12) in the clinical diagnosis of the ecological state of the landscape.

4.3 Main transformation modalities in the landscape

In a landscape or in its subsystems (i.e. Landscape Units) the main transformation processes depend on the hierarchical structuring of an ecological system and its non-equilibrium thermodynamics, metastability, coevolution, evolutionary changes and ecological reproduction. Let us review the main steps, essential to revise later some basic concepts of vegetation science:

i.   *Hierarchical structuring*. The behaviour of an ecological system is limited by: (a) the potential behaviour of its components on the lower level of scale, (b) the environmental constraints on the upper level of scale. This set of conditions represents the existence field in which the system of ecosystems must reside.

ii. *Non-equilibrium thermodynamic*. Thermodynamic bonds may determine an attractor, in its proper existence field, that represents a condition of minimum external energy dissipation. Possible macro-fluctuations produce instabilities, which move the system toward a new organisational state. These new states permit an increase of dissipation and move the system toward new thresholds to reach a new attractor. This could be represented as a cybernetic process of "order through fluctuation" (Cfr. Fig. 3 and 5).

iii. *Metastability*. An ecological system can remain within a limited set of conditions, but it may show alterations if these conditions change. The system may cross a critical threshold, approaching even radical changes. E.g. different types of landscapes or their parts may be correlated with diverse levels of metastability.

iv. *Coevolution*. The history of the interactions among the elements of a landscape in a given area shows a particular dominion that is characterised by the coherence of their reciprocal adaptation. This process leads to the stabilisation of different homeostatic and homeorhetic capacities of a landscape, which may be expressed with a particular degree of metastability of the entire system.

v.   *Evolutionary changes*. The structuring of every biological system may be pursued, that is the information may be transmitted, only if the final state of the considered system is less unstable (i.e. more metastable) than its initial state. The modalities by which these processes are realised may be different and not limited to a single scale.

vi. *Reproductive processes*. Each level of life organisation presents tipical reproductive processes: (a) system available to maintain information, (b) mutation phase, (c) protection of new elements, (d) selection phase, (e) crucial disturbance eliminating the old structure (Oldeman, 1990; Ingegnoli, 2002; Bengtsson et al. 2003). Following previous points and ranked processes, each level of life has to renew: note that both assembly rules and dispersal filters need also a context.

5. Non-equilibrium thermodynamics, landscape bionomics and vegetation science

Ecological succession in general ecology, is the most important process related to transformation: through serial stages, an ecosystem changes in a predictable way toward a final stage, called climax. After an outside perturbation (or partial substitution of inner components), succession returns the ecosystem to the climax. For instance, an abandoned field near a forested patch is re-colonised from the forest edge and, in a given time, after the re-growth of shrubs and then of trees, the succession restores the "climax". Succession is a concept of primary importance in ecological theory: it has become the basis for dynamical explanations of many ecological phenomena, such as in phytosociological sygmeta. But this

kind of succession is incompatible with the scientific principles underlined before, especially with non-equilibrium thermodynamics.

5.1 Limits with the reductionist concept of succession and the method of phytosociology

Remember the non-equilibrium thermodynamic with branching points after the instability threshold (Fig. 2), or the concepts of landscape metastability: in the first case, the history becomes the leading criterion of transformation; in the second, it is evident that, even when a succession to a climax may be considered valid at a single ecocoenotope scale, certainly it is not valid at a landscape scale.

Succession does not work as linear and mechanistic. According to Pignatti (1996), in the vegetational phytocoenosis of *Cytisus villosus* which follows after a fire of a *Viburno-Quercetum ilicis* patch, for instance in central Italy, or in the re-colonisation of *Picea abies* on abandoned alpine pastures in Central Europe (two cases in which normally succession is present) if more than one key factor becomes dominant, the ecological system and its transformation become unpredictable.

It should be always very important to remember that self-organising processes have to be considered at least on three scales: the one of interest, the upper (constraint) one and the lower one (significance). If some components of an autocatalytic set are excluded, the system will appear as linear. It is what happens to the classical theory of succession, because e.g. the landscape is never considered as a basic parameter. Therefore, in landscape bionomic the importance of ecological succession as linear and divided into primary and secondary phases is drastically reduced.

At present, especially in Europe, the vegetation is defined as a set of current vegetable individuals, growing in a determined site and in their natural disposition that it is assumed to be ordinated on the basis of self-organisation processes (Westhoff 1970): its study is principally founded on phytosociology (Braun-Blanquet, 1928). The logic of phytosociology derives from the correspondence between the existence of given environmental conditions of a site and the presence of plant species of a given statistical combination (Pignatti 1980, 1994). The relation between species and ecological factors, assumed as univocal, permits the definition of a n-dimensional ecological space: starting from a set of auto-ecological spaces, the synecological one is defined as the intersection set. For example, projecting on a plane the spaces of five species A,B,C,D,E, the frequencies of which are 0.6, 0.5, 0.4, 0.3, 0.2, the overlapping area may represent an association of these species: the probability of this set to be a casual one is only 0.0072 (Fig. 7). This limits the random character of the ecological relation obtained from the presence of species.
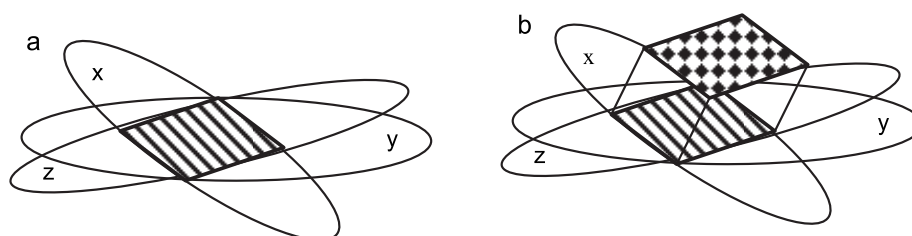

Fig. 7. Ecological space and the study of vegetation. **(a)** In the phytosociological model. **(b)** In the landscape ecological model. (from Ingegnoli, 2002).

Ecological information is often neglected, because of the supposed univocal ecological indication[5] of each species. Thus, the phytosociological model *presumes* the complete knowledge of an association only through its floristic description. This knowledge is then developed into syntaxonomy. The association dynamics is based on the concept of ecological succession and climax, assumed to be linear, with a deterministic sense, that is, on the concept of "potential natural vegetation" (Tüxen, 1956). Even the landscape is studied with the sygmetum method (Tüxen, 1978; Géhu 1988; Rivas-Martinez 1987).

At the ecosystem level, and for a formal description of the associations of vegetation, the method of phytosociology seems to give quite good results. Supporters of the use of this approach even in the study of the landscape are frequent in Europe: but not all scientists are in agreement. In fact, the described logic presents many limitations, especially from the point of view of landscape ecology (Naveh 1984; Ingegnoli 1997, 2002). The principal criticisms include at least these following points:

1. Phytosociology is based on too many deterministic aspects, first of all the importance given to the linear concept of ecological succession (seral steps), not compatible with the reality, being in contrast with the new scientific paradigms.

2. Until now, even in the representation of the ecological space, it has not been taken into consideration that an association must have an information content that is greater than the sum of the information acquired from the component species (Fig. 7). This is what allows an association to become an attractor within its context (i.e. ecotissue), in which it evolves and has to sustain a role (Ingegnoli 2002, 2005).

3. After about 100 years of investigations no true novelty changed the method of phytosociology, thus the results became more and more incoherent with the modern developments of science (Pignatti, Box & Fujiwara, 2002). Indeed this investigation remains in most cases a description of facts.

4. The method is scale dependent. What happens with relevés of 10 cm^2? What with 1 ha?

5. Moreover, the observations of Ellenberg (1960) on relative *Standortkonstanz* of species (relative dependence on site factors) are often not considered. Note that an ecological interpretation of genome redundant size reinforces this concept (Bennett and Smith 1991).

6. It is impossible to show properly the order existing in a vegetational community only with a floristic description[6] (e.g. phytosociologic table). Rather, if the shorter algorithmic description of a system coincides with the description of the entire system, the system has to be classified as chaotic, dependent from the initial condition (Pignatti et al. 1998).

7. The aims of phytosociology are more linked with a description and typing of a *supposed* natural set of plants than with a study of vegetation in its complete reality. Without an integration, the use of phytosociology in landscape ecology could be in many cases too limited or impossible (Ingegnoli 1997, 2002).

8. Studying landscapes, we must consider as a proper entity also the vegetational new coenosis, created in anthropised landscapes even by sets of alien species which have

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[5] E.g. Ellenberg bioindicator values of vascolar plants: light radiation, temperature, climate continentality, humidity, soil reaction, nutrients, salinity.

[6] Remember that the organisation of a vegetation coenosys concerns also the structuring of space-time (4 dimensions) and the relations with animals, human management, and so on.

replaced or are replacing autochthonous ones, especially with respect to former natural associations. This fact is confirmed also by cartography: many phytocoenosis can not be described in syntassonomy. Information related to natural species are not sufficient from a landscape ecological point of view.

9.   We have also to consider the possibilities of random variations.

5.2 From landscape bionomics a new definition of vegetation

To understand the transformation of a landscape it is useful to study its vegetation, which characterises the main "landscape apparatuses" (Ingegnoli 2002), or "context role sub-systems" (CRS-S).

A landscape CRS-S concerns functional systems of tesserae and ecotopes which form specific configurations in the complex mosaic (i.e. ecotissue) of a landscape. A tessera is the smallest homogeneus unit visible at the spatial scale of a landscape: it corresponds to the former definition of ecotope (Naveh, 1984; Haber, 1990; Zonneveld, 1995) as the sum of physiotope and biotope. An ecotope is now the smallest landscape unitary multidimensional element that presents all the structural and functional characters of its landscape (formed by at least two tesserae).

These CRS-S are distinguished by a specific landscape function (and/ or its range of sub-functions), not only by many local characters: e.g. productive, connective or stabilising functions. A first important landscape function results by the human habitat (HH) versus natural habitat (NH). The NH are the natural ecotopes, with dominance of natural components and biological processes, capable of normal self-regulation. Remember that the management role of human populations, if not directed against nature, may be considered in an ecotissue as semi-natural. Following the ecotissue model (Ingegnoli, 2002), the sum HH+NH > 1.

In this vision, the *definition* of vegetation has to be: the *whole of the plants* of a landscape element, considered in their aggregation capacities and in their relations with environmental and time-space factors. Thus, a cultivated tessera is to be considered as vegetation not only for its weeds (e.g. *Secalinetea, Chenopodietea*), but even for the cultivation itself (e.g. *Triticum aestivum, Hordeum vulgare*), without which the weeds does not succeed and the tessera does not become the habitat for many natural species (e.g. *Coturnix coturnix, Alauda arvensis*), besides to be a crucial ecological component for human population.

The frequent use of the concept of "potential natural vegetation" is not yet satisfactory for landscape ecological studies, because the word "potential" is intended to represent undisturbed conditions in a not defined time. The proposal of Ellenberg (1974), to distinguish among *zonal* vegetation, which expresses the responses of potential vegetation to climatic conditions; *extrazonal* vegetation, responding to local topoclimatic conditions; and *azonal* vegetation, responding to soil moisture conditions, was another good step, but it is again not sufficient for landscape bionomics theory, therefore even for vegetation science.

Remember that Ellenberg (1978) already perceived the ecosystem and man's dual part in the structure of a landscape, and Walter (1973) proposed to determine plant formations and types not only in their floristic aspect but also in stability, structure, human influence, diversity, productivity, etc. Note that the reasons for this criticism derive from the self-organisation processes especially when the role of disturbances is seen as structuring and when the transgressions in a linear succession are based on the interaction among landscape elements even in the same *zonal* area.

Trying to evaluate the actual vegetation on the basis of its ecological distance from the potential vegetation is not correct, because this implies the possibility that   potential

landscapes, reduced to very few, sometimes only one or two types of vegetation really exist. This is in contrast with all the main processes and dynamics of the landscape and it is a sort of "virtual ecology"! For instance, as pointed out by Pignatti even on the best primeval forest in Europe (i.e. the Perucica[7]), the large zonal ecosystems (e.g. tropical forests, taiga, savannah, Australian deserts, etc), nearly undisturbed, are never formed by a single association or very few ones!

In facts, it clashes with the non-equilibrium thermodynamic principle and the relative bifurcations of the state functions of a system in an instability field. Therefore, the concept of potential vegetation has to be strongly revised. It has to be defined not only for natural cases, but in relation to the main range of landscape disturbances (including man's) too, and with defined temporal conditions. It must never be considered as the optimum for a certain landscape (or part of it), but only as a general indication (never to be widely reached) in relation to the climate, the soil and the anthropisation of a certain limited period of time. It could be better named *the fittest vegetation for*.

This new concept refutes the general notion of 'potentiality' as the possibility of the coming into existence, in the absence of man and for large territories, of a deterministic, a priori fixed vegetation type and interpreted as the best condition for a place, independent of all other environmental and human factors in space and time. Moreover, no potential homogeneity can be a model for the develpoment of a landscape. On the contrary, the concept of *the fittest vegetation for* indicates the most suitable or suited vegetation for: the specific climate and geomorphic conditions, in a limited period of time and in a certain defined place; i.e. the main range of incorporable disturbances (including man's) under natural or not natural conditions. This could be a great change of perspective.

Note that it signifies also to eliminate, or at least declassify, the concept of primary succession and a revision of the concept of vegetation dynamics.

6. New method for vegetation evaluation in landscape bionomics

A new method of vegetation evaluation has been studied and proposed by Ingegnoli (2002, 2005), then discussed and completed with Elena Giglio and Sandro Pignatti (2005, 2007): it derives directly from the theoretical considerations reported here. This method can be named "Landscape Bionomics Survey of Vegetation" or LaBISV. A frame protocol is presented in Tab. 1: it is able to integrate three different criteria (a biotic one, an environmental one and a configuration one) with different temporal and spatial scales.

6.1 Frame protocol and parametric standard form

The below presented frame protocol uses a *parametric standard form* (a proper one for each type of vegetation) for the analysis and evaluation of a vegetated tessera. It is very helpful in the definition of the so called "*normal state*" for each specific type of tessera. Remember that landscape bionomics follows a clinical-diagnostic method and its main goal concern the evaluation of the healthy state of a landscape unit, in which the vegetation coenosis play a central role.

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[7] The Perucica Primeval Forest is located in the Sutjesca National Park, in Bosnia-Herzegovina, and together with the Bialowieza forest in Poland is one of the few oldest forest landscapes in Europe.

Phase	Activities	Main operations	Notes
I	Identification of the landscape unit, (LU)	Following the Biological Integrated School of Landscape Ecology, recognition of boundaries and of composing ecotopes.	Ingegnoli, 2002, 2005 Ingegnoli & Giglio 2005
II	Choose of the vegetation tesserae (Ts)	Identification of the vegetation type, of its ecological (structural/ functional) subdivisions and of the perimeter of the different tesserae.	Depending on ecological interest, Ts containing permanent plot too.
III	Collection of geographical data	Site and local data, e.g. climate, substrate, morphology, etc.	
IV	Collection of historical and human data	Old maps and books data, main human land uses, main historical changes.	
V	Survey of Ts characters	Vegetation height (canopy) and cover, structure, edge ratio, management, etc.	Ts as patch or corridor
VI	Survey of Plant Biomass parameters	Dead plant biomass, litter depth, biomass volume.	Above ground biomass
VII	Survey of Ecocoenotope parameters	Dominant sp, species richness, allochthonous sp, biological forms, stratification, threatened plants, renewal capacity, dynamic state, etc.	A phytosociological frame is needed
VIII	Survey of Ts/ LU parameters	Contiguity, source/ sink, functional role, disturbance incorporation, geophys. instability, fauna interest, transformation, etc.	
IX	Evaluation of vegetation parameters	Ordination of parameters in four classes in a standard form, then evaluation per column.	Scores depending on vegetation type
X	Evaluation of vegetation qualities (Q)	Evaluation (%) per group of parameters and/ or the entire Ts	
XI	BTC estimation	Estimation through equations linked with the development models and BTC theory	
XII	Diagnostic activities	Comparison with other Ts and with the LU. Underline of the altered parameters. Integration with other ecological indicators ...	

Note: more information, especially on the interpretation of the parameters and score, may be founded in Ingegnoli & Giglio (2005). From: Ingegnoli V (2006) in ICP Forests Monitoring, Göttingen. pp. 241-259,

Table 1. Landscape Bionomics Survey of Vegetation (LaBISV): frame protocol in synthesis

This form (Table 2) has been designed to check the organisation level and to estimate the metastability of a tessera considering both general ecological and landscape biononical characters: T = landscape element characters (e.g. tessera, corridor); F = plant biomass above ground; E = ecocoenotope parameters (i.e. integration of community, ecosystem and microchore); U = relation among the elements and their landscape parameters.

The parameters for each T,F,E,U groups range from 3 to 12, thereby reaching the number of 26-33. The evaluation classes are four, the weights per class depending on an evaluation model (Fig. 8). Remembering the well known relationships among gross productivity, net productivity and respiration in vegetation ecosystems (Odum 1971, Duvigneaud 1977), the development of a vegetation community may be synthesised in: (1) the growing phases from young-adult to maturity, expressed by an exponential process; (2) the growing phase from maturity toward old age, expressed by a logarithmic process.

Example of the LABISV methodology synthesized in the present standard form					
BOREAL FOREST	**1**	**5**	**14**	**25**	**score**
T.TESSERA CHARACTERS (TS)					
T1 – Vegetation height (m)	< 9	9.1-18	18.1-29	**> 29.1**	Canopy
T2 – Cover of the canopy (%)	< 30	> 90	**31-60**	61-90	Ts surface
T3 – Structural differentiation	low	medium	**good**	high	Age, space groups, etc.
T4- Interior/ edge (%)	none	< 30	**31-89**	> 90	(% Ts)
T5 - Management	simple coppice	coppice	wood	**natural forest**	Or similar
T6 – Permanence (years)	< 80	81-160	**161-240**	> 240	Old trees
F. VEGETATIONAL BIOMASS (ABOVE GROUND)					
F1- Dead plant biomass	near 0	> 10	**1-5**	5-10	% of living biomass
F2- Litter depth	near 0	< 1.5	**1.6-3.5**	> 3.5	cm
F3 – Biomass volume (m³/ ha)	< 200	201-500	**501-950**	> 950	pB = **696** m³/ ha
E. ECOCOENOTOPE PARAMETERS					
E1- Dominant species (n°)	> 3	3	2	**1**	As pB volume
E2- Species richness	< 15	16-30	31-40	**> 40**	n° sp./ Tessera
E3- Key species presence (%)	< 5	6-40	41-80	**> 80**	Phytosociological
E4- Alloctonous species (%)	> 10	10-4	< 4	**0**	From other ecoregions
E5- Infesting plants %	near all	> 25	< 25	**0**	Coverage on Ts
E6- Threatened plants	evident	suspect	risk	**0**	Even acid rain damage
E7- Biological forms (n°)	< 3	4-5	**6-7**	> 7	Cfr. Box 1987, mod.

E8- Vertical stratification	2	3	**4**	> 4	traditional
E9- renew capacity	none	intense	**sporadic**	normal	Dominant species
E10- Dynamic state	Degrada-tion	recreation	**Regenera-tion**	Fluctua-tion	Cfr. Ingegnoli 2002
U. LANDSCAPE UNIT (LU) PARAMETERS					
U1- Similar veg. contiguity	0	< 25	**26-75**	> 76	% of perimeter
U2- Source or sink	sink	neutral	**Partial**	source	Species & resources
U3- Functional role in LU	reduced	minor	**evident**	important	Context & typology
U4- Disturbances incorporation	insufficient	scarce	normal	**high**	Local disturbances
U5- Geophisical instabilities	evident	partial	**risk**	none	On the phisiotope
U6- Permeant fauna interest	low	medium	**good**	attraction	Key species
U7- Tranformation modalities of the Ts	strong distuba-nces	gradual changes	temporal instabilities	**fluctuation**	Today + tendency
U8- Landscape pathology interference	serious	near chronicle	**easy to incorporate**	none	From landscape
U9- Permanance of analogous vegetation (years)	< 100	100-300	300-1200	**> 1200**	Historical presence
RESULTS OF THE SURVEY					
Total score Y (= h+j+k+w)	h = 0	J= 0	K = 17	w = 11	Y = 513
Quality of the Ts	Q = Y / 700				**Q = 73,3** [%]
Estimation of the BTC	BTC (b) = 0,01339 (y-28) + 0,12 (pB / 70)				**BTC = 7,69** [Mcal/ m²/ yr]

Table 2. Example of the LaBISV methodology of survey synthesized in the present standard form. Forest permanent CONECOFOR plot TRE1 (Lavazè Pass[8]) *Piceion abietis*, 1.800 m. Survey: August 2004 by Ingegnoli and Giglio. Also the equation of estimation of the BTC derives from the model of Ingegnoli (2002).

Table 2 could be used also for Temperate deciduous forests, changing: (a) the parameters F3 (biomass volume) that become respectively < 150, 150-350, 350-600, > 600, and (b) the scores of the columns, which become 1,5, 12,22.

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[8] The Pass of Lavazé is located between the Fiemme Valley and the Egentall, in the Region of Trentino-Alto Adige (Sud Tirol). The CONECOFOR is a programme of forest research ruled by CFS (State Forest Corp) of forest ecosystems monitoring.
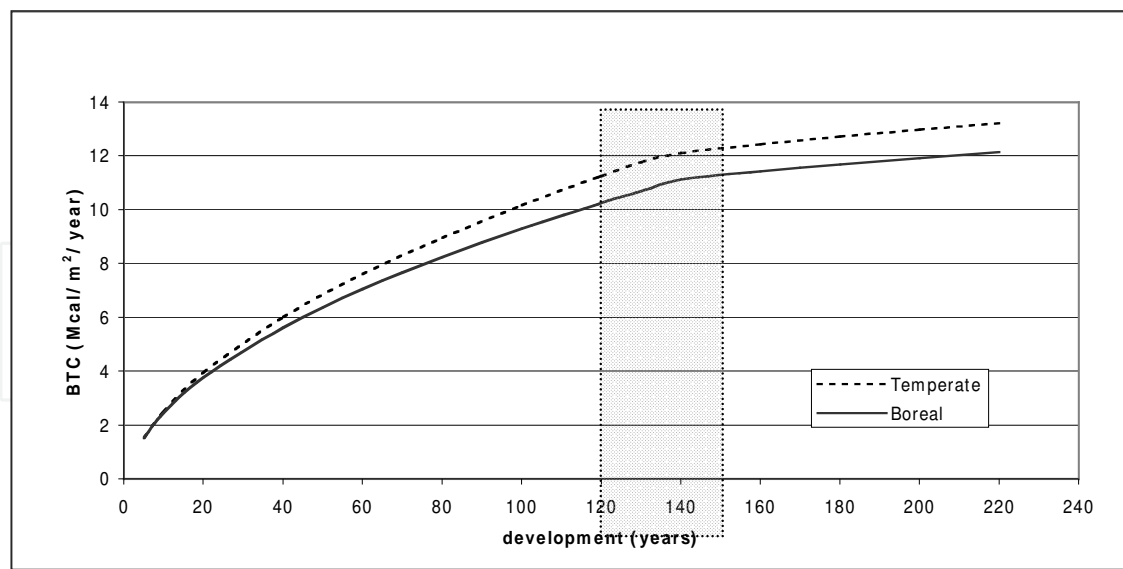
Fig. 8. Model for Temperate deciduous forest and Boreal coniferous forest. The vertical strip indicates the beginning of the maturity phase, from 120 to 150 years.

6.2 Main applications of the LaBISV

Following a similar method, a series of schedules (Ingegnoli & Giglio, 2005) have been designed, one for each main vegetation type (Table 3), other types are now in study.

Main vegetation types	Model BTC (max) Mcal/m²/yr	Model development (years)	BTC Estimation equations (Mcal/m²/year)
1. Boreal forest	11.0	120-150	$0,01339\,(y-28) + 0,12\,(pB/\,70)$
2. Temperate forest	12.0	120-150	$0,01667\,(y-28) + 0,13\,(pB/\,65)$
3. Sclerophyll forest	13.0	120-150	$0,01705\,(y-28) + 0,13\,(pB/\,60)$
4. Mediterranean pine forest	10,5	100-130	$0,01510\,(y-28) + 0,12\,(pB/\,65)$
5. Tall shrubland	4.0	30-40	$0,00344\,(y-30) + 0,10\,(pB/\,17)$
6. Low shrubland	2.6	25-35	$0,00247\,(y-30) + 0,03\,(pB/\,0,2)$
7. Prairie and pastures	1.4	20-24	$0,001335\,(y-29) + 0,02\,(pB/\,0,14)$
8. Reed	2.8	36-48	$0,0023\,(y-29) + 0,04\,(pB/\,0,3)$
9. Salt marshes	1,2	15-20	$0,00260\,(y-28) + 0,10\,(pB/\,1,4)$
10. Corridors with trees	9.5	90-130	$0,0072\,(y-33) + 0,10\,(pB/\,75)$
11. Wooded agrarian	4,5	30-40	$0,00575\,(Y-29) + 0,15\,(Fm/\,35)$
12. Agricultural field	2.0	10-20	$0,00192\,(y-26) + 0,09\,B3$
13. Urban garden	8.0	70-110	$0,00526\,(y-30) + 0,10\,(pB/\,45)$

Table 3. Synthesis of the main vegetation types considered by the model for vegetation survey proposed by Ingegnoli (1999, 2002, 2005).

This method and its schedules, to which the notes for each ecological parameter (Giglio & Ingegnoli, 2005) can be added, recently was used with success a s a tool for vegetation survey, and in many applications of vegetation science. Main application of this survey method are:

1. evaluate and compare the about 30 ecological parameters of vegetation, e.g. through radar plots;
2. evaluate the ecological quality (Q_x) of each group of parameters (T,F,E,U);
3. verify and to estimate the biological territorial capacity of a tessera (BTC);
4. check the level of ecological maturity of a tessera (BTC/ BTC*);
5. survey the mean BTC and the BTC classes composition of a landscape unit or one of its ecotopes (thus allowing the measure of other ecological indexes, Cfr. Ingegnoli 2002 and Giglio & Ingegnoli 2005);
6. estimate/ quantify results of management intervention on some parameters effects on the whole tesserae or LU.

7. An example of application: the forests of the territory of Mori (Trento)

The Mori municipality is about 35 sq.Km, 53% covered by forest. It consists of 4 Landscape Units (LU) presenting different landscape types (Fig. 9):

LU1 (Mori-Talpina): valley floor *rural-suburban landscape,*

LU2 (Loppio): valley floor agricultural-protective landscape

LU3 (Val di Gresta): mountain agricultural-protective landscape

LU4 (Biaena Mount): mountain forest-agricultural landscape

Note that the first LU, Mori-Talpina, is the lowest one (from 200 to 550 m a.s.l.) and the more urbanised one: anyway 1/ 3 is covered by forest.

Fig. 9. The localization of the municipality of Mori, in the Southern part of Trentino, near the upper Garda Lake, and (right) the division of the territory in 4 landscape units of : (1) Mori-Talpina (violet), (2) Loppio (pink), (3) val Gresta (green) and (4) mount Biaena (pale blue).

7.1 Character of the forests

The distribution and types of forests lying on the territory of the municipality of Mori (TN) were surveyed in the year 2007 by Ingegnoli and Giglio, following the LaBISV Method. Mixed oak forests (*Ostrya* woods) are the most widespread formation (59.7%) followed, in the upper vegetation belt, by pine forests (*Pinus sylvestris* and *Pinus nigra*), spruce forests

(*Picea abies*) and beach forests (*Fagus sylvatica*), respectively 11.5, 8.7 and 5.4%. To have an idea of these forests, see Fig. 10, in which is shown *Ostrya* formations and Conifers ones.

Fig. 10. Picture of the Mori territory: (*left*) a vision of an *Ostrya-Quercus* formation, with some Pines on the slope, and (right) a view of the mount Biaena, from 700 to 1400, which presents spruce and beach formations.

The most impressive characteristic of forest vegetation in Mori Municipality is the considerable difference between the physiognomy of the investigated forest and woods and their proper ecological characters, due to human management and historical events: the phytosociological attribution to a proper association is often very difficult. For 11 forested tesserae dominated by spruce – the attribution of which to a certain phytosociological syntaxa was not clear- data concerning species have been elaborated following this formula:

$$TFC = [k\,SP/SP^*] \times DM^{1\beta} \tag{13}$$

where: TFC = theoretical forest character; SP = surveyed species pertaining to a certain *Phytosociological Alliance;* SP* = possible species pertaining to the same Alliance; (SP/ SP* in %); k = coefficient available to consider misbehaving and companion species (e.g: k= 1,1); DM = dominant in % plant biomass (elevated 1/ 3).

11	PHYSIONOMY	Ostrya-wood A	ha 387,5
	SYSTEMIC CHARACTERS		
	PROPER ECOLOGICAL CHARACTERS		**Prealpine Ostrya-wood with Quercus petraea**
	PHYTOSOCIOLOGICAL ATTRIBUTION		cl. *Querco-Fagetea*, ord. *Quercetalia pubescentis*, all. *Orno-Ostrenyon*, ass. *Buglossoidi-Ostryetum*
	medium SPATIAL STRUCTURE		Deciduous broad-leaves 95%, medium high 12m
	medium BIOLOGICAL TERRITORIAL CAPACITY		BTC = 5,03 Mcal/ m²/ year
12	PHYSIONOMY	Ostrya-wood B	ha 531,93
	SYSTEMIC CHARACTERS		
	PROPER ECOLOGICAL CHARACTERS		**Mixed wood with Ostrya carpinifolia, Fraxinus ornus and Quercus pubescens**
	PHYTOSOCIOLOGICAL ATTRIBUTION		cl. *Querco-Fagetea*, ord. *Quercetalia pubescentis*, all. *Orno-Ostrenyon*, ass. *Orno-Ostryetum*
	medium SPATIAL STRUCTURE		Deciduous broad-leaves 97%, medium high 9,2m
	medium BIOLOGICAL TERRITORIAL CAPACITY		BTC = 4,93 Mcal/ m²/ year
13	PHYSIONOMY	Ostrya-wood C	ha 188,45
	SYSTEMIC CHARACTERS		
	PROPER ECOLOGICAL CHARACTERS		**Ostrya-wood with Quercus petraea and Quercus pubescens**
	PHYTOSOCIOLOGICAL ATTRIBUTION		cl. *Querco-Fagetea*, ord. *Quercetalia pubescentis*, all. *Orno-Ostrenyon*
	medium SPATIAL STRUCTURE		Deciduous broad-leaves 99%, medium high 10,6 m
	medium BIOLOGICAL TERRITORIAL CAPACITY		BTC = 5,4 Mcal/ m²/ anno

Table 4. Physionomic-ecological map of forests: legend and surfaces

Three Alliances have been concerned: *Erico-Pinion, Piceion abietis, Fagion* (see Fig. 11). Results are shown in the figure. As you can see, tesserae n° 1-8 may be ecologically considered as Spruce coenosys, while the last two are Pine forests with spruce; n° 9 is a mixed one.

Under the physiognomy of *Ostrya*-wood, we gather at least three types of coppice woods, related to the two phytosociological associations of *Buglossoidi-Ostryetum* and *Orno-Ostyetum,* as shown in table 4.

Concerning Pine wood (*Pinus nigra austriaca*) on mount Garda (Mori), mainly planted by foresters about 60 years ago, it presents many characters of the *Fraxino orni-Pinetum nigrae* Martin Bosse (1967). This formation has been described by Pollini (1969) in the Karst near Trieste, with species like: *Amelanchier ovalis, Lembotropis nigricans, Erica carnea, Goodiera repens, Sesleria* sp., etc. The present site in Mori could represent the most Western site of this association in Italy.
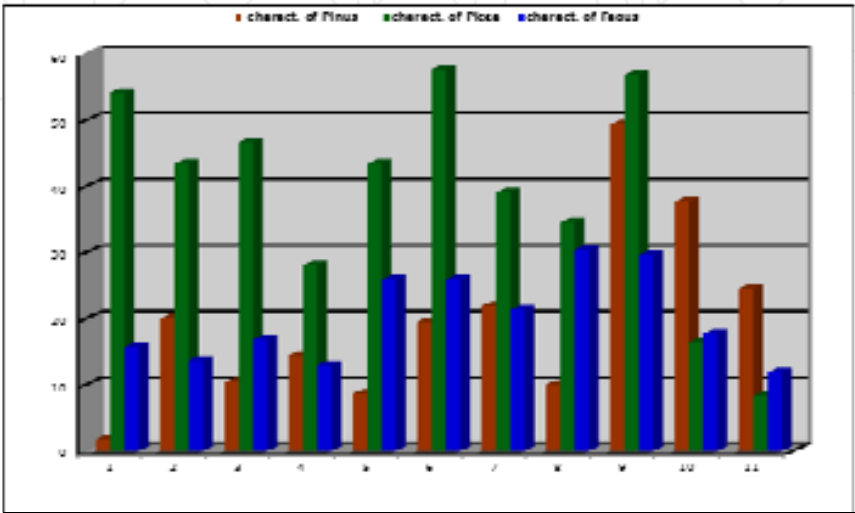

Fig. 11. The distribution of proper ecological characters of the alliance of Pinus (red), Picea (green) or Fagion (blue), following the above mentioned formula, within each surveyed tessera of spruce forest.

7.2 The thermophylous vegetation of Mori-Talpina

The results from the survey of 13 forested tesserae in the LU 1 of Mori-Talpina are shown in table 5, where: *pB* measure the plant biomass above ground; *BTC* is the biological territorial capacity of vegetation (Mcal/ m²/ year); *Q* represent the four ecological qualities of the tessera (Ect = ecocenotope, LU = landscape unit, Ts = tessera, pB = plant biomass, B = % of coniferous species, BTC* maturity threshold, 85% of the model curve).

The average BTC of the forests of this LU 1 is quite low (about 4.9 Mcal/ m²/ year) if compared with the values of the other 3 LU of Mori (see Tab. 6). Anyway, no one of the forest types reaches a hight mean of biological territorial capacity (e.g. BTC = 8-9 Mcal / m²/ yer). But the most evident difference among the 4 landscape units emerges in the chorological analysis, as we can see in Fig. 12, especially concerning the LU1 versus the others 3 regarding the Euri-Mediterranean, the Euro-Siberian and the Orophytae species. This analysis is based on 118-192 species per LU.

The Ellenberg indexes (*sensu* Pignatti, 2005) -resulted from the analysis of the species of the Mori-Talpina Landscape Unit- have been compared with 2 case study, the first in Menaggio (Lake of Como, Pre-Alpine climate), the second in Zoagli (near Genoa, Mediterranean climate). In figure 13, we may observe, despite the high presence of Euri-Mediterranean species, the good similarity with the other Pre-Alpine case and the differences versus the Ligurian landscape (true Mediterranean).

Rel. N°	Site	Height a.s.l.	*Dominant trees*	canopy height m	pB m³/ha	BTC Mcal /m²/a	% Q (Ts)	% Q (pB)	% Q (Ect)	% Q (LU)	B	BTC*
1	Zovo, p. 10	440 m	*Q. petraea Fraxinus ornus*	7,7	61,2	4,37	45,5	21,2	65	49	6	42,8
2	Besagno S	440	*Castanea sativa*	13,9	114,5	4,55	25	37,9	56,8	46,5	0	44,6
3	Talpina, p. 17a	410	*Q. petraea C. betulus*	12,1	126,7	4,52	32,6	37,9	57,3	45,5	0	44,3
4	Talpina, p. 17b	440	*Fagus sylatica*	17,2	255,1	6,41	51,5	59	65	52,5	0	62,8
5	N Corno	230	*Pinus nigra*	16,4	205,6	6,1	51,7	59	74,6	52,3	67	63,3
6	Le Coste	360	*Pinus strobus*	16,2	279,5	3,77	35,3	43,9	46	30,3	86	40,3
7	Talpina, Cava p-18	380	*Pinus nigra, Q. petraea C. betulus*	12,2	173,1	4,99	38,4	43,9	57,8	52,5	17	48,9
8	Coste di Tierno p-15	490	*Pinus nigra, Pinus strobus*	12,7	156,9	4,28	35,4	38,5	50,5	49,9	80	45,8
9	Santuario	320	*Pinus nigra*	16,6	238,1	5,48	39,3	44	70	62,6	97	58,6
10	Mori Vecchio W	280	*Pinus nigra, Ostrya carpin.*	11,3	143,3	4,57	34,3	53,3	60,4	43,3	72	47,4
11	Piede la Lasta	270	*Celtis australis, Q. pubescens*	8,7	117,4	5,00	40,2	37,9	54,1	59,1	0	49
12	Talpina vallecola	350	*Fraxinus excelsior, Fraxinus ornus*	18,6	200,1	4,84	41,6	43,9	61,2	30,1	23	48,8
13	Talpina Doss del Gal	430	*Pinus Nigra, Quercus sp. Carpinus betul.*	16.3	137	4.67	18.8	38	69.6	47.5	43	47.7
	Average values	**372**		**13.8**	**169.9**	**4.89**	**37.7**	**43.0**	**60.6**	**47,8**	**37,8**	**49,6**

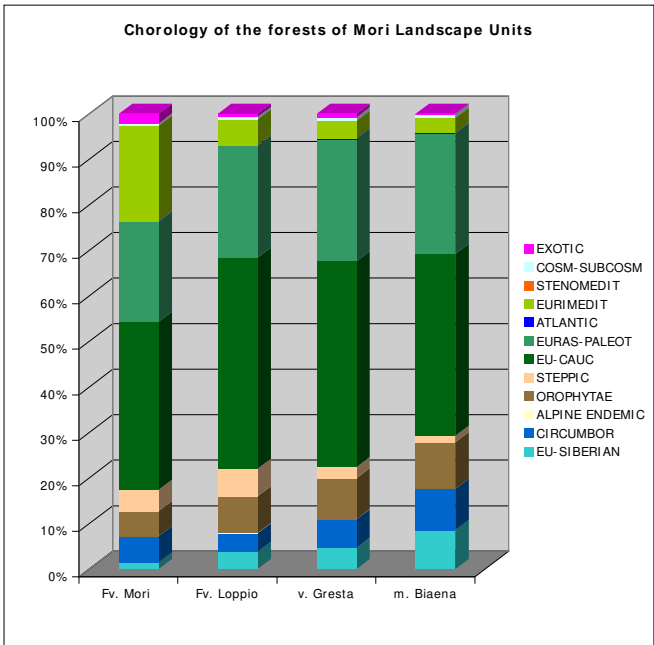Table 5. Landscape Unit 1 MORI forested area Km² 3,29 (27,7% LU)

Fig. 12. The chorological spectrum of the forests of Mori LU shows the difference between the LU1 and the others, especially regarding the Euri-Mediterranean the Orophytae and the Euro-Siberian species.
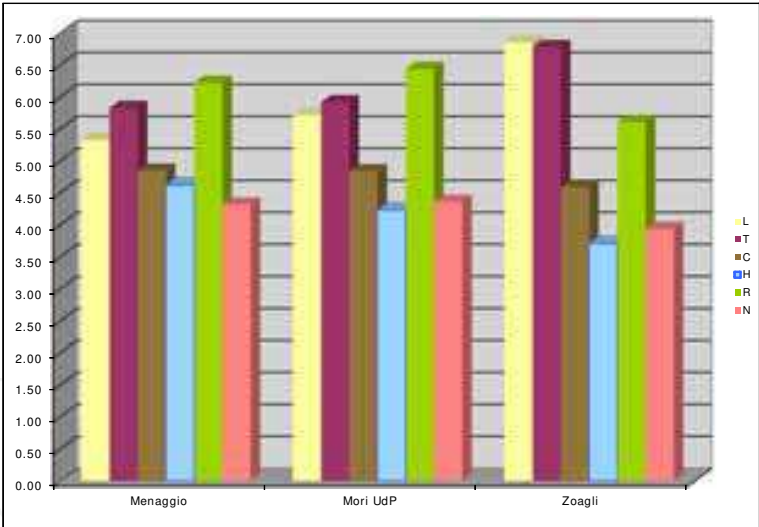

Fig. 13. The Ellenberg indexes resulted from the analysis of the species of the Mori-Talpina Landscape Unit have been compared with 2 case study, the first in Menaggio (Pre-Alpine conditions), the second in Zoagli (Mediterranean conditions). L= Light, T = temperature, C = continentality, H = humidity, R = soil reaction, N = soil nutrients.

7.3 Further applications of the LaBISV and their importance

It could be very important to remember that studying the landscape we can not measure and evaluate only the natural vegetation. Today, many of the European municipality-maybe the most parts of them- have few remnant patches of natural vegetation, and wide areas of human or near-human vegetation, *in primis* the agricultural one. Even in this case

study of Mori, we expose table 6, in which some examples of survey of human vegetation are shown.

Tesserae	Sites	N°	Q Ts	Q pB	Q Ect	Q LU	BTC	pB	Hv
Vineyard I	Besagno	1	57,7	9,5	49,6	37,3	**1,93**	13,5	2,5
Vineyard II	Piantino/ VGr.	2	28,1	9,5	47,8	31,3	**1,47**	10,6	2,3
Vineyard III	stadio/ Mori	3	33,8	9,5	42,8	23,8	**1,35**	12	2,5
Vineyard IV	terrazzo/ Mori	4	45,9	9,5	48,2	33,7	**1,71**	11	2,4
Vineyard V	Valle S. Felice	11	29,6	12,6	45	36,9	**1,63**	12,5	2,3
Vineyard VI	Valle S.F.	12	50,5	36,9	65,7	45,6	**2,36**	14	2,4
Potato field	Sud di Nomesino	5	17,4	7,6	65,8	50,2	**0,71**	0,9	0,7
Cabbage field I	Nagia/ VGr.	6	34,2	37,6	74,8	53,9	**0,97**	2,5	Bare s.
Cabbage field II	Pannone/ VGr.	7	44,5	26,9	62,2	41	**0,87**	2,5	0,4
Meadow II	Nagia/ VGr.	10	27,7	21,9	61,9	39,2	**0,59**	0,7	0,7

BTC is the biological territorial capacity of vegetation (Mcal/ m²/ year); *Q* represent the four ecological qualities of the tessera (Ect = ecocenotope, LU = landscape unit, Ts = tessera, pB = plant biomass as % of the maximum quality, Hv = high of vegetation.

Table 6. Example of survey through the LaBISV method of human vegetation (agricolture) in Mori.

We are now prepared to answer to crucial questions like these:
- how to consider the contribution of any tessera to the metastability of the landscape unit (LU)?
- how to compare the data of the forest patch with those of other vegetation elements in this LU?
- how to use the ecological characters of all the different types of vegetation, existing within a LU, to arrive to a diagnostic evaluation of the entire landscape?
- how to integrate the other main ecological parameters of the LU, like the ones related to animals and the ones related to human habitat or the carrying capacity[9] (SH/ SH*) ?

The scientific diagnostic evaluation of the ecological state of a landscape unit allows a "physician of the environment" to change the present methodologies on territorial planning. As shown in Tab. 7, the LaBISV survey, allowed to elaborate interesting data on the ecological state of this territory, useful to avoid to consider the parameters pertaining to the entire municipality, in contrast with the bureaucratic procedure. In reality, it is possible to demonstrate that the sharp differences among the landscape units bring planning towards these ecological division of the territory, not towards the administrative ones.

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[9] In landscape bionomics the ratio between the measured standard habitat per capita and the theoretical one (SH/ SH*) gives the value of the carrying capacity of a landscape unit (see Ingegnoli, 1993, 2002; Ingegnoli & Giglio, 2005).

Landscape Unit	Area (ha)	Human Habitat (% LU)	Forest Cover (% LU)	BTC of the forests Mcal/ m²/ year	BTC of the LU Mcal/ m²/ year
LU1 (Mori-Talpina)	1.175	57.9	36.8	4.87	2.33
LU2 (Loppio)	602	45.5	43.8	5.08	3.04
LU3 (Gresta valley)	847	30.5	65.5	5.40	3.84
LU4 (mount Biaena)	836	23.3	72.0	5.90	4.47
Mori Municipality	3.460	40.7	52.5	5.28	3.34

Table 7. Differences among the ecological parameters of the entire municipality of Mori and the four landscape units.

8. Conclusion

At the end of this chapter, it is necessary to present another aspect of the application derived from the principles and methods proposed by Ingegnoli. Let us consider a case study, again in Mori, related to the EIS (Environmental Impact Statement) for a cave in the hill of Talpina.
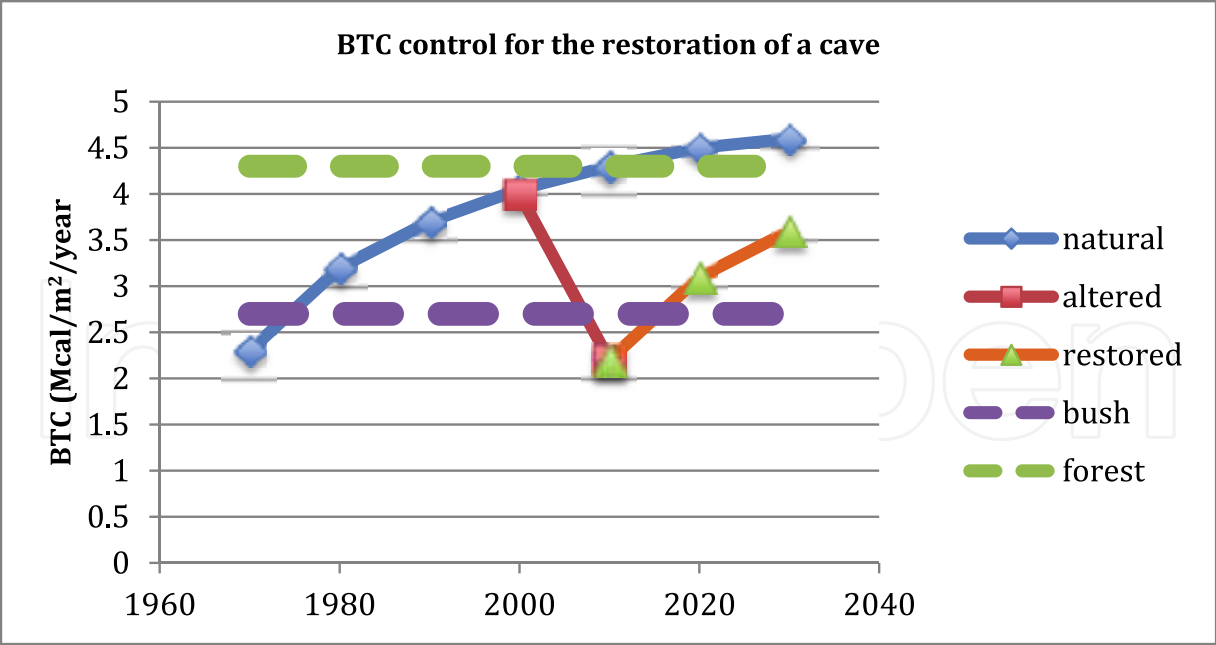
Fig. 14. Example of the ecological control of the restoration of a cave. The BTC function is available to evaluate the proposed opening of a cave after the comparison of the previewed restoration actions with the natural growth of the area and the thresholds indicating the main self-organisation structure of the ecocoenotope, from bush to forest.

The main model elaborated for the EIS, shown in Fig. 14, contributed to avoid the opening of a cave in the SCI area Talpina (Site of Community Importance, EU). The mentioned limits of the old concept of succession, due to non-equilibrium thermodynamics (Cfr. 5.1), eliminate the efficiency of environmental compensation, today based on restoration actions. This method of compensation does not consider the concept of "transformation deficit" (*sensu* Ingegnoli, 2002), which measure the lack of dissipation (of energy and related information) of a landscape system. In Fig. 14, this deficit concern the area between the lines of natural behaviour and the restored one, after the break of alteration. Moreover, the function of BTC allows to underline the thresholds indicating the main self-organisation structure of the ecocoenotope, from bush to forest.

In conclusion, the aim of this chapter is: (a) to demonstrate the possibility and the necessity to revise basic concepts of landscape ecology in the light of the new scientific theory, mainly derived from the non-equilibrium thermodynamics, concerning living systems and, consequently, (b) to revise the main concepts of vegetation science in the light of the new "Landscape Bionomics" and indicate the new methodological approach LaBISV (c) to underline the possibility to use the biological territorial capacity of vegetation (BTC) to evaluate landscape transformations.

Finally, note that human and animal coenosis have been investigated too, with analogous methodologies related to non equilibrium thermodynamics, trying to quantify the field of existence of about 12 temperate landscape types, with the help of a parametric diagnostic index.

9. Acknowledgement

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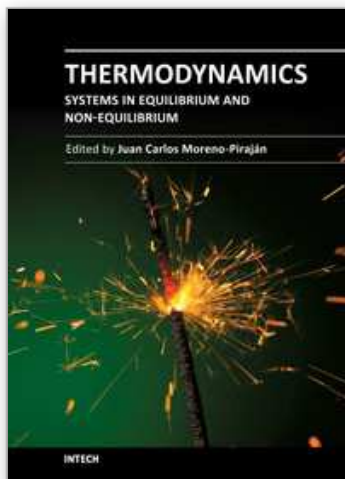
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