PROPOSAL OF A SYNTHETIC INDICATOR TO CONTROL ECOLOGICAL DYNAMICS AT AN ECOLOGICAL MOSAIC SCALE

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Abstract - The problem to control transformations of an ecological mosaic is becoming more and more important. These transformations occur according to processes linked with thresholds of metastability, which correspond to a passage from a metastable *equilibrium* to another. Trying to evaluate the metastability of a certain ecological mosaic, it is necessary to identify the levels of replacement and to measure the metastability of each element, in order to consider their complementarity. It is possible to measure the capacity of an ecological mosaic, formed by a vegetational mosaic, defining a synthetic quantity, named biological territorial capacity, or Btc. It ranks landscape's elements, giving high values to high-resistance ecosystems. Therefore, it is possible to use the Btc as a synthetic indicator of the metastability of an ecological mosaic. Some examples of application regard Gallarate heath-land (local scale) and Lathium, Lombardy and Sicily (regional scales).
Key words - Landscape Ecology, Biological territorial capacity, Synthetic indicator

THE PROBLEM OF THE (META) STABILITY OF A BIOLOGICAL SYSTEM

During these years, the problem to control transformations of an ecological mosaic is becoming more and more important. An ecological mosaic is a part of a landscape, which is a system of ecosystems and thus a specific level of life organisation; hence, the changes of its structural patterns produce consequences over all these components, bringing the landscape towards different behavioural states. Note that traditional ecological indexes are not always available for problems like these. The Biosphere may proceed in structuring itself (i.e. information can be transmitted) only if the final state of each biological system is less unstable (i.e. more metastable) than the initial state (Godron, 1984). So, the problem of the stability of a biological system assumes a great importance: it needs to be evaluated at each state, following the history of the system itself. In fact, each ecological system is characterised by a condition of temporary stationary state, liable to evolve in a more organised one (less unstable) or to degrade (more unstable).

Therefore, it is possible to define the metastability of an ecological system as its possibility to remain within a limited around of conditions, being able to reach other conditions if its range of co-actions continues changing (Forman & Godron, 1986). Dealing with an ecological mosaic, we may observe that its transformations occur according to processes of overcoming of a threshold of metastability, which correspond to a passage from a metastable *equilibrium* to another (Ingegnoli, 1991; 1993).

THE PROBLEM OF THE (META) STABILITY OF AN ECOLOGICAL MOSAIC

Note that an ecological mosaic is generally formed by the vegetational associations : in fact the control on the flux of energy and matter and the capacity to create the proper environment are pertaining to them. This fact is in accordance with the non-equilibrium thermodynamics: where an energy concentration (i.e. photosynthetic plants) produces structure and organisation in a landscape matrix with arising entropy, the Schrödinger effect creates a patch, which acquires a specific landscape role. May be this is the principal way by which ecological systems become heterogeneous (Ingegnoli, 1980; Forman & Moore, 1991).

In order to analyse the human influences in the landscape's change too, we have to clarify the problem of the metastability of an ecological mosaic. In an ecological mosaic, the level of metastability depends on the complexity of order, which gives a threshold of homeostasis: it doesn't depend only on the amount of potential energy (i.e. biomass). If the elements of the ecological mosaic have complementary levels of metastability, they enhance the homeostasis threshold of the entire ecological mosaic. So, the maximum metastability of an ecological mosaic does not correspond to the sum of the maximum metastabilities of each component ecosystems. It may be reached only through a good *equilibrium* among elements with complementary levels of metastability, as the most adapted organisation concerning with a particular type of landscape. In fact, an ecological mosaic is composed of low metastable elements, with a little resistance to disturbances but a rapid recovery capacity, and of high metastable elements, with a high resistance but a slower recovery capacity.

The concept of adaptation referred to a landscape organisation depends on the active responses of its elements to the environmental disturbances. If these elements have complementary levels of metastability, they enhance the capacity of the landscape to incorporate a wider range of perturbations.

EVALUATING THRESHOLDS OF METASTABILITY TO CONTROL ECOLOGICAL DYNAMICS

As pointed out by E. Odum (1971), it isn't possible to understand a specific level of life organisation without the specification of characters depending exclusively on its structure and its dynamics. So, the analysis of vegetation at the landscape scale does not coincide with the analysis of vegetation for single associations.

Large-scale changes are difficult to be measured directly, even in an ecological mosaic, and it may not be possible to detect whether a change is good or bad.

However, it may be possible to detect whether changes are leading the ecological mosaic to a point of instability by monitoring its metastability.

As it has been mentioned above, reaching a threshold of metastability means to change a type of ecological mosaic with another: this one can be, or cannot be, compatible with the larger scale landscape or it can be able to incorporate the local disturbance regime. In the second case, it may indicate that the total system is degraded and remedial actions are called for.

Trying to evaluate the metastability of a certain ecological mosaic, we need to identify these levels of replacement and to measure the metastability of each element in order to consider their complementarity.

THE BIOLOGICAL TERRITORIAL CAPACITY (BTC)

A new quantity refers to the concept of latent capacity of homeostasis of an ecosystem and takes into consideration all the principal types of ecosystems of the biosphere, together with their metabolic data (biomass, gross primary production, respiration, R/PG, R/B). It is composed by two coefficients for each one of the principal ecosystems of the biosphere:

$a_i = (R/PG)_i / (R/PG)_{max}$ measuring the degree of their relative metabolic capacity

$b_i = (dS/S)_{min} / (dS/S)_i$ measuring the degree of their relative antithermic maintenance,

being :

R = respiration;
PG = gross production;
dS/S = R/B = maintenance to structure ratio;
i = principal ecosystems of the biosphere.

It is well-known that the degree of homeostatic capacity of an ecosystem is proportional to its respiration (Odum, 1971). As a consequence, the a_i and b_i coefficients, even related in the simplest way, give the possibility to have a measure of the capacity of an ecological mosaic, defining a synthetic quantity, named biological territorial capacity, or Btc (Ingegnoli, 1980; 1987; 1991):

$$Btc = {}^1/_2\,(a_i + b_i) \times R_i \quad [Mcal/m^2/yr]$$

PROPOSAL OF THE BTC AS A NEW SYNTHETIC INDICATOR

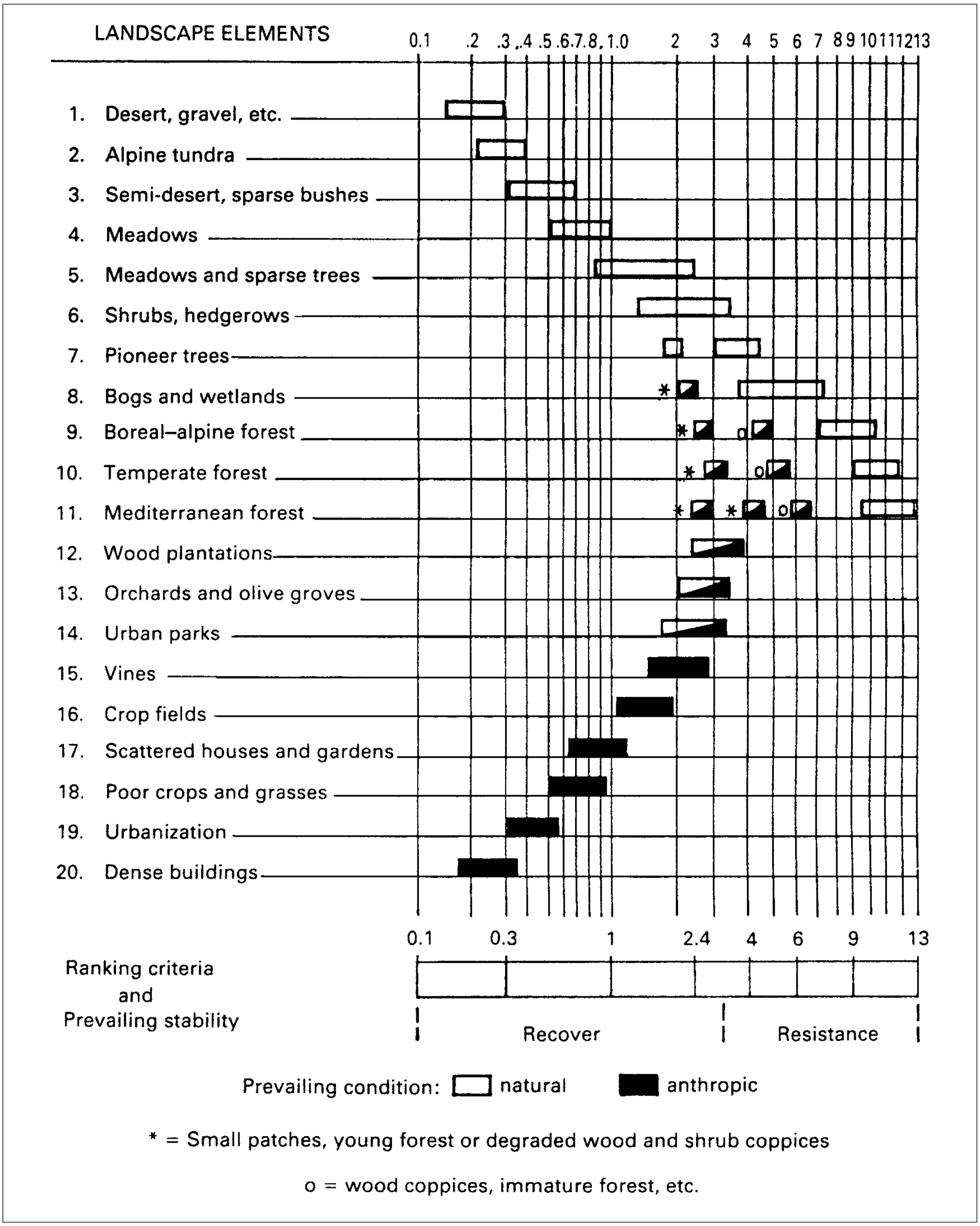


Fig. 1 - Indicative values of biological territorial capacity (Btc), calculated in Mcal m^{-2} yr^{-1}, related to the regions of central-southern Europe

Data needed to ponder this ecological quantity have been gathered from Golley (1972), Golley & Vyas (1975), Whittaker (1975), Pignatti (1995) with reference to a group of 15-20 principal types of ecosystems. In particular, Btc ranks elements, giving high values to high-resistance ecosystems (that are ecosystems with high-metastability), so that the landscape's elements with low Btc usually correspond to low-metastability ecosystems. Therefore, it is possible to use the Btc as a synthetic indicator of the metastability of an ecological mosaic.

A range of indicative values of Btc has been calculated on the media of typical landscape elements of Central-Southern Europe, ranking from natural to anthropic ecosystems (fig.1).

APPLICATIONS

One can use Btc in many cases of territorial studies. The most important application is the possibility to control the main ecological balance after a transformation of a landscape unit. Another application may be the analysis of the more characteristic ecological functions concerning the human habitat. A merit of Btc is that the levels of metastability of a landscape's elements have been defined in bands, so Btc could be used even without a great precision. This becomes a true necessity when the analysis of a landscape is to be compared with precedent historical structures, with low information depending on ancient maps.

Some examples will be reported.

Land transformations at local scale

An example from the North-West territory of Milan. This case study concerns the transformation of a wooded territory, once characterised by the heath-land of Gallarate. The dominant species of the heath-land (Giacomini, 1958) were: *Calluna vulgaris*, *Molinia coerula*, *Cytisus scoparius*, *Pteridium aquilinum*, with same remnant patches of English oak (*Quercus robur*) and birch trees (*Betula pendula*) and sometimes even Scotch pine (*Pinus sylvestris*). Today, these woods of the *Carpinion* alliance are degraded, with the presence of many allocthonous plants, like *Robinia pseudoacacia* trees, but also *Phytolacca americana, Solidago canadensis,* and specially *Prunus serotina*: more than 21% of cosmopolite and allocthonous, versus only 4% in the *Carpinion*, mainly eliminating eurasian species.

The transformation of the ecotissue was indeed evident: in 1856 the local landscape mosaic was composed with: Health = 15%, Wood = 14%, Coppice = 55%, Agriculture + 16%. Today the same mosaic is: Woods = 5.6%, Coppice = 40%, Agriculture = 39.5%, Urbanised = 14.9%. The difference in Btc between 1856 and 1997 is impressive: 3.71 vs 1.92 (-48.2%) even in the human habitat 2.53 vs 0.91 (-64.0%).

The fractal dimension D has been calculated on the basis of the entire configuration of the wooded tesserae in 1856 and 1998. D changed from the value of 1.9 in 1856 to 1.3 in 1998, with an evident fragmentation. Anyway, we need to better estimate the ecological value of the tesserae of the local mosaic, in order to plan a good restoration project. Therefore, five samples of wooded tesserae have been analysed (tab.1) and their values were used to estimate the entire mosaic.

Land transformations at regional scale

Table 1 - Five samples of wooded tesserae in the study area of Gallarate, as representative of the main type of tesserae of the entire mosaic

	Tessera 1	Tessera 2	Tessera 3	Tessera 4	Tessera 5
Biomass [m^3/ha]	121.2	471.0	233.6	70.0	59.0
Btc [Mcal/m^2/yr]	3.4	6.9	7.0	4.3	4.5
Biotope (wood type)	Robinietum coppice (young)	Quercetum seminatural	Quercetum seminatural	Robinietum coppice	Caricetum Robinietum (peat bog)

The Btc, associated with statistical data on a given territory, permits the recognition of the regional capacity of ecological re-equilibrium (i.e. metastability thresholds) during time, controlling the landscape changes, even under human influence. In fact, according with the hierarchical theory of ecological systems (O'Neill *et al*., 1986), the knowledge of the latent capacity of homeostasis at a superior scale (e.g. the regional scale) is necessary to take stock of the situation of our ecological mosaic. The possibility of being able to analyse large-scale changes allows us to study the past of a landscape, to control the present state and to predict effects of different hypothesis of future management, helping us in making decisions.

We report the case of three administrative Italian regions (pointing out that they do not coincide with eco-regions sensu Bailey), but we may refer to regarding them as eco-regional units and analysing them through appropriated ecological methods).

Lombardy (north Italy)

Geographical co-ordinates: 8°30'- 11°26' East; 44°42'- 46°40' North

Eco-regions: (Bailey, 1996) Moist temperate Domain: Oceanic division : 59,5%; Oceanic regime mountains: 40,5%

Tab. 2 - Land transformations in Lombardy and regional ecological indexes

Lombardy	**1878**	**1911**	**1928**	**1951**	**1968**	**1987**	**1993**

forests %	19	16	16,1	18,8	20,1	20,6	20,7
wood plantations %	6,2	1,9	1,8	2,2	2,2	1,6	1,6
crop fields %	39,8	43	44,6	44	39,5	33,6	32,3
meadows & pastures%	17	16	16,3	15,7	17	13,6	11,4
uncultivated%	3,6	8,3	7,9	4,4	2,8	9,4	12
nat. unprod.%	12,7	12,6	12,8	12,8	12,8	13	13
urbanised km^2	400	460	500	573	1145	1956	2147
inhabitants x1000	3500	4790	5450	6610	8330	8890	8910
surface km^2	23530	24180	23810	23850	23850	23850	23860
Hh %	74,3	73,9	77,1	74,3	71,5	67,6	66,3
Nh km^2	6050	6310	5790	6130	6800	7730	8050
ecol.dens. inhab./km^2	200,2	268,0	302,4	373,0	488,6	551,5	563,6
Btc kcal/m^2/a	2050	1900	1890	2030	1970	1940	1950
Sh/Sh_{min}	3,62	2,71	2,39	1,95	1,49	1,31	1,29

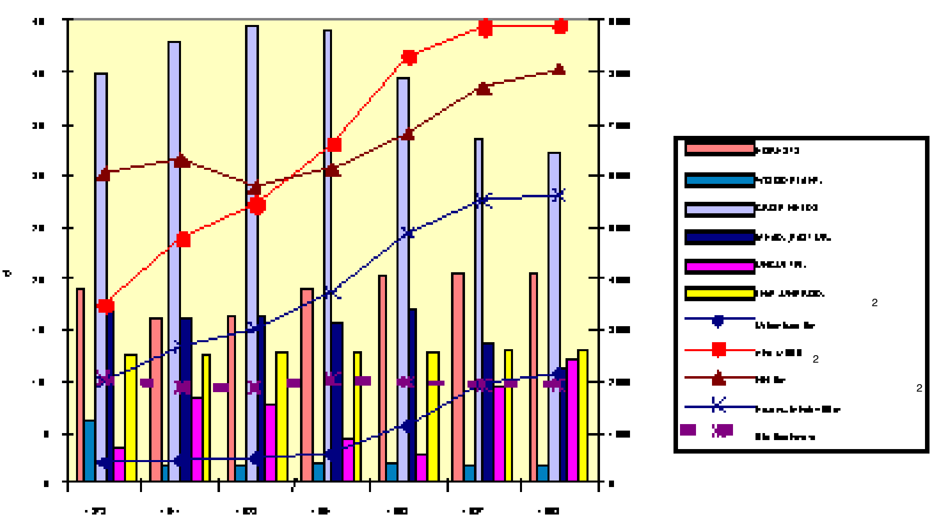
Where: Hh= human habitat, Nh= natural habitat, Sh=standard habitat

Lathium (central Italy)

Geographical co-ordinates: 11°33'-14°01'East ; 41°12'-42°50'North

Eco-regions: (Bailey, 1996) Moist temperate Domain: Mediterranean division, 73,9%;

Land transformations and ecological regional indexes in



Mediterranean regime mountains, 26,1%

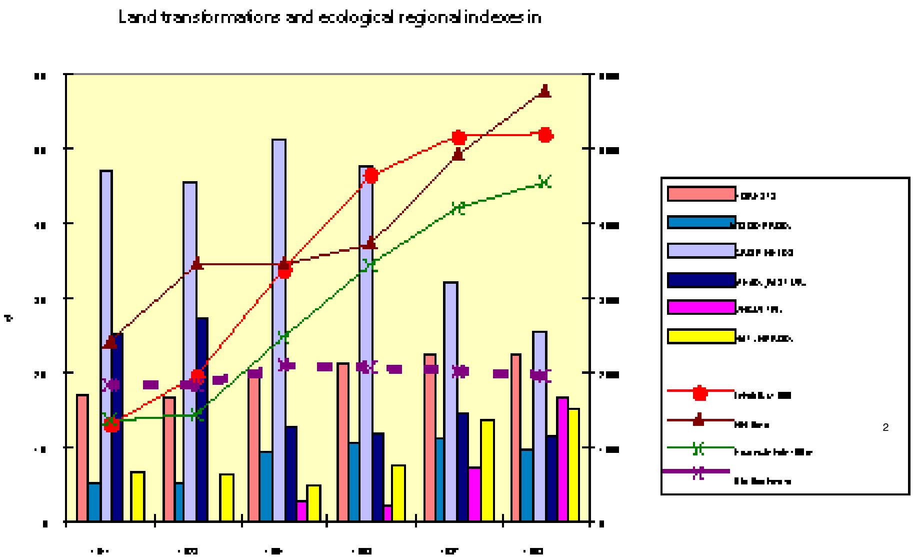
TAB. 3 - LAND TRANSFORMATIONS IN LAZIO AND REGIONAL ECOLOGICAL INDEXES

Lazio	1911	1928	1951	1968	1987	1993
forests%	16,7	16,5	20	21,1	22,2	22,2
wood plantations %	4,9	4,9	9,2	10,6	11	9,5
crop fields %	46,8	45,3	51,1	47,4	32	25,4
meadows & pastures %	25	27	12,5	11,7	14,3	11,5
uncultivated %	0	0	2,6	1,9	7,1	16,4
natural unproductive %	6,6	6,3	4,7	7,5	13,6	15
inhabitants x1000	1302	1957	3384	4635	5156	5198
surface km^2	12000	17180	17190	17200	17200	17200
Hu %	80	79,9	79,9	78,5	71,5	66,5
Nh km^2	2400	3450	3455	3715	4902	5762
ecol. density inhab/km^2	136,0	143,0	246,0	344,0	419,0	454,5
Btc kcal/m^2/a	1830	1820	2080	2060	2010	1950
Sh / Sh_{min}	5,21	4,95	2,87	2,57	1,69	1,55

Where: Hh= human habitat, Nh= natural habitat, Sh=standard habitat

Sicily (south Italy)

GEOGRAPHICAL CO-ORDINATES : 12°27'-15°36'EAST ; 36°40'-38°18'NORTH
Eco-regions (Bailey, 1996) Moist temperate Domain: Mediterranean division, 75,7%; Mediterranean regime mountain, 24,3%

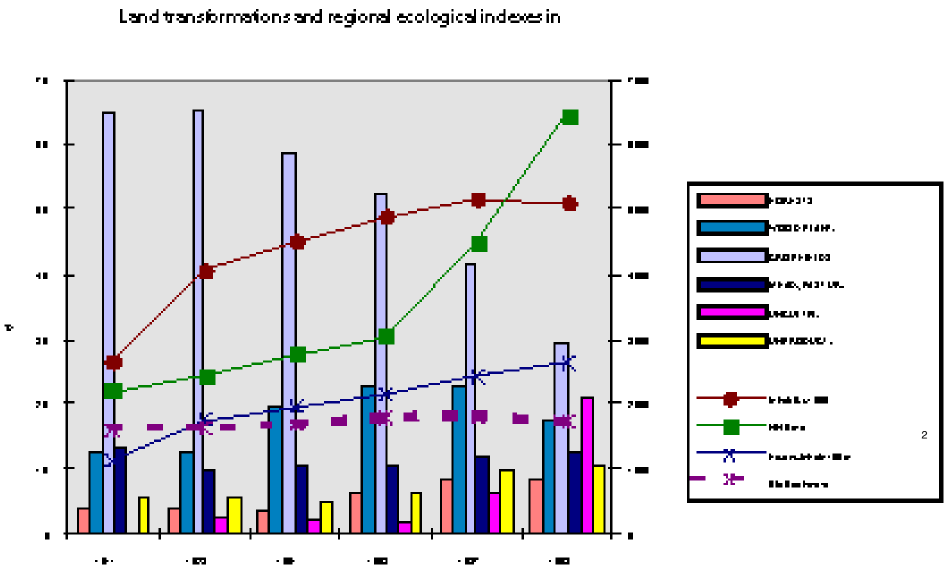


TAB. 4 - LAND TRANSFORMATIONS IN SICILY AND REGIONAL ECOLOGICAL INDEXES

Sicily	**1911**	**1928**	**1951**	**1968**	**1987**	**1993**
forests %	3,7	3,9	3,4	6,6	8,3	8,5
wood plantations %	12,4	12,8	19,7	22,5	22,5	17,6
crop fields %	64,9	65,3	58,5	52,4	41,5	29,7
meadows & pastures %	13,6	9,7	10,7	10,3	11,7	12,5
uncultivated %	0	2,7	2,5	1,7	6,2	21,2
unproductive %	5,4	5,4	5,1	6,4	9,8	10,5
inhabitants x1000	2670	4061	4499	4876	5164	5090
surface km^2	25710	25710	25710	25710	25710	25710
Hh %	91,4	90,5	89,3	88,2	82,6	74,9
Nh km^2	2202	2443	2751	3038	4472	6465
ecological density inhab/km^2	113,5	174,6	196,0	215,1	243,2	264,5
Btc kcal/m^2/a	1630	1650	1690	1800	1820	1730
Sh / Sh_{min}	6,93	4,51	4,01	3,66	3,23	2,97

Where: Hh= human habitat, Nh= natural habitat, Sh=standard habitat

These studies demonstrate that all strong changes occurred in the last century in Italian landscapes have been incorporated by ecological systems till now at regional scale. However, today some negative signals seem to threaten this situation, which need to be carefully controlled.



Conclusions

We have to remark that the importance of the biological territorial capacity (Btc) is related to its ability to quantify the latent capacity of homeostasis of an ecological mosaic and to follow its state along different spatio-temporal scales. In the same moment, Btc supports all the other different indicators in global understanding of ecological mosaics dynamics.

First studies demonstrate that great transformations, at regional scale, have been led by landscape ecological laws until present years. We hope for a widening of these researches to all other Italian region, and to European ones too, in order to obtain a more complete outline of ecological dynamics of transformations landscapes.

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