A NEW PARADIGM FOR THE XXIth CENTURY#

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Dedicated to Akira Miyawaki

FOREWORD

The first clear, methodical exposition of phytosociology was given in the classical book by Braun-Blanquet (1928): this was the beginning of a long period of investigations which now is lasting over 70 years. Since then, the vegetation of most temperate countries has been described, and a huge quantity of information was collected. Indeed, this investigation was mostly a description of facts, rather than an attempt to propose causal interpretations. Basic ideas and methods remained mainly unchanged, and this seems to be an exception in a rapidly changing scientific scenario. This is probably the only field of Biology still using methods developed more than 100 years ago. Dramatic developments in genetics, biophysics and molecular biology had only a limited impact on phytosociology or no consequences at all. The static condition of phytosociology was not an advantage in the attempt to construct its own scientific framework. On the contrary, it provoked a progressive divorce of phytosociology from other more vital branches of biology. Many major problems remained unsolved: continuum or discrete structure of vegetation, forces driving succession, competition versus interaction, stability in space versus change in time etc.; the energy was often concentrated in formalism. Positive developments were directed more toward solution of practical problems, where phytosociology showed some success, as in environmental cartography, rehabilitation and nature conservation, than toward the continuous revision of basic concepts. The results became more and more incoherent with the modern developments of science, not only biological science.

An important experience was started in 1969 from the Working group for data processing, with the set up of automatized methods of data processing. More recently the achievements from other fields of science as ecophysiology, population biology, general ecology and bioclimatology offered new hints for the solution of old problems and cross-fertilization with related fields of research. At the same time a large experience was collected by the investigation on vegetation of similar environments studied in different continents and the information about European vegetation was compared with the vegetation of Japan, South and North America, Australia and of tropical countries.

The whole development of phytosociology was gained in a period, when linear thinking was the fundament of biological science. At the end of the XIX century the struggle of biologists was to adopt and use the concepts of the newtonian determinism. With this philosophy a large quantity of facts was collected, which allow a general description of the vegetation as a phenomenon existent in this world, but this phenomenon remained completely incomprehensible based on the principles of Physics. Indeed, in recent years the theory of complexity and self-organizing systems proposed a bridge between the frontier of physical science and the results of descriptive biology.

In our opinion, these are the reasons which at the beginning of 2000 transform the attempt to concentrate energy and work to express a modern theory of vegetation science in a very challenging task. In traditional XX century thinking, vegetation is considered as an assemblage of plant material which can be perceived as a combination of different species in different quantities. We proposed in a previous paper an axiomatic definition: *Vegetation is organized in communities* (Pignatti, 1980). We will here develop this basic statement in a theory for a more advanced conception, based on the causal analysis of this object.

1. INTRODUCTION

1.1. Complex self-organizing systems

Vegetation Science is the study of the green sheet covering most of the Earth surface. The causal understanding of plant distribution on Earth can be studied only with the investigation of the relationships between plants and environment. The basic level of investigation is the ecosystem, where plants and environment are interacting as a physico-chemical system. Interactions consist in exchanges of matter/energy. The science dealing with exchanges of matter/energy is Thermodynamics

Def. – *System: a whole of parts interacting together*

Systems are subject to changes under 3 different conditions: isolated – closed – open

i, Isolated systems – entropy increases steadily and the system evolves naturally to thermodynamic equilibrium, exchanges of matter and energy are impossible; this condition is described by the general equation

$$\delta S / \delta t > 0$$

where S = entropy, δ = variation, t = time.

ii, Closed systems – can exchange energy but not matter

iii, Open systems – are exchanging energy and matter with the environment; if a strong energy flow acts on the system, then the internal entropy decreases and *dissipative structures* appear. As a consequence, the system starts self-organization.

from Thermodynamics

entropy – the function of state increasing when the system is approaching thermodynamical equilibrium

order – an improbable configuration, corresponding to the condition of low entropy in the system

statements:

- in isolated systems entropy is always increasing up to the equilibrium where every further change stops
- in open systems entropy can be exported so that the system maintains the possibility to produce work

1.2. Self-organization

If a gradient in the surroundings of the system exists, e.g. solar energy naturally transforming to low temperature heat, then the system can capture some energy which can be used to reduce internal entropy. The gradient is acting in the sense of thermodynamics near to equilibrium but the following transformation shifts the complex system in the direction of thermodynamics far from equilibrium. This change is giving the possibility of recursive cycles and self-organization.

Def. – *Complex systems exhibit feedback loops, work in cycle and reduce entropy by introducing energy or energy rich compounds from the environment.*

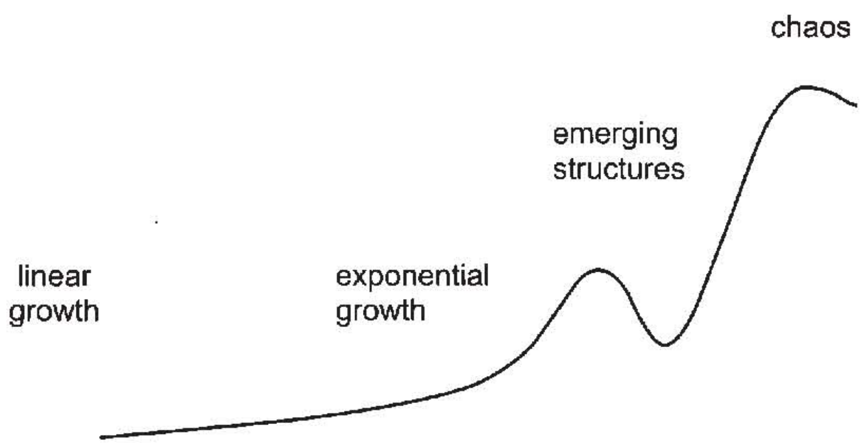

Fig. 1 - The self-organization in complex systems can be visualized as a progressing accumulation of order, when the system is included in a flow of energy, leading to a phase of *emerging structures*. With the following accumulation, the system approaches bifurcations and enters in a phase of instability, with the possibility of transition to chaos

Self-organization in complex systems (fig. 1)	
transition to deterministic chaos	
emerging structures - order at the edge of chaos	
dissipative structures	attractors
operators	equilibrium
fractal geometry	bifurcations
feedback	recursive cycles
bootstrapping	symmetry break
energy flow	

1.3. Living systems (fig. 2)

Def. - *Vegetation is a living system resulting from the self-organization processes of plant individual and plant populations under the selective (driving) influence of environmental factors.*

The basic structures emerging with self-organization consist of

(a) increase of biomass / biodiversity which are organized in

(b) spatial structures

(c) food chain.

Increase of biodiversity

In the context of self-organization, living systems are exploring their space of possibility and approach their attractors becoming more and more diversified. The process is discontinuous and there are phases of intensive emergence of new genotypes, which may be stabilized by natural selection, and phases of relative quiet. In general such phases with emergence of new genotypes follow an episode of sudden extinction. The new genotypes are interpreted as species.

Increase of biomass

The process at the beginning is linear, but rapidly is changing to a nearly exponential dynamics, with the progress of growth, limiting factors become more and more effective and finally the growth ends. It is described by the *logistic equation* producing a *sigmoid curve*.

1.4. Energy flow

The energy irradiated from the Sun as light arrives on the Earth surface. If the surface consists of non-biological material (e.g. of stones), light is transformed upon impact into heat, which increases temperature of the rock and finally becames dissipated as low temperature heat into the atmosphere. If the surface is composed of plants with photosynthetic systems, then energy is transferred to the chlorophyll molecule and successively transferred to energy-rich compounds, and finally enters cell metabolism.

Necessity to have a system of receptors: light energy is captured by the photo-sensible system of the chloroplast (submicroscopic ultra-structures).

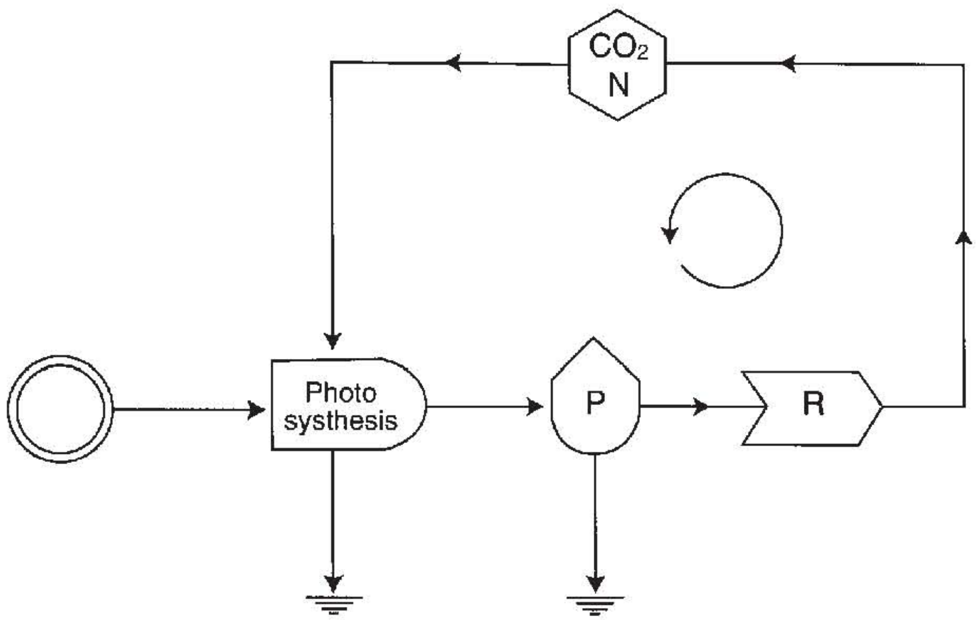

Fig. 2 - Flow diagram for a living system in general. Sun energy is partly (98%) dissipated, partly used for photosynthesis and trasferred to productors (P), then used for respiration; at the end organic matter is oxydized to carbon dioxyde and nitrogen compounds, which newly enter in photosynthesis.

1.5. Homeostasis, resilience

The physico-chemical transformations in the living system are always very slow. Sudden variations would stress the delicate structures of the living system. In consequence there are feedback systems which maintain the system in steady state, far from the thermodynamic equilibrium. When internal conditions change, then the possibility exists to return in the previous condition.

1.6. Emerging structures

In the earliest phases the system develops slowly, then processes of self-organization are accelerated. The order of the system is steadily growing. The attractor may drive the system to increase biodiversity or biomass. Bifurcation is possible. The system is exploring its space of possibility. Main structures emergent in the ecosystem are light cascade and food chain.

The light cascade – receptors (see 1.4) are contained in the basic photosynthetic unit: leaf. Here the complete process takes place: energy input, biochemical transformations, water and carbon dioxide supply, synthesis of glucides. Leaves are ordered in a multi-layered system which gives account for the optimal light absorption: light energy flows from the upper layers to the lower ones and is progressively captured by the photosynthetic system. Species having leaves in the upper layer are adapted to elevate light intensity, species in the lower layer are adapted to shadow (the "light cascade" effect); a selection takes place: this is an anti-entropic process producing accumulation of order and self organization. .

Food chain - Vegetation is producing biomass. At the end of life processes this is organic matter. The chemical composition establishes a gradient *organic matter / environment*: this is subject to the law of maximum entropy and struggle to reach thermodynamical equilibrium, in this process some energy is liberated which can be used for further work. This energy is captured by organisms other as plants: (1) saprophytes (bacteria and mykota), and (2) herbivores; the transfer progresses and other organisms appear: (3) carnivores. By each link of the chain only 10 % of the energy is transferred, the rest is dissipated; at the end the whole energy is dissipated in the space as low temperature heat.

1.7. Transition to chaos

In general there are sufficient feedback to avoid the transition to chaos. This implies to stop the processes of order accumulation. Such feedbacks are in general ineffective when system works in condition of low constraints, and then the system develops to chaos. The order stored in the system is dissipated. Chaos is mostly thought as something negative. In the study of complexity, deterministic chaos is devoid of any sense of value: it is an unpredictable condition. This means that the plant community as a self-organizing system, runs in recursive cycles which produce the transition to chaos: in general this is a consequence of the condition when energy is largely available, e.g. in the tropical forest or in strongly eutrophied systems; a particular case is the synanthropic vegetation, where a rapid dynamics is given by the influence of man's rationality. In general, plant communities behave as a structure ad the edge of chaos.

1.8. Vegetation in a classical view of the world

In the classical concept proposed by Braun-Blanquet and developed by his scholars, vegetation is composed by species and develops in space and time as a consequence of laws of general validity: this is the *floristical-statistical approach*. Indeed, species are abstract concepts proposed by arbitrary procedures; the significance of space and time is limited by relativistic physics and by the principle of indetermination prohibiting to measure in the same time with infinite precision both structural and functional parameters; in addition, the basic laws for vegetation were never defined. Consequently, the representation of vegetation as a phenomenon coherent with the conception of nature in classical Physics has to be updated.

1.9. A NEW PARADIGM

As a consequence of the general conditions regulating life, it is now possible to propose a new paradigm for vegetation science, based on relationships more than on the presence of invariant species. Vegetation appears as a material component consisting of plants, organized in a system, working in the condition far from the thermodynamic equilibrium. The system, interacting with the environment, produces non-linear processes of self-organization, increase of biomass and biodiversity. The consequence is the emergence of structures in its spatial architecture, in species composition etc.; these result from self-organization processes and can be described by means of artificial groups of plant individual and plant populations with similar eco-morphological and eco-physiological adaptations, better than with the formal concept of crystal-like species. The new paradigm can be summarized as follows:

Vegetation is a self-organizing system, working in the sense of accumulation of order (eliminating internal entropy) and producing structures emerging in a world of pure relationships, with the general aim to reach the optimal limit for the colonization of the Earth's surface.

This formulation derives directly from the general axiom quoted in the foreword, stating that vegetation is organized in communities: now we examine where this organization results. In fact, this is the consequence of the process of self-organization, which is inherent to the nature of the system "vegetation". Organization derives from the accumulation of order, which is possible using the Sun as the energetic source. Vegetation science is the study of this organization; it is the study of a living system in steady change and transformation.

The concept is now possible of a vegetation cover in the world, which results from historical and contingent processes of self-organization rather than to be imposed by an absolute and pre-existent general law.

PRINCIPLES OF VEGETATION SCIENCE - A ATTEMPT SUMMAR

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SOME SELECTED ARGUMENTS

2.1. Destruction of gradients

In the present time condition, the universe is full of gradients: matter and energy have discontinuous distribution defining gradients; most important for life is the energy gradient between the center of the Sun (with temperatures of 2.5 x 10^{10}C°) and the Earth surface (0-40 °C). There are gradients of energy, gradients in concentration of chemical compounds, pressure etc. Indeed, the system has always the tendency, following the II Principle, to eliminate discontinuities and gradients and reach the complete uniformity. This is the condition of equilibrium at the maximal entropy, corresponding to the destruction of gradients. The transformation towards equilibrium develops energy, which is suitable to perform work. This energy is used by the living system. In this sense, life is the result of the destruction of gradients, or it is possible to point out that the living system is struggling gradient destruction.

The life phenomenon depends strictly on the energy flow on Earth, which maintains the system in the condition of thermodynamics far from equilibrium. As a consequence, the process of self-organization is possible and there are emergent structures and an accumulation of order in the system:

- at the species level: morphology of plant individuals
- at the ecosystem level: vegetation as an emergent structure.

From the treatment of the preceding chapter it is clear that vegetation is not only an assemblage of plant species, but can be interpreted based on a global view of the energy flow. Vegetation is an essential point in the process of order accumulation in the biosphere. In consequence, it seems necessary to give a more complete definition.

Def.: *Vegetation is the emergent structure of the ecosystem resulting from the self-organization processes of plant individuals and plant populations under the selective influence of environmental factors. The ecosystem works in dependence on the energy flow generated by the Sun, conserving a condition far from equilibrium.*

The study of vegetation belongs to ecology. Since in vegetation different components occur (individuals, populations, species, life forms), but in general they are perceived at the level of different species, two different approaches are possible: to consider the occurring species separately (autoecology) or to consider the community as a whole (synecology). On these problems there are accurate formulations by Whittaker (1967) and Austin and co-workers (1985, 1989, 1994a, 1994b). In origin both theories were considered as alternatives "The concept of vegetation as a continuum with changing species composition along environmental gradients arose in antithesis to the community-unit theory which stated that plant communities are natural units of coevolved species populations forming homogeneous, discrete and recognizable units" (Austin, 1985), but in recent years they are more and more formulated as complementary approaches not excluding one another: in order to have a satisfying knowledge of vegetation it is always advantageous to combine both visions.

2.2. The continuum concept

Is based on the distribution of species along an environmental gradient, The range of the species can be represented with a bell-shaped curve (with the aspect of a gaussian, but with different meaning). In the theorization by Austin (1985, 1989) several possibilities exist: two of these are the regular sequence of species (resource-partitioned continuum, fig. 1c) and the disordered condition (individualistic continuum, fig. 1b), which are to be investigated using the autoecological approach. This approach has advantages and limits. Every species has its peculiar curve of distribution along environmental gradients and the possibility that many species have exactly the same distribution (as in fig. 1a) can be excluded; in addition, working with single species it is possible to eliminate much noise that makes the interpretation of results difficult. Indeed, as pointed out by Austin (1985) "the hypothesis that species are randomly distributed with respect to environmental gradients constitutes a null model": and in our opinion, this model is not falsifiable and seems not adequate to construct a scientific theory. In fact, in a successive paper Austin (1989) proposed different and more complex models of species response curves.

In accord with Austin and Whittaker (ibid.) two limits in gradient analysis have to be pointed out:

- the pseudo-gaussian model for species distribution along linear gradients is an abstraction which can hardly be applied to any set of experimental data,
- linear correlation implies the assumption that between environmental factors and species response a deterministic relation exists: there is no place for complexity.

On these problems important experimental research has been done by Ellenberg (1953, 1954), supporting the conclusion that the physiological optimum of the species (resulting from monoculture experiments) is not corresponding to its optimum when exposed to natural conditions of competition.

2.3. Community theory

Is based on the hypothesis that species are distributed non-randomly. In the original model proposed by Austin (1985, fig. 1a) the curves of all species are completely coherent, but this representation is not corresponding to the empirical results, at least for plant species, and can be easily falsified. A more realistic model is given in fig. 1d as resource-partitioned continuum within strata, which can also represent the conditions illustrated by Ellenberg (l.c.). Community is a condition of relative overlapping of species with different physiological responses under the pressure of competition. Such overlapping effect is evident in the real landscapes, where "co-occurring groups of species can be recognised for any particular region with a recurrent pattern of landscape", and consequently "community is a landscape property" (Austin, 1989). In this sense, the difference between autoecological and synecological approaches seems to depend mainly on the scale adopted for the investigation: "the continuum concept applies to the abstract environmental space" as effect of a large scale survey in very homotonous environments, whereas community concept is a function of the landscape. It is not by chance that phytosociology arose just in such highly diversified contexts as the alpine and mediterranean environment. If community is conceived as an abstract unit, species combination can be considered as a process of self-organization.

Self-organization

Under natural conditions every living system has the tendency to grow (see 1.3); vegetation, as a living system grows, because its components (plant individuals, plant species) grow. The process of growth produces self-organization, which results from production of new cells, new individuals, new structures and occupation of space. Self-organization in the ecosystem consists in the growth of biomass and biodiversity as an ordered whole (see 1.3e-1.3f). Growth is regulated by external (ecological) factors, which in a general sense may be included into two sectors: the climatic envelope and resources. Organization results at three levels:

- organization in space (Chapter 4)
- organization in time (Chapter 5)
- integration of informational niches (Chapt. 6).

Competition, niche, r/K selection

As pointed out under 1.3, competition is the consequence of the condition of steady growth, which is given for every living being. Competition occurs when two or more organisms grow, so that their ecological spaces overlap. In vegetation, competition is among different individuals of the same species and among different species living in the same space. Braun-Blanquet distinguishes concurrence on space (if a space is occupied by a plant, it is not available for another) and competition on resources, mostly nutrients in soil; there are also other conditions of competition, determined by the direct action of an organism on another, e.g. saprophytism, parasitism, grazing, predation; an important form of ecological relationships among different plants is produced by the flow of solar energy through the different vegetation layers (the "light cascade" effect, 1.6). The consequence of all these forms of competition is the selection of the fittest species and the selection of the fittest plant individuals. Competition is a mechanism of natural selection, acting as a constraint, but which is the essential factor for evolution; systems with strong constraints have in general elevate biodiversity.

In the case of concurrence for space, life phenomena are placed in a geometric (euclidean) tri-dimensional space. Competition for resources, on the contrary, is based on a more elevated number of factors, always more than 3 factors, each acting as a dimension of the system, and in consequence phenomena are to be interpreted in a multidimensional space. In the case that competition is among different organisms there are very complicate relationships (for a theoretical treatment see Maynard Smith, 1974; Austin, 1989).

Such relationships can be described in space (e.g. access to the water table by the root system) or in time (different resources for the different periods of the year) or as multiple relationships among vicariant organisms (predation, epiphytism, pollination): every organism can define its own niche, which results from the natural selection, as a highly multidimensional hyperspace (tab. 2.1).

TABLE 2.1. : RELATIONSHIPS OF CONCURRENCE AND COMPETITION IN THE ECOSYSTEM

concurrence for space	3 dimensions	geometrical (euclidean) space
competition for resources	>3 dimensions	ecological space (multidimensional)
competition among organisms	n dimensions	niche (hyperspace)

As a consequence of natural selection a "theory on strategies" was proposed by animal ecologists (Mac Arthur & Wilson, 1967; Pianka, 1970): it is possible to distinguish two different strategies:

r-selection: organisms of small size and rapid life cycle, producing a very numerous progeny (e.g. mice, flies),

K-selection: organisms of large dimensions, long living, with few offspring, protected by parental care (e.g. elephant, whale).

The concept of niche was developed mainly by zoologists and includes nutritional and behavioral aspects, which are own of animals. Following Grime (1985), at least with some adaptation it can be applied to plants. Species typically r-selective are most pioneers, e.g. (in Europe) *Polygonum* gr. *aviculare, Poa annua, Melilotus, Eruca, Diplotaxis, Stellaria* etc. Examples of K-selection are oaks, with seed germination around the basis of stem, which can be interpreted as a form of parental care. Indeed, such relationships are very complex: e.g., Orchidaceae produce many seeds but are to be included among K strategists because of their complicated pollination behaviour. Plants describe their "informational niche" (see Chapter 6), resulting from the geographical and ecological distribution of the species.

The plant community

Environmental gradients are of quite different nature: the fundamental light gradient, which is basic for photosynthesis, and then: chemical gradients (humus, nitrogen, other nutrients or toxic substances), mesoclimatic gradients (elevation), microclimatic gradients (exposure), water etc. These gradients are available for the needs of organisms; but every organism has the tendency to become specialized on a relatively narrow range of ecological factors, describing its ecological niche. In consequence, every organism can use only a part of the life support offered by the environment: the utilization is complete only when more organisms live together, in a condition which can be defined as the *integration of ecological niches*. This is the result of natural selection in the frame of micro-evolutionary processes ruled by the general tendency to growth and expansion (1.3) and to utilize ecological gradients. This is a fundamental process of self-organization, and the consequence is the plant community as an organized whole (fig. 4).

The attractor of the system corresponds to the condition when the number of participating organisms is as high as possible, so that the system can exhibit a maximal functionality in steady state, because of the optimal utilization of available resources. In this sense, biodiversity is directly depending on competition, at least under normal conditions (this will be further discussed under 2.6). Only extreme ecological conditions (near the limit of tolerance for a toxic factor, e.g. magnesium on serpentine rocks, sodium chloride near the sea) can produce a biodiversity shock and only few or one species is in the condition of surviving.

The plant community can be interpreted with a rather complicate flow diagram. The main condition is the energy gradient and final dissipation, but in this case two important feedback have to be emphasized: buffering and organizing. At the base of buffering is the natural tendency of vegetation growth, as indicated in 2.

There are two distinct *buffering* effects:

(1) Stem elongation is producing a stratification in vegetation: the upper layer is directly exposed to sun light and to thermal and water stress, but the lower layers are more and more protected; microclimate inside of vegetation is more temperate as outside (and this even in the case of herbaceous vegetation).

(2) Production of organic matter increases biomass, and at the end on the life cycle this organic matter is transferred to the soil, transformed in humus, and improving the conditions of growth of the surrounding plants.

The effect on *organization* is the phenomenon of integration of spatial niches described above. Integration is progressing as a consequence of continuous selection of the fittest and as long-term processes of evolution.

Buffering and organization are changing the conditions of the plant community.

There are strong homeostatic mechanisms, which maintain the community in steady state, but with continuous fluctuations (the "carousel" model, van der Maarel, 1990). Otherwise, variations over a certain threshold are producing phenomena of succession in vegetation, which will be discussed in the following chapter (5) on vegetation in time.

2.4. The climatic envelope

Vegetation is composed of plants, living at certain sites and strongly adherent to a substrate: they do not have the possibility of autonomous movements to other places when environmental conditions become unfavorable. In consequence, there is an obvious link between vegetation and the climate of the surrounding area. This link may be very strong or relatively weak: in general the dependence on the climate is maximal for undisturbed vegetation (climax or climax-like), whereas vegetation submitted to strong constraints or vegetation growing under conditions of buffering are relatively independent from climate (see fig. 3). In any case this is a "one way" influence: climate is affecting vegetation, but vegetation can have only little influence on climate, mainly as buffering function of microclimate; the climatic effect can be interpreted as an "envelope" for vegetation (Box, 1996, 1997); on these relationships we return in Chapter 3.4.

2.5. The soil/vegetation continuum under temperate and cold climates

We discussed the consequences of growth processes in vegetation. Let us consider now the problem of sinks. Organic matter, at the end of life, is deposited in the soil. Under conditions of temperate or cold climate, organic matter is stored in the form of humus. Also in this case a process of self-organization occurs, with the transition from raw humus (directly derived from dead plant material) to Mull, after bacterial

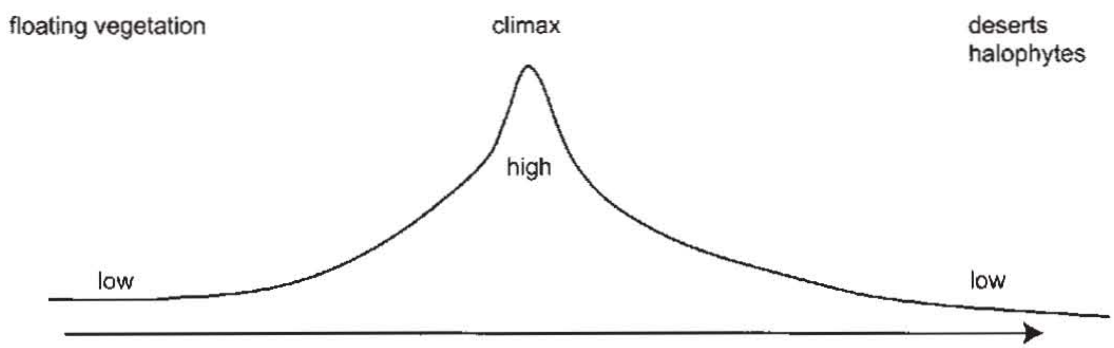

Fig. 3 - Dependence on climate of vegetation structures. Close relationships exist mainly for the climax vegetation developing in mesic environments. Under extremely moist or arid conditions vegetation is lesser dependent from climate.

fermentation, digestion through micro-organisms and saturation with cations. The presence of Mull is a powerful contribution to ecological buffering of the environment. It is clear that, at the end of the process, this organic matter will become completely oxidized and dispersed in the atmosphere as carbon dioxide, available for new photosynthesis, but it is possible that the transformation of this material may be complete only in a very long time and organic matter remains layered for geological times (this was often the origin of deposits of fossil fuel). In fact, world is divided into decomposition vs. accumulation climates, depending on relative rates: under tropical climates e.g. the process of recycling is in general very rapid and only a small portion of the organic matter is stored in the soil.

Humus originates mostly from plant material and derives only in little part from animals (a proportion of 10-100:1 seems reasonable, sometimes even 1000:1). In soil, meteorological events distribute humus in different layers, where organic matter is directly deposed (the A horizons) or transferred (the B horizons of podzolic soils): these layers are important for the functionality of roots and plant nutrition. In conclusion, under conditions of temperate and cold climates plants modify soil structure with the deposition of organic matter resulting from growth and soil is modifying the growth conditions of plants: this is a strong feedback. The *soil-vegetation continuum* is the basic feature of the plant community and the level of integration produced by the process of self-organization. At least in the temperate and cold regions of the world and in tropical mountains, it is impossible to have a complete knowledge of a plant community without taking into consideration the soil. Under warmer climates the organic matter is directly available for metabolic processes and a direct feedback links the dead material with the biological component.

2.6. Morpho/functional complementarity

Growth processes are producing increase of biomass or increase of biodiversity (see 2). Lets now consider this process more in detail. In both cases energy and matter have to be supplied. Biomass consists mainly of matter, but energy is necessary for the production of organic compounds; in consequence, the growth of biomass is given by the synthesis of carbohydrates, fat and proteins, requiring many resources such as carbon compounds, nitrogen, and water. On the contrary, growth of biodiversity consists mainly in modifications of sequences in polynucleotide macromolecules (in DNA), and results are practically at "zero cost" in material resources, only requiring energy resources. As pointed out in Pignatti & Trezza (2000), this is a fundamental bifurcation in the dynamics of the system. In a condition of large availability of material resources, the system is driving to production of organic matter and the attractor is quantitative growth; further intensity of energy flow can produce chaos. On the contrary, systems in the condition of scarce material resources and with relevant constraints but with sufficient energy supply are driving in mainly deterministic way to the production of highly structured compounds, and the attractor is qualitative growth. Available resources can be used for the one or the other task, but not for both in the same time. The *Principle of Morpho/functional Complementarity* can be expressed as follows: *biomass and biodiversity are complementary aspects of the same process, therefore it is impossible to increase both in the same time.*

3. VEGETATION ANALYSIS

3.1. Structure in space, fractal geometry of stratification

The basic structure in vegetation is the distribution of the vegetable mass in space. This is not only a problem of spatial structures, but also of functional relationships. The simplest vegetation examples, as some crusts of cyanobacteria, form a mono-cellular film on barren rocks and here every cell is submitted to nearly identical conditions. With progressing complexity vegetation is becoming more and more dense and vegetative conditions on cells directly exposed to light irradiation differ from those of the lower strata: vegetation is differentiated in separate layers. This is a fundamental symmetry break and eventually cells of the different layers change in structure and function, or even different organisms occupy the different layers. Herbaceous vegetation is formally considered as mono-layered, but in fact there are consistent differences between the ecology of the upper and the lower parts. With increasing complexity of the vegetation, stratification becomes a main structure, influencing biomass and biodiversity.

Vegetation layers are mainly the consequence of the penetration of light through the leaves. In a forest, light energy is first filtered by the tree canopy, then by shrub foliage, then by herbs and so on: the energy flow (and the dependent photosynthesis) are determined by the density of the superimposed vegetation layers. In this sense, the energy flow through vegetation can be considered in analogy of the food chain in ecosystems.

Maximum complication is reached in the tropical rain forest with up to 5-6 vegetation layers.

The spatial structure of vegetation can be interpreted at two levels:

bi-dimensional (surface) – the notation "*Cynodon dactylon* 2.2" means that this species is covering a certain surface, and in fact, photosynthetic structures develop as surface.

tri-dimensional (space) – the notation "height 12 m" means that trees are tri-dimensional, and in fact, vegetation layers develop as spaces.

But vegetation is not only bidimensional, and at the other extreme is not completely tridimensional; it is something intermediate: a *fractal geometry*. In accord with Mandelbrot a general tridimensional *wrapping* (container) and *filling* (vegetable material in its natural order) can be distinguished.

The fractal structure is dependent on the field created by a general force (in this case: gravity) and on constraints; plants adapted to the optimal condition to utilize natural resources.

General forces
the light cascade (photonic flow) – for energy transfer, active on photosynthetic structures – flat (dimension 2)
gravity – for traslocation of matter (water, starch, growth substances), organizing stems – volumes (dimension 3)
Constraints:
thermic energy – insufficient in cold climates
water – insufficient in dry climates
nutrients – insufficient in barren environments

3.2. Detecting plant communities

3.3. Vegetation complex

3.4. Remote sensing

Already in the earliest examples of vegetation cartography, the identification of the different plant communities was made from an outlook; later, after World War II, accurate air photographs were available, with the possibility of stereoscopic vision. Such photographs have been a big help for vegetation cartography, but always with man as an intermediary: the botanist carried out his experience in the field, drawing a sketch of the map, then observed the air photograph and gained information, mainly to improve the limits of the different communities. The real breakthrough is the possibility to use satellite data, e.g. Landsat, which were available since the '90ies with records in different wavelength. In this case, information is given in discrete units (pixels) that can be treated by automatic methods and clustered to compose units with the same spectral trace: such units are supposed to correspond to vegetation types. In the '80ies, a pixel had a surface of over 100 x 100 m, too large for the description of single plant communities, later the power of resolution was improved (30 x 30 m) and now there are further improvements, so that the surface of a pixel is inferior than the surface of most plant communities. On the basis of remote sensing the cartography of large geographical surfaces appears possible.

Table 4.1 : Self-organizatio n at the different scales

Scale	*biomass*	*Biodiversity*	*complexity*
Ecotope	vegetation layers: trees – shrubs – herbs etc. integration of spatial niches	specialization of taxonomic groups	the "light cascade"
Topography	selection of ecological groups	species density in different sectors of the landscape floristic inventories	catenary links
Geography	life forms (from Raunkiaer to Box)	Chorotypes	information entropy along a climatic gradient

The importance of remote sensing consists in the fact, that in the previous experiences, vegetation first is perceived by the human eye and processed in the brain, and then a process of conceptualization takes place. The procedure is governed by man and it is not possible to exclude a certain subjective component. Now the entire process is carried out by automatic sensors and elaborators and only software is implemented by man. Results in both cases are largely comparable. This is a direct demonstration, that plant communities are not only a creation of the investigator.

TAB. 5.1 – SELF-ORGANIZATION IN TIME

Scale	*Biomass*	*Biodiversity*	*Complexity*
at the species level	swarms of annuals	adaptations to tidal conditions	pollination ecology
Community level	increasing biomass in the succession resprouting after fire germination after rain	decreasing biodiversity in the succession seasonal variants	syn-phenology on plant communities seed germination in forest gaps
Interactions plant-animals	fodder for herbivores, grazing	microevolution (e.g. *Ophrys)*	interactions geophytes-insects in deciduous forests
Biomes		evolution of the synanthropic flora in the mediterranean post-glacial speciation	

4. SELF-ORGANIZATION IN SPACE: LANDSCAPE AND TERRITORY

Vegetation exhibits a process of self-organization in space in dependence of ecological gradients: these are gradients of light, of chemical compounds (water, nutrients) and of climate and represent the most effective examples of symmetry break for vegetation. Light is falling more or less in the vertical and is filtered from the chlorophyll layers; in consequence vegetation becames organized in different layers (cfr. 3.1.3) at the ecotope scale. Water and nutrients are governing the catenary distribution of vegetation in the topographic scale. Climate is responsible for the continental distribution of vegetation (geographical scale).

5. SELF-ORGANIZATION IN TIME: FUNCTION AND TURNOVER

Vegetation is self-organizing and this process has the consequence of a continuous transformation (1.3b), indicated as *succession*. In phytosociological literature the succession is mostly indicated with arrows as a linear process, but, in fact, self-organization is progressing with recursive cycles, and its dynamics too is cyclic.

Def.: *Succession is the developing in time of a plant community into another when self-organizing processes are directed to increasing complexity.*

5.2. Succession

Once one of the authors (SP) was in a tourist resort on the coast of Thailand, sitting in shadow with a cold drink; some cubes of ice were floating on the surface of the liquid. With the drinking straw he pressed the ice on the ground, but ice every time escaped the straw and returned to float on the surface. Indeed, SP was fascinated by a parallel: also vegetation first has its place and stays in the climax, then man destroys it (pressing it to the ground) but, after the action is finished vegetation returns in time again to the climax. Now, the force driving the ice to the surface is clear: gravity (in fact it is not driving the ice *above* the liquid, but driving the liquid *below* the ice, but the effect is the same): what force is driving the vegetation? With this simple experiment we can approach the problem of vegetation changes in time.

Succession: cyclic versus linear - The traditional representation of succession is a series of communities following one another to the climax, e.g. in the primary succession on limestone in the Alps:

Thlaspietum → Caricetum firmae → Seslerio-Caricetum sempervirentis→ Caricetum curvulae

This is a strong simplification, reducing this process to his more visible aspect, i.e. the sequence of communities with different species composition: intermediary phases don't appear. In this scheme the most significant place is the final one: the climax; here the process stops. Variations are possible at each stage of the succession, only the climax is certain. This is a teleological description implying a finalistic interpretation of the whole.

In fact, the driving force of the succession is not finalistic, it is the turnover of organic matter in vegetation, operated by Sun energy through photosynthesis: this process is continuous and based on recursive cycles. There is no place for teleological implications. It represents the natural condition of vegetation in the stages occupied by the different communities, as well as in the intermediary stages and in climax. In consequence, succession is a cyclical phenomenon (as most subsystems of the living system) and cannot be interpreted as a linear series of events. Some components and phases of the succession can be pointed out:

Attractors
Bifurcations
Bootstrapping
Dependence on the initial conditions – Imprinting
Transition to chaos

5.3. Exploration of attractors

Most of the changes in vegetation can be interpreted as exploration of attractors. The system maintains itself far from the equilibrium, but it remains reactive to processes of self-organization. The system is moving towards an attractor, but not as a direct transition; it is approaching the attractor slowly and following some complex and mainly impredictable trajectory. In theory, there are different possibilities, e.g. the system can describe a spiral in the space of phases, slowly approaching the final point of equilibrium, or the system can exhibit a cyclic behavior and rotate around the attractor, describing more or less irregular loops steadily repeating with minor variations; under particular conditions the transition to chaos is possible. A more concrete example of exploration of attractors is the role of pioneer trees in the forest succession: in the pristine forest of Bialowieza (Poland), after severe grazing, the mixed deciduous forest regenerates exploring first the option *Salix caprea*, as described by Falinski (1998), and then with the expansion of other, "harder" trees, later remaining as the definitive dominants. Similar pioneer (Vorwald-Arten) are *Acer pseudoplatanus* in Central Europe and *Betula papyrifera-Populus tremuloides* in Canada; they play an important role in the improvement of soil conditions.

5.4. Nutrient cycling

5.5. Natural potential vegetation (NPV), climax

5.6. Dissipation of order

5.7. Fire, grazing

5.8. Forest cycles

5.9. Global changes

As pointed out by Lovelock (1988) vegetation is interacting with the atmosphere producing variations of the glasshouse effect and changes in the global climate Under normal conditions, the atmosphere has a low content of carbon dioxide (ca. 100-180 ppm) producing a low glasshouse effect: as a consequence the climate is markedly colder than in the present time and the ice-cap expands over the northern hemisphere. Such conditions for the circumboreal countries have been considered as "glaciations"; water remained immobilized as ice above the continents, the sea level was 100 m lower than at present, and the consequence was the emerging of a surface nearly as large as Africa , mainly in SE Asia: in the tropical regions this produced a huge expansion of forests. The self-regulating system maintains a dynamic condition which guarantees a steady state at low temperatures: (a) ice and snow reflect the thermal radiation (geophysical feedback) and more carbon dioxide is sequestrated in the biomass, and maintain a low level of glasshouse effect in the atmosphere (the biological feedback); "*the glacial cool is the preferred state of Gaia*". This system is "inherently unstable" and in consequence of astronomic events (the Milankovitch's cycles) a heating process eventually starts. The consequence is an increasing sea level, then reduction of the biomass, carbon dioxide is liberated in the atmosphere, glasshouse effect too is increasing and global temperature rises to the present time values. Under such conditions there is an intense flow of sulfur compounds from the oceans to the atmosphere and this is producing increased condensation of clouds, reflecting the thermal radiation: a new self-catalytic process of cooling starts. The interactions in the system atmosphere – oceans – forests are an amazing example of self-regulation at the global scale.

The global change of the present time has to be shortly discussed from this point of view. The natural condition of the Earth is a cool climate, with transitory phases of heating (like fever in the human organism); but the hot climate was an essential factor for the development of civilization. Our social equilibrium depends on stable climatic conditions, which warrant for elevate crop production and a rich natural vegetation. Presently the environment is mature for the start of a new glacial era: and just under this condition man manipulates the level of carbon dioxide (as a consequence of use and misuse of combustibles) increasing the glasshouse effect and producing more global heating. The consequence will be the expansion of deserts, forest decline, increasing sea level. This is a process in contra-tendency with the natural evolution of the biosphere and consequently a period of dramatic instability may begin. These reflections are a reason for deep concern.

6. BIODIVERSITY

What about phytosociology if the Earth were occupied by only one type of vegetation? In fact, probably in the earliest phases of life on Earth this was just the situation, probably only one type of methanogenous bacterium was diffused on the Earth surface, then, in consequence of evolution, a second species appeared: this was the fundamental symmetry break, probably followed by more and more species. Later, the first photosynthetic cell appeared, and this was the second dramatic symmetry break, then animals: another symmetry break, then terrestrial plants, and so on. The presently biodiversity consists of 1 million of vegetal species and possibly 10-20 millions of animals.

Def. – *Biodiversity is the whole of structures and functions produced by living systems in order to obtain the most efficient use of material and energetic resources. This is result of a process of self-organization (in space, time and information) at the level of organisms, species and communities.*

Biodiversity is the source for vegetation, and vegetation (as a component of the ecosystem) is the context where biodiversity can develop. Biodiversity can be perceived at different levels: Flora, Life forms, Chorotypes, Polyploidy, Invasion, Insularity, Seed bank, Dispersal, Population analysis

6.1. Flora

6.2. Life forms

6.3. Chorotypes

6.4. Polyploidy

6.5. Invasion, Insularity

6.6. Seed bank, dispersal, population analysis

7. SYNTHESIS

7.1. Methods for typifying vegetation

7.2. Land cover cartography

7.3. Data banks, expert systems

7.4. The law "Gesetz der bedingten Standortsabhängigkeit"

Table 7.1 : Phases of succession to organize vegetation classes

Start Imprinting	Linear Growth	exponential growth	Emerging structures	Transition to chaos	Chaos

7.5. Vegetation history, evolution, coevolution

7.6. Vegetation Systematics, Syntaxonomy

Classification is a practical need to bring order among a very diversified information. As a matter of fact the system is a artificial one and everybody can propose its own system. In phytosociology every community has a name (just a label, like chemical compounds) and different communities have different names. Associations are ordered in alliances, orders and classes, but can also be ordered in a different way, e.g. in alphabetical order. Only in alphabetical order *Abietetum* stands near *Acacietum* and very far from *Fagetum*, then the need for syntaxonomy.

To construct a classification every character may be used. In plant systematics the first system was proposed by Linnaeus, and successively others by De Candolle, Engler, Taktadjan etc., always with large differences. There is not a system which is true and another one wrong: proposed systems are only more o lesser useful. The original system by Linnaeus was based on the number of stamens and consequently for the student it was possible to read directly on the flower to what class the species belonged. In spite of this useful aspect, it is now abandoned because of other incongruences. Syntaxonomy is somewhat similar, because still examining a vegetation stand, from the presence of indicators (character species) it is possible to identify the syntaxon to which the community belongs. With time probably also syntaxonomy will be substituted by new criteria, like the Linnean system.

Vegetation taxonomy starts with classification and ordination and today this can be carried out with automatic methods. It is easy to create classes in vegetation, basing on the different species combinations. In the last decades a large quantity of taxonomical units has been published, but with little success, because of the fact that presence/absence of species have only descriptive significance. There is an infinite number of possible combinations, and consequently infinite classes can be defined. The attempt was made to circumscribe such classes by means of introducing other information, e.g. ecology and chorology. Indeed, the system remains arbitrary.

This frame was called syntaxonomy, meaning "taxonomy of communities", but a true taxonomy should be based on the paradigm giving an interpretation of the system (e.g. for taxonomy of species this paradigm is the evolutionary model of plant and animal species). The mere specific combination is not a paradigm, and consequently, what today is called syntaxonomy is nothing more than a arbitrary classification. Indeed, it is useful because it is possibile to read directly in vegetation to what class the community belongs (like as in linnean taxonomy).

The paradigm of the self-organizing system is a useful basis for a more advanced taxonomy of vegetation. As a first step the different phases of the succession have to be defined. They correspond to the phases of evolution for a monophyletic group of species. Every vegetation class corresponds to a particular phase of the succession. It is possible to distinguish 6 phases that are indicated in tab. 7.1.

For a causal interpretation of the vegetation classes, not only their position in the succession is relevant, but the contribution to the process of self-organization. It is important to point out the presence of constraints, which can be represented by the presence of particular chemical compounds in soil (e.g. sodium chloride) or by extreme climatic conditions. Basing on these aspects it is possible to have an outlook on the relationships between different vegetation classes, considering their floristic composition only as a lesser significant character.

7.7. Filogenesis of vegetation

8 – VEGETATION-BASED ECOTECHNOLOGY

All activities of the human society are embodied in some form of the environment. In its earliest phases of culture man was completely dependent from the environmental resources. With the neolithic revolution man learned the possibility to drive the biological component of the ecosystem (the plants through agriculture and the animals through pastoralism) in order to obtain larger resources. In the densely populated areas (the Mediterranean, Middle Orient, India and China), the rural development imposed over millennia a deep re-structuring of the environment, indeed a degree of compatibility was preserved, mainly because of energy limitations. In modern times the human society developed the technology to obtain a complete transformation of environment. Presently humans are mostly living in a completely artificial medium, including their homes, cities, and cars. Indeed such containers can be used only for short times, and man has the necessity to return from time to time to the contact with natural forms of life. Vegetation remains the necessary interface between man and environment. From this need derives the necessity to develop new forms of technology, which can be indicated as Ecotechnologies.

As ecotechnology we understand environmental soft technologies, which can be used for a better partnership between the living component of the ecosystem and man. Plants are in general the principal living component of the ecosystem, based on surface area occupied, volume, biomass, energy flow and biological production; consequently an essential part of all ecotechnologies is based on vegetation. In this context vegetation can be considered as capital which is essential to maintain correct relationships between man and environment. When technology is applied to transform a habitat and use it for human purposes, the surface is subtracted to its natural status, and this capital is simply destroyed. But technology is not necessarily destroying, and it is possible to imagine forms of technology which can help a better compatibility of human needs. Ecotechnology is the use of environment friendly technologies, with the following main tasks: **Ecomonitoring, Conservation, Landscape planning, Bio-engineering, Ecosystem management, Rehabilitation, Biosphere restoration.**

Vegetation, as a complex self-organizing system, is adapted to work remaining far from equilibrium. Human impacts have in general the objective to drive the system (or some subsystems) in a condition differing from full naturalness, and man acts on the external parameters in order to obtain the desired change of the system, suppressing homeostasis and feedback. The system is organized from the external intervention and looses the capacity of self-organization, at least in part and consequently the system is a regression to a condition close to equilibrium.

The aim of applied vegetation science is to manage the simplified system, increase the storage of information, increase complexity, and possibly to restore the condition of self-organization.

INVITATION TO COLLABORATE

In this draft manuscript the authors, after long experience in the study of real vegetation, propose the new idea of self-organization as the paradigm for the scientific investigation of plant cover. Self-organization may represent a basis for fundamental research as well to confront the dramatic problem of biosphere depletion. This is only a basic concept, and it remains to develop this in a coherent theory. Several points can be improved and gaps can be filled. This cannot be the task of only three authors, and other competence is needed. We invite to propose collaboration in order to produce, in a reasonable time, an expanded statement of these ideas.

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