The Official Journal of the International Association for Landscape Ecology, Chapter Germany (IALE-D)

Landscape Online

International Peer-Review Free-Access Online

Received: 30.08.07 Received in revision: 03.12.07 Accepted: 01.04.08 Published: 17.08.2008

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Landscape Online 6, 1-12 . **DOI:10.3097/LO.200806**

From Ecosystem Ecology to Landscape Ecology: a Progression Calling for a Well-founded Research and Appropriate Disillusions

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Abstract

In this paper, 1) a delineation of main theoretical, methodological and applicative issues of landscape ecology, 2) a comparison between landscape and ecosystem ecology, 3) a critical overview of actual limits of landscape ecology, are depicted. We conclude that: a) from a theoretical viewpoint, ecosystem and landscape ecology differ since they deal with ecological topics having very different spatial and temporal scales, b) from a practical standpoint, they deal with dissimilar purposes emerging both from unlike research scales and different approaches, as the interest of landscape ecology is mainly focused on the whole ecological mosaic rather than on single components, in this view assuming an "horizontal" ecological perspective, c) transdisciplinarity is still a work in progress in landscape ecology, d) several research purposes in landscape ecology are far from being reached, e) a bridge lacks between the "horizontal" perspective adopted from landscape ecology and the "vertical" approach distinctive of ecosystem ecology, therefore, they actually behave as detached disciplines. However, in our vision, landscape ecology contains the seeds for becoming a self-contained scientific discipline as well as the interface among the distinct sectors of environmental research and planning.

Keywords:

Landscape Ecology, Ecosystem Ecology, Issues In Progress, Research Challenges

1 Introduction

1.1 Motivation

After a descendent phase, coinciding with the exponential growth of the research in population and community ecology, the ecosystem approach has acquired new vigor. Various research lines contributed to this trend, stimulated by the diffusion of a more vital attention to the goals of the protection and conservation of natural resources and, at the same time, by the growth of an urgent need to better define criteria and methods, indicators and procedures for an environmental planning inspired by principles and objectives of sustainability. One might think of the raise of adaptive management experiments linked to the promotion of long-range monitoring programs (Norton & Steinemann 2001, Gregory et al. 2006) or of the success of Costanza's ideas on evaluating, in monetary terms, the natural capital that ecosystem functions and services represent (Costanza et al. 1997, Farber et al. 2002).

On the other hand, the reappearance of ecosystem ecology as pivotal discipline in environmental analysis revealed non-marginal elements of fragility concerning both the theoretical basis and the practical value of this approach. The progress of the scientific research, which in last decades has been consistent and significant in Italy as well, brought to our attention serious knowledge gaps within areas of primary interest (e.g., population and community dynamics, functions linked to the microbial loop, key mechanisms for regulating cycles of material, relationships between functions of the ecosystem and biodiversity), revealing the substantial inadequacy of models that, for a long time, appeared promising also for their transfer to applications. The reluctance of aquatic communities to adhere to the assumptions of the trophic cascade theory and to the results expected from top-down bio-manipulation practices may be remarked as a pivotal example (Gliwicz 2005). Some authors (Belovsky et al. 2004) wrote about the transience of the theoretical constructions of ecology and the occurrence of fashions which, from time to time, attract ecologists.

The spread of the scientific research aiming at a) conserving environmental integrity, b) analyzing various types of impact on biodiversity, c) restoring degraded areas, d) applying and validating methods and models for protective environmental management, has inevitably transcended the level of ecosystem research, and large-scale studies on population biology and ecology have been deeply developed with important results and, above all, extensive investigations at the landscape scale were experimented with positive outcomes (Roy et al. 2000, Zurlini et al. 2004). In this view, the ideas promoted by Holling (Holling et al. 1998, Holling 1998) on the need for an integrated science of the conservation in support of a sustainable development appear to have been successful.

1.2 Goals of the paper

Many recent experiments concerning the interaction between ecologists of different extraction (e.g., geographers, city planners, landscape architects) evoked new and stimulating questions, and helped define landscape ecology as an emergent approach for dealing with integrated large-scale ecological processes (Antrop 1998, Leitao & Ahern 2002). In this view, the evidence for a renewed vigor of ecosystem research and the concomitant diffusion of awareness about limits and delays still afflicting it led us to reason about the actual consistency of the shift of theoretical and methodological suggestions from the ecosystem scale to the landscape level.

In particular, we seek to answer three questions:

1) is there a bridge between ecosystem and landscape ecology, or they should be considered detached, even if complementary, disciplines?;

2) is landscape ecology actually answering the need for an effective scientific transdisciplinarity in ecology?;

3) can landscape ecology drive the challenging process of intermixing the different sectors of environmental research?

2 From ecosystem to landscape ecology

Landscape as a scientific subject, conceptualized by Carl Troll (Schreiber 1990), is a particular level of organization in the hierarchy of life, i.e. a mosaic of ecosystems (or ecotopes) sensu Forman & Godron (1986). When enlarging the view from one ecosytem to a mosaic of ecosystems, various topics emerge (Forman & Godron 1986, Forman 1995) :

a) a global ecological perspective replaces a more local one; the "inside-outside" metaphor shared by ecosystem ecology is substituted by the contextual view proposed by landscape ecology; no internal or external environments really exist, but a mosaic of systems separated by structural boundaries where the outside of a system is the inside of another;

b) man and anthropogenic areas become an essential and endogenous constituent of the research area rather than external agents as they are usually handled in ecosystem ecology; towns, industrial areas, quarries and so forth are conceived as "human ecosystems" and they are studied through the same methdological and conceptual instruments as natural or semi-natural ones;

c) the functioning of the whole system (landscape) becomes predominat with respect to its components (ecosystems); how individual ecosystems work is not of primary importance as their functioning is mainly determined by the surroundings;

d) landscape is revealed as a complex system in which heterogeneity, non-linearity and contingency are the norm. Emergent properties, phase transitions, and threshold behavior characterise the landscapes since they are the outcomes of nonlinear dynamics of spatially heterogeneous ecosystems.

As discussed below, these topics involved new theoretical and methodological paradigms when compared to those inherent in ecosystem ecology.

The meaning of contemporaneous holistic landscape ecology can be fully perceived only in the broader context of the post-modern scientific revolution (Kuhn, 1970). This revolution started when new conceptual schemes replaced those of well-established paradigms of the conventional science. Such a conceptual change replaced the blind trust on entirely linear and deterministic processes with non-linear, cybernetic and chaotic driving forces. In the holistic perspective we can expect that by putting the elemental parts of complex phenomena together conceptually or experimentally, the whole both with its complex functions and structures will emerge (Mandelbrot 1982).

Landscape ecology is also closely related to hierarchy theory (Allen & Starr 1982) whose basic paradigm is the hierarchical organization of nature with multi-leveled stratified open systems, ranging from sub-atomic entities as the smallest natural entities, to universe as the largest. In this hierarchical organization, each higher level acquires new emerging properties and it is therefore more complex than lower subsystems. Moreover, higher levels are functionally and spatially more constant over time and thereby they also serves as the context for lower levels. In addition, the functioning of each system is given by its lower sub-system, while the purpose is given by its super-systems.

Transdisciplinarity is another prerequisite in landscape ecology (Musacchio et al. 2005). In fact, when facing the increasing complexity of environmental topics, landscape researchers have to venture frequently into other fields, even if for limited periods of time, thus implying a "come-and-go" between disciplinary and transdisciplinary approaches. The previous paradigms (holism, hierarchic teory and transdisciplinarity) were first proposed during the 1960s (Buckley 1967, Klin 1969, Steiss 1967), but they were then neglected throughout the successive 2 decades, at least from a methodological and applicative point of view. Landscape ecology first retrieved these conceptual schemes during the 1980s (Forman & Godron 1986) and tried to implement them into methodological tools and operative models.

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Does landscape ecology actually serve these paradigms in a competent manner? If so, can landscape ecology be considered a detached, despite complementary, discipline with respect to ecosystem ecology, or does a bridge exist between these disciplines? To answer these questions, a brief and comparative overview of the theoretical, methodological and applicative aspects of landscape and ecosystem ecology is required.

From a theoretical viewpoint, ecosystem and landscape ecology can be compared along time and space dimensions (Fig. 1). Undoubtedly they deal with different spatial extents, as landscape ecology generally involves areas from hundreds to hundred thousands of hectares. Sometimes these areas correspond to administrative limits (e.g. provinces, regions, seldom municipalities), more often they match natural boundaries such as a single watershed or groups of watersheds. These extents represent land mosaics with hundreds or thousands of ecosystems and the focus is mainly on the mosaic rather than on single ecosystems. As the spatial window is so wide, the spatial resolving unit is logically inversely correlated, being 1:50,000 and 1:25,000 scales the most common resolutions in landscape ecology. On the contrary, ecosystem ecology privileges micro- (1:1,000) and meso- (1:10,000) scales.

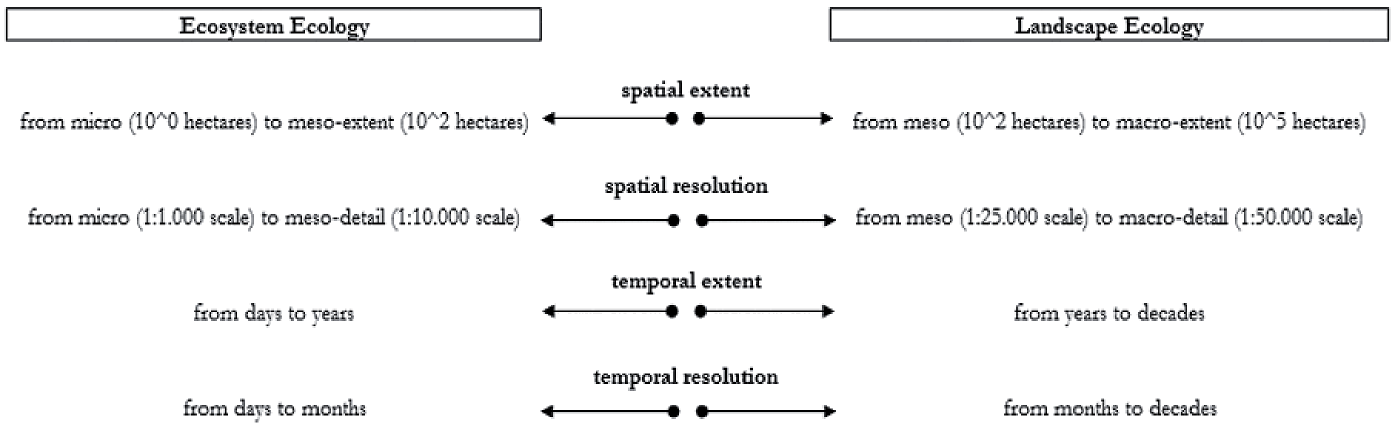

Figure 1: Schematic comparison between ecosystem and landscape ecology along time and space dimensions.

Temporal scales are different too. Landscape ecology privileges wide temporal extents (years or decades) with coarse resolution, as the focus is on processes having broad wavelengths. In fact, according to the hierarchy theory, higher levels of life organisation bear a lower frequency behavior.

From a methodological point of view, ecosystem and landscape ecology actually show both similarities and divergences (Fig. 2). Both disciplines use GIS widely, while remote sensing is much more common in landscape ecology as it gives a synoptic view of large areas of landscape where ecologists rarely visit. Ground truth is thus an essential divergence between ecosystem and landscape ecology, since the former is usually based on in situ surveys while the latter makes heavy use of remote information, such as satellite images. Statistics is common in both disciplines, but ecosystem ecology privileges univariate methods, while landscape ecology favours multivariate ones. This discrepancy is based on the fact that the landscape ecologist attempts to observe very large areas where environmental processes are due to multiple factors that act simultaneously and interactively. His interest is not focused on testing inferential hypotheses, but mainly on building overall descriptive models of the landscape functioning. The use of spatial statistics (geo-statistics) is also different: in ecosystem ecology geo-statistics is frequently used to analyze point and linear (transect) data coming from samplings of the study area; on the contrary, landscape ecology privileges areal statistics, such as moving window analysis or landcover pattern analysis (e.g. Olsen

 ISSN 1865-1542

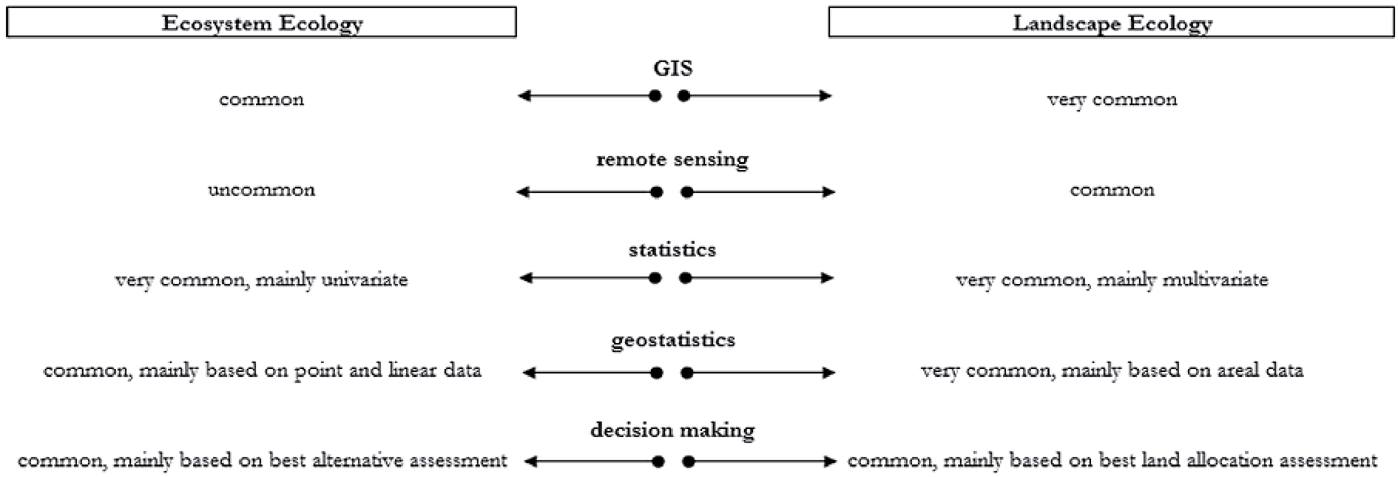

Figure 2: Schematic comparison between ecosystem and landscape ecology with respect to methodological issues.

et al. 2007). Decision making is common in both disciplines but, as for statistics, the current use is rather different: the ecosystem ecologist is more interested in the best scenario assessment, while the landscape ecologist is usually concerned in best allocation estimation (e.g. Geneletti & van Duren 2008). From an operative standpoint, the topics faced by landscape ecology during last ten years are various (Tab. 1).

Some of these topics seem distinctive of landscape ecology, such as landscape multiscalar (Riitters et al. 2000; Zurlini et al. 2006) and structure (Gustafson 1998, Bartel 2000) assessment, landscape planning (Leitao & Ahern 2002, Lenz et al. 2006), land use change (Cousins 2001, Hietel et al. 2004) and forecasting (Lopez et al. 2001, Sui &Zeng 2001). Other issues such as ecological flows (Adriaensen et al. 2003, Morales et al. 2005), scenic perception (Parsons & Daniel 2002, Palmer, 2004), human impacts assessment (Saunders & Briggs 2002, Sukopp, 2004), decision making (Phua & Minowa 2005; Svoray et al. 2005) and species suitability (Miller et al. 1997, Riitters et al. 1997) appear to be the same as for ecosystem ecology, even if applied to a different hierarchic level.

Nonetheless, when describing the characteristics of landscape ecology, it should be noted that landscape ecology has developed two distinct approaches that, although not mutually exclusive, have led to some jumble about its scope. The European tradition of landscape ecology often emphasizes the role of humans and their activities, being aligned closely with land planning: its focus is mainly anthropocentric (Opdam et al. 2002). However, landscape ecology also encompasses the causes and consequences of spatial pattern at variable resolution scales as determined by the organisms or processes of interest, thus reflecting the traditions in North America and Australia (Turner 2005). The two approaches are both contrasting and complementary (Wu & Hobbs 2002). The North American school undoubtedly pays more attention to quantitative and methodological topics, while the European approach is more qualitative, rarely relying on complex algorithms for the analysis, modelling and simulation of the landscape. As a consequence, the European school focuses on arguments that are "softer" from a methodological viewpoint, such as the assessment of the visual quality of landscape and its psychological effects on people (Krause 2001, Lange 2001, Arriaza et al. 2004).

We repute that the primary difference between ecosystem and landscape ecology is the contrasting approach: landscape ecology applicative interest is almost entirely focused on the mosaic of ecosystems rather than on single components, in this view assuming a "horizontal" ecological perspective. Single components of the landscape are virtually viewed as a part of the whole mosaic, thus no interest is given to them individually. In

ISSN 1865-1542

Table 1: A list of the most common arguments faced by landscape ecology during last ten years. For each subject, two significative references are accounted.

Arguments	References
landscape structure assessment	Gustafson 1998; Bartel 2000
landscape multiscalar assessment	Purtauf et al. 2005; Zurlini et al. 2006
land use and land cover change	Cousins 2001; Hietel. et al. 2004
land use and land cover forecasting	Lopez 2001; Sui & Zeng 2001
species suitability at landscape level	Miller et al. 1997; Riitters et al. 1997
ecological flows at landscape level	Adriaensen et al. 2003; Morales et al. 2005
human impacts at landscape level	Saunders & Briggs 2002; Sukopp 2004
landscape scenic perception	Parsons & Daniel 2002; Palmer 2004
decision making at landscape level	Phua & Minowa 2005; Svoray et al. 2005
landscape planning	Leitao & Ahern 2002; Lenz & Peters 2006

this view, the holistic approach is actually met in landscape ecology. On the other hand, ecosystem ecology assumes a more "vertical" viewpoint, since spatial and temporal boundaries are narrow and the "research volume" is mainly given by the deep knowledge of single ecosystems.

3 Landscape ecology: limits and disillusions

Holism in landscape ecology is undoubtedly observed. Many works show the integration of environmental, social and economic spheres over larges study areas (e.g. Ferrarini et al. 2001, Wiggering et al. 2006). A risk we perceive in these studies is that the horizontal perspective (i.e. different scientific and disciplinary points of view) may become overloaded with respect to the vertical perspective (i.e. the use of a deeply-probed single discipline of investigation). Holism cannot be the disposition to know a little about many disciplines, moreover developing activities at interdisciplinary interfaces, such as linking the hard sciences to the social ones, must be based on specific and precise disciplinary skills. Our feeling is that this risk is actually present in landscape ecology but it is not overwhelming, since holism's limitations are well-known from many years to the scientific community. Rather than a trivial use of different scientific spheres, we observe that the actual risk of holism in landscape ecology is the moment in which these disciplines become integrated to determine the final outcomes about, for instance, landscape planning. We repute that the convergence point is the weak ring of the scientific chain claimed by holism, since individual disciplines follow their own paths up to the moment in which they are integrated, thus risking a collision instead of a compounding. In this view, multidisciplinarity seems to be the rule in landscape ecology rather than transdisciplinarity.

In effect, we think that transdisciplinarity is still a work in progress in landscape ecology (Bastian 2001). Many papers show a considerable degree of multidisciplinarity but an effective transdisciplinarity is often lacking, since transdisciplinary research requires both cross-disciplinary interactions and participation from non-academic stakeholders and governmental agencies bearing a common goal. It might not be easy to overcome the strict conditioning of the implicit infrastructure of the modern discipline-oriented academic thought that led

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to the fragmentation of science and to a fundamental collapse of communications between areas which are considered to be reciprocally irrelevant.

Furthermore, it is also necessary to get a clear idea of the disciplinary boundaries and a more unpretentious view of one‘s own disciplinary expertise. The acceptance of these scientific developments may also be hampered in landscape ecology by the tendency of many scientists to rigidly adhere to a familiar idea of “inner order“. This is especially true for those paradigms arised in a narrow-minded reductionistic, mechanistic and positivistic perception of science, ignoring the broader cultural, psychological and socio-economic issues which landscape ecology comprehends. For these reasons, scientists still retreat to the familiarity of their own disciplines when faced with problems of extreme complexity, thus making transdisciplinarity very infrequent (Allen et al. 1992).

Moreover, several other issues in landscape ecology seem far from being reached. One of these limitations has to do with the pivotal aspect of the structure-functions relationship, i.e. the ecological flows (energy, material, information, organisms) through landscape mosaic. How does landscape pattern influence populations movements or exotic species intrusions? How do changes (e.g. land cover transitions) at a particular point propagate along the landscape? How long does a barrier to species movement persist as a constraint before becoming just a friction cost?

Another limit deals with proper landscape indicators relating to ecological processes (Müller & Lenz 2006). The underlying hypothesis that processes can be inferred by structural patterns needs to be critically examined and better documented and the inherent mechanisms understood (Tischendorf 2001, Li et al. 2004). How much does a landscape need to change before a metric can detect such change? How to determine whether or not changes in landscape indicators are statistically and ecologically significant? Which metrics are most sensitive to human disturbance?

A third problem we repute very far from a satisfying conclusion in landscape ecology is the integration of nonlinear dynamics into landscape modelling. Very common models based on multivariate statistics suffers a deficiency of realism as they are nearly linear, not interactive (predictor variables act independently) and monotonic (predictor variables always act in the same direction). Instead, the integration of nonlinear modelling (neural networks, cellular automata, system-based modelling, if-then-else methods, multi-agent systems, individual-based models) should be the rule and not the exception (Lek et al. 1996, Lek & Guegan 1999). Finally, we stress the need for a sufficiently developed theory on how to optimize the landscape pattern. If landscape pattern influence landscape processes, how can we optimize the landscape pattern to regulate (i.e., turn on, turn off, increase, decrease) processes we are interested in? Or, how can we force landscape processes in order to regulate landscape structure? Which are the bottlenecks we can control to drive landscape ?

Concerning previous reflections, our feeling is that landscape ecology has mainly developed its basic conceptual references using the descriptive models of holistic ecology of the 1960’s and 1970’s, without considering their limited heuristic relevance, and perhaps strengthening a tendency to adopt ideologically even the most recent innovative contributions (e.g., evaluating ecosystem health and integrity, assessing natural capital value, testing sensitivity and vulnerability indicators on large scale). In its turn, landscape ecology transferred many crucial concepts (e.g., fragmentation and connectivity, networks and corridors) to a wide public, helping to enrich the glossary currently used by environmental and landscape planners, who however rarely are notable for the consistent application of the ecological knowledge.

Passing from ecosystem to landscape ecology, a progressive lessening of the interest for the rigor of crucial findings can be observed. The unpredictability of the assumptions about the ecosystem extends to the higher levels, thus causing an even more obvious effect of imprecision and approximation. The result is upsetting, above all with regard to semantic aspects. The abused and abusive use of theories, methods and expressions taken from basic ecology, such as “ecological functions and related services” or “environmental

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quality and related indicators", reminds us of Pantagruel on the island of the ice words which provoke a frightful confusion when melting. In addition, landscape ecology actually suffers a series of drawbacks that are diffused within ecology in general. An article by Belovsky et al. (2004) contains a series of appeals to ecologists in order to stimulate them to overcome defects and mistakes that strongly limit the effectiveness of their research.

The authors consider the integration between empirical and theoretical ecology and between natural history and experimentation to be inadequate; they complain of

a) the persistence of useless conflicts between modelers of equilibrium and those of non-equilibrium;

b) the lack of precision in gathering data aimed at creating long-term series;

c) the dependence of research on the availability of advanced technologies and methodologies made massive and pervasive by the scientific market when collecting and statistically processing ecological data; finally,

d) they point out the tendency of many researchers to follow recent fashions dedicating little attention to the literature of the past, an attitude that is favored by the mercantile drift of the publishers of international journals.

A few words about the feasibility of a "cross-disciplinary language" to improve communication within the ecological community are of absolute priority here (Buchecker et al. 2003). There is in fact an urgent need for developing landscape ecological principles and pragmatic guidelines for applications in resource management, land use planning, and biodiversity conservation (Antrop 2001). Landscape ecology should be an integrative science in which basic research and applications are fully merged. Such an integration should be mutual, i.e. research directs practical applications and applications feed back to research. We perceive some encouraging signals, such as

a) the significant experiments developed to link naturalists' experiences with those traditionally expressed by urban planners and landscape architects;

b) the gradual maturing of a new generation of administrators having a more vital scientific and cultural sensitivity;

c) the activities of several environmental associations, non-governmental organizations among them, marked by a substantial scientific awareness.

We also refer to the spontaneous aligning dynamics that follow the strategic indications and requisites involved by the latest EU directives regarding environmental protection. The initiatives of scientific societies outside universities give a healthy boost to these dynamics and help contrast the inertia and inconsistencies still widely diffused in the world of academic research. These positive signals are too weak however with respect to the opposition coming from many areas of civil society and from the worlds of business, politics and information. A strong commitment (e.g., governments, public and business institutions) is required to support qualified environmental research projects; moreover a coherent effort is needed for reorganizing the formative system (first of all, the academic system) to provide incentives for transdisciplinary experiments on which basing the preparation of a new generation of experts in environmental and landscape analysis and management (Wu 2006).

Linked to these issues, there should be a process of improvement of activities regarding environmental education and communication, as well as the experimenting of ways of public participation open to solid knowledge and real competence about pivotal environmental questions. Maybe these observations betray a disenchanted mental habit, but the dramatic size and complexity of problems about health and quality of our environments should led us to radically changed approaches in order to overcome "élite" attitudes. We should "disarrange ourselves", sensu Bateson (Bateson 1979, Manghi 2004), rethinking new possibilities for

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improving the "triangle model" based on the hypothesis of a geometry of skilled retroactions among education, research and environmental decision-making, as proposed by the American Society of Ecology (Lubchenco et al. 1991) before the Summit at Rio in 1992.

4 Conclusions

The idea of ecology as a sovereign science that synthesizes the knowledge provided by many specialized disciplines is over. Ecology cannot make it on its own, nor can an improbable coalition of hundreds of ecologists involved in autonomous disciplines. The opportunities for contaminating ecology with the learning coming from human and social sciences and from technological innovations should be fostered. Ecologists should occupy the spaces at the interface with other fields of knowledge and research, disassembling those mechanisms of closure of the disciplinary boundaries on which the ordinary functioning of our academic system thrives. This effort will not be easy for sure, but it appears increasingly indispensable. The challenge for a potential future of environmental sustainability involves deep innovations in approaches and methods, in the cultural predisposition and in the professional skills; it calls for the mental skill of understanding, analyzing and foreseeing by interweaving and integrating an extremely wide range of competences. It is clear that not only ecologists and naturalists, but also experts belonging to the most solid professional tradition in various sectors of environmental research and planning, should cooperate in this skilled integration process.

The role of landscape ecology could be overriding in this operation, because of its prevailing holistic and transdisciplinary trait. Unfortunately, several theoretical, methodological and applicative advances will be needed before landscape ecology is equipped to lead this revolutionary development. In our vision, however, landscape ecology contains the seeds for becoming both a self-contained scientific discipline and the adhesive agent among various sectors of environmental research and planning. In this view, this paper was intended to be a sincere contribution to the construction of a "cross-disciplinary language", an objective that presumes the disposition to venture into paths of auto-critical evaluation by the researchers of other disciplines as well.

Acknowledgments

Anonymous reviewers helped us improve the manuscript. We thank them all.

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ISSN 1865-1542