

# HOLISM VS. REDUCTIONISM: DO ECOSYSTEM ECOLOGY AND LANDSCAPE ECOLOGY CLARIFY THE DEBATE?

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## ABSTRACT

The holism-reductionism debate, one of the classic subjects of study in the philosophy of science, is currently at the heart of epistemological concerns in ecology. Yet the division between holism and reductionism does not always stand out clearly in this field. In particular, almost all work in ecosystem ecology and landscape ecology presents itself as holistic and emergentist. Nonetheless, the operational approaches used rely on conventional reductionist methodology.

From an emergentist epistemological perspective, a set of general 'transactional' principles inspired by the work of J. Dewey and J.K. Feibleman are proposed in an effort to develop a coherent ontological and methodological semantics.

## 1. INTRODUCTION

The theoretical debate between holism and reductionism concerns every area of study in the various scientific disciplines. The same questions are raised, whether in physics or sociology, biology or ecology. Is the way to understand an object an increasingly in-depth analysis of its components, or is it necessary to 'contextualise' it, respecting its phenomenological integrity as much as possible? In undertaking the consideration of one or several levels of integration, each scientific discipline is obliged to choose a proper approach to study.

In many disciplines, however, these questions are often put aside. In day-to-day research, the analytical method proves itself effective, leading some researchers, whose work has never been examined from an epistemological viewpoint, to treat the holism-reductionism debate as a pointless game. Nonetheless, in the field of ecology, the need for a holistic approach has been affirmed repeatedly. One purpose has been to distinguish ecology from other fields, such as genetics or molecular biology, which are commonly accused of reductionism. This is taking place, of course, in a context of increasingly sharp competition for funds.

Perhaps, however, the frequent invocation of holism by ecologists reflects more than their desire to establish a unique identity: could it be the case that, because of the nature of its subject matter, ecology has a greater need than other disciplines to imbue

the concept of holism with an operational content? If this were indeed true, then ecology could shed light, ontologically, methodologically and epistemologically, on a debate that is once again assuming great importance.

This is the central question this article will address, without, of course, pretending to be exhaustive. The first section will attempt to summarise the debate between reductionism and holism, as it has developed from the point of view of the philosophy of science. The second part is devoted to a critical review of ecosystem and landscape ecology, and examines the significance of holism in the works of these two major branches of modern ecology. Finally, several guidelines will be offered for developing a genuinely holistic approach.

## 2. EMERGENCE AND CRYPTO-REDUCTIONISM

Reductionism and holism<sup>1</sup> represent two world-views (ontologies), two epistemologies and two research strategies<sup>2</sup> that are utterly opposed. Nonetheless, these radically antinomic perspectives share the belief common to contemporary scientific models that physico-chemical processes underlie psychobiological phenomena.<sup>3</sup> The basic difference concerns their respective conceptions about the applicability of the laws of physics and chemistry to psychobiological phenomena. Epistemological reductionism assumes that these laws are fully applicable to every level of organization of the universe: ultimately all phenomena are explicable in physico-chemical terms. Emergentism tends to reject this epistemological perspective and instead affirms the specificity of the laws of a given level of integration vis-à-vis the explanatory laws of lower levels of integration. Each level is characterized by the existence of what are called 'emergent' properties, which are not fully explicable by the laws that operate at lower levels. Hence, no level of integration would have a more basic 'value' than any other. All this has direct methodological implications. Reductionism considers the additional-analysis method sufficient, whereas holism emphasizes its intrinsic limits, often by means of the well-known, but hackneyed phrase, "the whole is greater than the sum of its parts" (see Appendix).

The concept of emergence is at the heart of the holism-reductionism debate. A detailed historico-philosophical analysis would be needed to understand all the

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<sup>1</sup> It would be better to use the term 'emergentism' to denote the approach counterposed to reductionism, in order to emphasize its fundamental opposition to the latter. The term 'holism' would retain the more strictly philosophical meaning of the inter-relation or interconnection existing between the entities being examined.

<sup>2</sup> The distinction between these three analytical frameworks was first proposed by Ayala and Dobzansky (1974), then retaken up by Mayr (1982, 1988) and Amsterdamski (1986). See also: Amsterdamski (1981); for a more detailed analysis, see Bergandi (1995a). Note that the use of the term 'epistemology', *stricto sensu*, is meant to denote the epistemological analysis of the relationships between theories and laws corresponding to different levels of integration.

<sup>3</sup> There is a tendency in the scientific literature to confuse materialist emergentism with vitalism, which makes reference to super-natural principles, for example, 'entelechies' - spiritual factors which govern all living activity (Driesch, 1907) - or 'the vital force', which drives organisms to evolve (Bergson, 1905). Although both of these arise out of holistic philosophical soil, their explanatory functions are reached differently. Materialist emergentism, even while criticizing the current scientific paradigm, remains within its boundaries, whereas the vitalist currents are part of a super-natural epistemological perspective, at least in the sense that we give to the term 'scientific' today.

different aspects of this concept (Bergandi, 1995a), but here a few basic points will suffice. In contemporary philosophy, it was G.H. Lewes (1875, pp. 97-98) who was the first to propose and explain the term "emergence". He postulated that chemical compounds as well as living, biological entities were "emergents", whose characteristics could not be fully determined simply by analyzing or making deductions from their component parts. Lewes made a fundamental distinction between, on the one hand, "emergents", with their new, irreducible phenomena, and on the other hand, entities that he called "resultants". The latter resulted from the simple addition of the parts making them up, and thus their properties could be explained completely by the additional-analysis method.

Lewes' conception became a landmark, because it emphasized the need to approach reality using different methods, depending on the nature of the object studied. Nonetheless, it must be qualified as proto-emergentist, in that, even though Lewes formulated the problem of emergence in a way that has barely changed even today, he still did not develop a methodological approach that would enable research to free itself from the reductionist framework.

More recently, Bertalanffy (1952, 1968), who helped lay the theoretical and operational basis for General Systems Theory, treated emergence as a concrete feature of nature. He thus stands in opposition to other authors who view any affirmation of the existence of emergent properties as a sign that our level of knowledge is still insufficient (Hempel & Oppenheim, 1948, pp. 150-151). According to Bertalanffy, systems – organic, psychological, social – are characterized by the existence of mutually interacting elements (see also: Ackoff *et al.*, 1957; Hall & Fagen, 1968, p.81; Rapoport, 1968, p. xvii; Delattre, 1982, pp. 33-38; Rosnay, 1975, p. 93; Morin, 1977, pp. 101-102). These interactions are "strong", in the sense that they are the basis for the existence of these systems. The systems are "open", in that they are connected to their environment through the exchange of matter and energy, by means of which they maintain a "nearly stationary" state. This conceptual core of General Systems Theory has taken on the value of a paradigm for any scientific discipline that, regardless of the level of organization considered, takes a systemic approach to reality.

Bertalanffy was aware of the limits of the additional-analysis approach, and he explained that each element of a system, each event, depends not only on its own mechanisms, but also on the state of the higher order systems to which the element or event are subordinate (1952, p. 11-12). However, despite his observations about the limits of reductionist analysis, Bertalanffy himself failed to avoid the pitfall of a reductionist approach in his attempt to present an emergentist methodology:

The meaning of the somewhat mystical expression, "the whole is more than the sum of parts" is simply that constitutive characteristics are not explainable from the characteristics of isolated parts. The characteristics of the complex, therefore, compared to those of the elements, appear as 'new' or 'emergent'. If, however, we know the total of parts contained in a system and the relations between them, the behavior of the system may be derived from the behavior of the parts. We can also say: while we can conceive of a sum as being composed gradually, a system as total of parts with its interrelations has to be conceived of as being composed instantly. (Bertalanffy, 1968, p. 55; cf. also: 1952, p. 148).

Similar positions can be found in many other authors, including Simon (1962 [reprinted in Simon 1969, p. 86]; Kremyanskiy, 1968, p. 78; Laszlo, 1972, p. 5 et seq.;

Grobstein, 1973, pp. 31-33; Bunge, 1979, p. 40; 1981, p. 27; 1983, p. 126; Varela, 1979<sup>4</sup>, Dawkins, 1986, p. 13). This methodological orientation, which most authors follow in practice, reflects a serious logical contradiction: either Bertalanffy must accept that the relationships between the parts give rise to 'dynamic transformative' functions that modify the properties of the parts and thus cause new properties to emerge at the level of the system, or he must accept that he only recognizes the intrinsic value of the properties of the parts, to which the relationships bring nothing new other than the simple effect of juxtaposition.

Bertalanffy failed to understand a point that Broad (1925) perceived clearly: an analysis of a totality or a system that only takes into account the 'relationships' between its 'parts' ultimately amounts to a mechanical, reductionist approach, which only considers the subject of study in terms of its constituents from lower levels of integration. Broad stigmatized the reductionist nature of this kind of approach, which Gerard (1956, reprinted in Buckley, 1968, p. 53) also understood, in these terms:

...the characteristic behavior of the whole could not, even in theory, be deduced from the most complete knowledge of the behavior of its components, taken separately or in other combinations, and of their proportions and arrangements in this whole (Broad, 1925, p. 59 and p. 63).

According to Broad, a system must be considered in its own right (1925, pp. 64-65, 74). Similarly, Alexander, another author inextricably linked to classic emergentist thought (1920, vol. I, p. 46), emphasized this when he pointed out that an emergent property from a specific level is rooted in lower levels of integration, but, at the same time, it is representative of a new level which has corresponding specific laws, a point of view which is characteristic of epistemological emergentism (see also Thom, 1984, pp. 166-167) (cf. Appendix).

A conception very similar to that of Broad has been proposed more recently by Ashby, an author who, together with Simon (1962, 1968), gave a very clear exposition of the core concepts of cybernetics. According to Ashby (1956, pp. 53-54), the concept of "feedback", which is obviously useful whenever considering a system composed of a limited number of inter-related elements, is inappropriate and useless when the inter-relationships between the constituents become more complex. Even in a system consisting of four inter-related elements, useful information can only be obtained by treating it in its totality. Thus, according to cybernetics itself, the complexity of the interactions within a system makes it impossible to dissect the system to determine its properties: a system is not equal to a whole constituted exclusively by the parts and the relationships among the parts, at least once a certain level of complexity has been reached.

Not long thereafter, in view of the difficulty of studying complex systems, Simon (1969, p. 86) proposed an apparent compromise between holism and reductionism, which he presented as "pragmatic holism": once the properties of the parts and the laws governing the relationships between the parts were known, then it would become possible to make inferences about the properties of the whole, even if this were not easy. This in fact amounted to a form of methodological reductionism (cf. Appendix).

In the effort to define a truly emergentist approach, it is crucial to grasp that the positions of, among others, Simon (1969), Varela (1979) and Bunge (1979, 1981,

<sup>4</sup> The 'autopoietic biological systemism' of Varela, even though characterized by an obvious rejection of epistemological reductionism, winds up methodologically accepting the Bertalanffian position (Chap. 2).

1983), like Bertalanffy, are not representative of a genuinely emergentist outlook. It is true that their perspective is systemic, but that is not enough. They could more accurately be termed a form of "reductionist systemism", as they incorporate an intrinsically reductionist methodology. Despite their emergentist pretensions, they are closer to a crypto-reductionism, which can sometimes be even more difficult to detect, as their professions of holism are so vehement.

Far too many authors have ignored Feibleman's pioneering work towards the development of a truly emergentist methodology in an article he wrote for *The British Journal for the Philosophy of Science* (1954, p. 61). Feibleman's ideas had a widely differing impact in the various scientific disciplines<sup>5</sup>. Feibleman postulated the necessity of taking into account levels of integration higher than that of the primary object studied (that is, the main object of research): this was because the higher level systems are necessarily involved in determining the "purposes" of the object studied, whereas the lower level systems determine the mechanisms (cf. also: Jacob, 1970, pp. 323, 328, 342-343; Salthe, 1985; Salthe, 1991, pp. 252-255; Bonabeau, *et al.*, 1995, p. 351; Mikulecky 1996, p. 189). In this sense, once emergence is considered to be an ontological characteristic of reality, then any effort to understand a system cannot be limited to simply analyzing the relationships between its constituents<sup>6</sup>.

### 3. ECOSYSTEM ECOLOGY AND LANDSCAPE ECOLOGY IN THE HOLISM-REDUCTIONISM DEBATE

#### 3.1 Ecosystem Ecology

*"The concept of ecosystem is powerful because it is holistic, emphasizing the interconnections among things and events sometimes distant in space and time"* (Burns, 1990, p. 193). This statement is unambiguous. In the article's conclusion, the author even points out the significant role the ecosystem paradigm could play in the future of humanity:

The ecosystem concept and paradigm thus offer a hope of an enlightened public and a holistic Ecology for tomorrow. Most ecologists already recognize the concept of ecosystem as being central to their discipline, and citizens all over the world are beginning to understand the ecosystems of the biosphere of which they are an integral part. Through this holistic conception of the unitary relationship of mankind to its environment, our species has the power to alter

<sup>5</sup> For example, his ideas are explicitly dealt with in ecology by E.P. Odum (1971), and more recently by Naveh and Lieberman (1984), but so far as we are aware there is no trace of them in the writings of the followers of General Systems Theory.

<sup>6</sup> The multilevel analysis of Augier (1989, see particularly pp. 117-141), who explicitly sets himself the task of taking into account sometimes bottom-top interactions and sometimes top-bottom interactions, nonetheless proposes a hierarchically organized model of systems in which there is no role for the concept of 'emergence'. This raises two theoretical difficulties. First, there is no way to distinguish methodological abstractions based on description (for example, the levels of the individual, population, ecosystem, etc.) with a low value of reality from those which, in contrast, have a high reality value. Second, even when it is made clear that three levels of integration are simultaneously taken into account, the properties detected by the analysis are collective (for example: the mortality rates or birth rates of individuals in a population) and not emergent (see Salt, 1979).

the course of history and achieve an improved quality of coexistence, a symbiosis, with the rest of life on this planet (Burns, 1990, p. 196).

Many authors point out what they consider to be the holistic character of ecology (Odum, 1993), both in order to affirm, like Burns, that humanity belongs unconditionally to the planetary system, and in order to emphasize the uniqueness of ecology vis-à-vis other biological disciplines, which are treated, often pejoratively, as 'reductionist'. To many, the concept of the ecosystem is in one way or another emblematic of the holistic dimension of ecology. This concept formed the cornerstone of the work of the brothers E.P. Odum and H.T. Odum, the latter of whom paid special attention to the thermodynamic implications of the concept. An article criticizing the concepts of H.T. Odum (Mansson & McGlade, 1993) provoked a vigorous comment from Patten (1993), entitled: "Toward a more holistic ecology, and science: the contribution of H.T. Odum". Patten argued that, however vulnerable to criticism the technical contributions of H.T. Odum might be, his approach was basically holistic and scientific. In addition, Patten emphasized that a holistic conception of the organization of ecological systems was a prerequisite to and essential basis of Darwinian evolutionism (Patten, 1993, p. 598). But beyond such affirmations, what is the relevance of holism for actual research on ecosystems?

The concept of the ecosystem was at the heart of the work of the International Biological Program (IBP) conducted under the aegis of the International Council of Scientific Union between 1964 and 1974, with the aim of describing the structure and functioning of the fundamental types of ecosystems. At the core of this Odumian program was the conceptual approach of Tansley (1935), who coined the term 'ecosystem', and the 'trophico-dynamic' methodology of Lindeman (1942). Lindeman had proposed an economicist analytical procedure based on thermodynamics, which aimed at measuring the stocks and flows of matter and energy in the food-web of each ecosystem, as well as among the organisms involved in the network and their physico-chemical environment.

From a methodological viewpoint, this was an additional-analysis approach for which "the whole is equal to the sum of its parts". The total production of a lake, for example, was the sum of the estimates of the production of each trophic level. At each level, the theory called for determining the contribution of the species at that level, or at least the species with the most significant contributions. The species therefore had to be determined and then their production established by characterizing their density, their mode of reproduction of new generations, weight increases (of individuals) converted into energy equivalents, etc. Once an estimate of the production of each trophic level had been made, then the total production of the ecosystem would be equal to the sum of all the productions of all the trophic levels (Lindeman, 1942, pp. 402-406; E.P. Odum, 1971, Chap. 3; Duvigneaud, 1974; Ricklefs, 1990; Dajoz, 1996. Cf. also: Palka-Santini & Palka, 1997; Larrère & Larrère, 1997).

One especially typical example of this approach was the study of a savanna ecosystem by a French team taking part in the IBP program (see, for example, Lamotte, 1978, pp. 303-307, in regards to the procedure for making an overall energy assessment of an ecosystem). A trophico-dynamic analysis of the savanna was made that included an estimate of the energy flows through a 'compartment' formed by numerous small predator invertebrates, the spiders. The stages of the procedure included an inventory of species and a calculation of the overall annual flow. This gives a good illustration of the features and limits of a truly additional-analytical

approach, which required extrapolations that sometimes amounted to acrobatic feats in order to transpose the data acquired for a handful of samples to the level of a community formed by many species (Blandin & Célerier, 1981, pp. 447-483). Nonetheless, despite this kind of technical difficulty, which often leads to risky approximations, energy analysis is, according to E.P. Odum, still the central focus of ecology:

In ecology, we are fundamentally concerned with the manner in which light is related to ecological systems, and with the manner in which energy is transformed within the system. Thus, the relationships between producer plants and consumer animals, between predator and prey, not to mention the numbers and kinds of organisms in a given environment, are all limited and controlled by the same basic laws which govern nonliving systems, such as electric motors or automobiles (1971, p. 37).

It is of course legitimate to analyze ecosystems from an energy point of view. However, this can become a source of epistemological confusion when it is offered as emblematic of a holistic perspective, as does E.P. Odum at various times. He even occasionally treats the productivity of an ecosystem as an emergent property (Odum, 1977, p. 1290). Although the concept of emergent property does indeed represent an epistemological cornerstone of holism, it is difficult to treat as an emergent property of an ecosystem a characteristic that can be determined exclusively by the additional-analysis method. This is why Månsson and McGlade wrote:

The main failing... is the contradiction between the aim of applying a holistic perspective in the study of ecosystems and the inherent and far-reaching reductionism in the conceptual framework, e.g. using energy as a numeraire (Månsson & McGlade, 1993, p. 593).

It is highly likely that E.P. Odum was influenced by a methodological distinction set forth by Hutchinson in an article in 1943 (p. 152). Hutchinson proposed studying a system (S) in two ways: he contrasted the 'holological' approach ("*in which matter and energy changes across its boundaries are studied*") to the 'merological' approach ("*in which the behavior of individual systems of lower order composing S are examined*"). Of course Hutchinson would perhaps have considered Lindeman's approach holological, since the ecosystem is treated as a whole - but a physical whole and not an ecological one. In contrast, when E.P. Odum joins Lindeman's holological approach with Feibleman's hierarchical principle (1954), he is turning down the wrong path, since the first approach is reductionist whereas the second is emergentist. Nonetheless, by garbing one of the paradigmatic texts in modern ecology, *Fundamentals of Ecology* (1953, 1959, 1971), in holistic terminology, E.P. Odum has gone down in history as the pioneer of an emergentist epistemological approach to ecology, especially since his new 1971 (pp. 5-6) edition explicitly gives key importance to the work of Feibleman (1954).

Ontologically, E.P. Odum believes that the ecosystem, as the "*basic functional unit in ecology*" (1971, p. 8; 1953, p. 9; 1959, p.10), represents an element that must be comprehended in its 'totality' by determining the energy relationships between its compartments (1953, p. 89; 1959, pp. 147-148). Similarly, the way he defines population and community is also based on a typically holistic logical structure: for E.P. Odum, their characteristics and properties, including even their statistical

magnitudes, are characteristics of the whole and not of the individuals<sup>7</sup> (1953, p. 91 and 181; 1959, p. 149 and 245; 1971, p. 172 and 140). Thus, E.P. Odum's failure to clearly define the concept of emergence leads him to methodologically confuse emergent properties with collective properties that can be understood simply by using additional-analysis methods (cf. Salt 1979, p. 145; Bergandi 1993, 1995b).

From a strictly epistemological viewpoint, even if E.P. and H.T. Odum reject the reductionist perspective according to which some levels of integration are more important than others (1959, p. 7; 1971, p. 5), the pre-eminent role they assign to the energy aspect of ecosystems reflects a tendency to accept physicalist explanations rather than emergentist ones (Månsson & McGlade, 1993).

Finally, by treating cybernetic models composed of 'black boxes' in a network as "a formalized approach to holism", the Odum brothers open the door to a hyper-simplification of the ecosystem. They reduce it to the components that ensure the bulk of the energy transfers and to several supposedly key factors. Whereas reductionism aims to be exhaustive, since an understanding of all of the parts should lead to a perfect understanding of the whole, the Odumian approach consists of limiting the ecosystem to several supposedly key components, and considers an understanding of these 'principal' components to be sufficient (E.P. Odum 1971, p. 279). Since being exhaustive is an unrealizable ideal, such an approach may appear logical, but at the same time it is a 'reducing' procedure that is not without risk. The Odumian approach, which claims to be holistic, is limited to describing certain structural and functional features of an ecosystem that is reduced (in the sense of 'simplified') using a methodology that is in practice reductionist.

In the context of Odumian ecology, the ecosystem is thus above all an arbitrary, conventional, fictive construction that has no concrete spatial position – it is not truly mappable, as it has no limits, no well-defined boundaries. In fact, in the protocols for analyzing ecosystems inspired by the International Biological Program, it was generally recommended to define the boundaries of the zone for data collection while paying as little attention as possible to the visible limits of the milieu being studied. In practice, the Odumian ecosystem is a sort of methodological abstraction useful for analyzing the basic components of a system with a minimum number of components and relationships, which ideally is perfectly autonomous. Nonetheless, the representation of the ecosystem in the form of a structural-functional model is supposed to correspond to a concrete, cartographically determinable situation, and in that sense Odumian ecology has remained especially ambiguous (see, for example, Blandin & Lamotte, 1989, pp. 36-38). In fact, for ecologists who have developed programs from an Odumian perspective, the ecosystem has a concrete character. This can be seen in the definition proposed by Bourlière and Lamotte, the two organizers of the French Committee of the IBP:

An ecosystem is a fragment of the biosphere that can be considered as a relatively autonomous entity in relation to neighbouring ecosystems and which it is thus possible to analyze – and this is the basic value of the concept – in terms of its structure and functioning (Bourlière & Lamotte, 1978, p. 1).

The use of the term 'fragment' clearly emphasizes the material character of the ecosystem for these authors, who thus hearken back to Tansley's point of departure:

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<sup>7</sup> Properties such as, in the case of population, density, birth rate, death rate, and dispersion, and, for the community, species diversity, community metabolism, etc.



It is the systems so formed which, from the point of view of the ecologist, are the basic units of nature on the face of the earth.... These ecosystems, as we may call them, are of the most various kinds and sizes (Tansley, 1935, p. 299).

Thus, ecosystem ecology is torn between two tendencies, which often coexist within a single author. One, which can be considered "naturalist", treats each ecosystem as a real, discrete entity with its own 'autonomous' structure and functioning, although functional links with other ecological systems exist. The other, which can be considered as "model-building", aims to represent a category of ecosystems by a generally valid functional model, the result of a process of analysis and reconstruction that gives it a high degree of abstraction. The first trend explicitly treats the ecosystem as a concrete whole possessing emergent properties, but it has not yet proven capable of showing how to determine those properties. The second also proclaims to be holistic, however, like the first, it is marked by a typical crypto-reductionism. Whether naturalistic or model-building, ecosystem ecology has thus far proved incapable of giving rise to an authentically emergentist approach.

### 3.2 Landscape Ecology

Beginning in the 1980s, the Franco-American-Canadian school of *landscape ecology* energetically built up the theoretical and methodological core that today serves as the basis for the landscape ecology paradigm. *Landscape Ecology* by Forman and Godron (1986) plays a landmark role in this discipline similar to that played by *Fundamentals of Ecology in ecosystem ecology*. The landscape is defined as an 'ecological mosaic' composed of various types of elements linked by flows of energy, minerals and species (Forman, 1979, 1981, p. 36; Forman & Godron, 1981, p. 733; Godron & Forman, 1983, p. 21; Forman & Godron, 1986, p. 11; Forman, 1995). Each of these elements is in turn made up of a particular set of plant and animal species, associated with a particular physico-chemical context. Conventionally, there can be distinguished a category of 'patches', clearly bounded ecological structures within a 'matrix', a relatively uniform, continuous system composed of different species. Thus, a grove of trees found in a field is a 'patch' located in a 'matrix' of agrosystems.

From a broad epistemological viewpoint, the most important problem raised by landscape ecology is perhaps the development of the role assigned to the concept of an ecosystem. Depending on whether one accepts that there are concrete entities observable in nature that correspond to this concept, the question of the existence of emergent properties is posed differently.

By introducing the term 'ecosystem patch' (Forman & Godron, 1986, p. 14; see also: Shaver *et al.*, 1991, pp. 108-110), landscape ecology seems to eliminate the ambiguity in the Odumian view of an ecosystem and reinforces the empirical approach of many ecologists by treating the ecosystem as an entity with a high value of reality:

The 'patch' has achieved a central focus in landscape ecology, primarily because it can be visualized easily as a structural attribute of landscapes. The patch is identifiable not necessarily by ecosystem properties, but rather because it is different from a matrix or from another patch, that is, a patch is identifiable because there is a high spatial auto-correlation among the entities composing the patch. Nevertheless, patches defined in this way may have functional boundaries and, if so, a whole new set of principles can be applied: for example, membrane or boundary dynamics (Risser, 1987, p. 12; see also: Stolz *et al.*, 1989, p. 35; Zonneveld, 1990, p. 8).

Thus, a 'patch' is easily visualized and can be perceived in its totality. Furthermore, likening a patch to an ecosystem changes the perception of the ecosystem itself: it becomes a physical, tangible entity. In this process, the organicist metaphor of the cell membrane, used to evoke the boundaries of the patch, plays a fundamental role (Platt, 1969; Canny, 1981; Allen & Starr, 1982; Wiens *et al.*, 1985, pp. 422 et seq.; Ambrose, 1987; Johnston & Naiman, 1987, pp. 50 et seq.; Hansen *et al.*, 1988, pp. 26-28; Forman & Moore, 1992). Thus the path is clear for the ecosystem to be treated as an entity that is subordinate to a higher-order system, the landscape, just as the cell is subordinate to the organism. In this context, the landscape itself is considered to be an entity formed by elements that each might have relations with all the other elements. This entity is portrayed not only as the fundamental unit of ecology, but also as the basic unit at the level at which decisions must be made about the use of space:

As ecologists, planners, landscape architects, geographers and conservationists, we have for too long considered a landscape element as an isolated ecosystem. The manifold fluxes linking ecosystems demand a novel way of thinking. Rather than making land-use decisions based entirely upon the characteristics of a landscape element, such decisions must be based primarily upon the specific linkages that exist with surrounding landscape elements (Forman (1981, p. 45; see also: Forman & Godron, 1986, p. 528, Baudry, 1984, pp. 55 and 61).

Similarly, the concept of "ecocomplex" was introduced in order to deal with problems of land use. This term designates a group of interactive ecosystems that occupy a specific territory and that have developed over the ecological history of that space, a history in which specific historical human activity has often been an intervening factor (Blandin & Lamotte, 1984, p. 143; Blandin & Lamotte, 1988, p. 554). Hence the concept of "ecocomplex" is used to denote a level of integration, in the strict sense of the term, which is higher than the ecosystem level. The "ecocomplex" is situated within a structuralist conception of ecology inspired by Piaget (1968) and Jacob (1970), who viewed the living world as a group of structural-functional entities, "integrans", nested in successive levels of integration (see Blandin & Chapouthier, 1970, pp. 53-54, Blandin, 1975, p. 359). This conception resembles that of Koestler (1969), and assumes a priori that the entities corresponding to each level of integration have a high reality value. However, in practice, the situation is not so clear.

In asserting the need for a new approach, Forman and Godron emphasize the fact that ecosystem analysis is based on a fiction, since an ecosystem is never isolated, but interconnected with other entities of the same type. At the same time, a fundamental contradiction has appeared in the approach of landscape ecology: on the one hand, it tends to give the ecosystem a material character, by likening it structurally and spatially to a patch within a mosaic, while on the other hand it tends to dilute it within a network of interactions and flows that alone holds real significance. Ultimately, it has to be asked whether the concepts of ecosystem and landscape, even though they are only abstract, arbitrary instruments for analysis, have not unconsciously and unjustly become hypostases in the minds of ecologists?

In this context, there is particular confusion about the role of landscape ecology in the reductionism-holism debate. This is reflected in a founding article on landscape ecology, published in 1987 by Urban, O'Neill and Shugart under the title, "Landscape

Ecology”, which is one of the most frequently cited articles, alongside those of Forman and Godron. The outlook of these authors is rooted in the work of Simon (1973), Allen & Starr (1982), Allen *et al.*, (1984), O’Neill *et al.*, (1986). This work, along with others (Risser, 1987, pp. 10-11; Hansen *et al.*, 1988, pp. 24-26), asserts the central role of hierarchical thinking in landscape ecology:

As applied to landscape ecology the hierarchical paradigm provides the guidelines for defining the functional components of a system, and defines ways components at different scales are related to one another (e.g., lower-level units interact to generate higher-level behaviours and higher-level units control those at lower levels) (p. 121).

Urban and his colleagues are aware that it is not always easy to decompose ecological phenomena - some of them are said to be “nearly” decomposable (Simon, 1973) – and that the landscape is a complex unit that interacts with higher levels of integration. They explain clearly that:

We can go a long way toward understanding a complex phenomenon when we explain its behavior in terms of interactions among its parts. But understanding a hierarchical phenomenon requires more than mechanism. Understanding requires that the mechanisms be considered in context (p. 122).

However, when they attempt to concretely analyze a landscape, they only consider the elements making it up (*watershed, stand, gap*) and their interactions, without specifying what ‘context’ sets the framework in which the landscape is to be understood. In fact, the landscape is treated as a hierarchical level without a higher reference level. Finally, even though their work contains a set of principles that could form the basis of a genuinely holistic approach, the authors do not succeed in freeing themselves from an intrinsically reductionist attitude. In particular, they do not use the concept of emergence. But does a hierarchy of levels of integration that takes no cognizance of the existence of emergent properties have any real meaning?

The works of Naveh (1982), Naveh & Lieberman (1984) and Zonneveld (1990) often refer to the emergentist paradigm more explicitly, although sometimes with confusion.<sup>8</sup> However, they do not have any more success in proposing an operational holistic approach. Zonneveld (1990, p. 9), for example, is content with treating the classic cybernetic model, of black boxes and flows, as the expression of a holistic methodology. In doing so, he is merely following in the wake of Odum (1971). As for Naveh & Lieberman (1984, p. 78), their belief that productivity and biotic diversity are emergent properties perpetuates the confusion with additive properties.

Ultimately, landscape ecology runs into the same difficulties as ecosystem ecology, in that the reality values of the objects it studies are no higher than those studied by the latter. Moreover, even though it claims to be holistic, and sometimes emergentist, it turns out to be reductionist in practice: its profession of the importance of a hierarchical approach to reality and of the existence of emergent properties remains a dead letter.

Thus, despite the declarations of authors who have played a major role in the development of ecology, the discipline has not succeeded in developing a truly

<sup>8</sup> In modern times, the first to explicitly propose the holistic axiom, “the whole is greater than the sum of its parts”, was not Smuts (1926), but Ehrenfels (1890). The term was implicitly introduced into ecology by Clements (1905, 1916) and explicitly by Phillips (1931, p. 20), and not, as Naveh states, by Eglar (1942) (cf. Naveh, 1984, p. 35; Naveh & Lieberman, 1984, pp. 50 and 74).

emergentist approach. The question thus remains as to whether this is indeed possible, in which case the failure of ecology would only be temporary, or whether an emergentist approach is utopian, in which case ecology should do away with its emergentist pretensions once and for all, so as to end the reigning confusion.

#### 4. GUIDELINES FOR AN EMERGENTIST METHODOLOGY

Two basic questions are posed, as illustrated by this analysis of ecosystem ecology and landscape ecology. Can there be found in nature ecological entities that have a high value of reality and are nested in hierarchical levels of integration? Can the concept of emergent properties be given a realistic content, so that the actual identification of emergent properties becomes an instrument for identifying entities that have the characteristics of a whole and that are definitively inaccessible to the additional-analysis method alone?

To begin to answer these questions, it is useful to turn to the broader epistemological framework of Dewey's "transactional" epistemology (1938, Dewey & Bentley, 1949). This epistemology follows along the same lines as the "organism philosophy" of Whitehead (1920), but, unlike the latter, it offers an effective methodological tool. As in the case of the classic emergentist authors, its basis is a rejection of the naive realistic ontology implicit in the work of most scientists. For Dewey and Bentley, since the question of ontological reality goes beyond what can be achieved by scientific research, it must be acknowledged that the act of knowing is not independent from what is known. They both develop in the course of a never-ending dynamic process. In particular, any description must be considered as provisional, so that what is inevitably the result of a 'simplifying artifice' does not become a rigidified hypostasis in the mind of the researchers: the dynamic process 'knowing – known – knowing – known – ...' must never become frozen.

Dewey and Bentley set out a succession of three stages in the history of scientific thought, which are characterized by different ways of 'constructing' the world. The first is said to be "auto-action": the entities are analyzed as if their dynamics originated exclusively in themselves, as if they acted *motu proprio*. The second is termed "interaction": the entities, entirely defined by their intrinsic characteristics, are set against each other in relations of causal connection, which are likely to modify their spatio-temporal trajectories without, however, these interactions changing anything about the characteristics of the entities. The simplifying character of this 'staging' of scientific thought is of course open to discussion. However, the third stage set out by Dewey and Bentley, that of "transaction", brings about a very helpful change in approach: rejecting all immediate reification of research results, Dewey and Bentley emphasize what they consider the essence of scientific research: a process "...where systems of description and naming are employed to deal with aspects and phases of action, without final attribution to 'elements' or other presumptively detachable or independent 'entities', 'essences', or 'realities', and without isolation of presumptively detachable 'relations' from such detachable 'elements'" (1949, pp. 101-102). Hence, 'knowing' and 'known' are co-determined in an endless transaction. A transactional approach is thus recursively self-questioning, as the 'elements-relations' set is re-determined at every stage of the research. The work of Ashby (1956) is situated in this kind of epistemological perspective, whereas Bertalanffy

(1968) and Simon (1962, 1969) tend to be rooted rather in an interactional perspective<sup>9</sup>.

The epistemology of Dewey and Bentley is undoubtedly based on what we could call "transactional ontology": isn't cognitive dynamics merely one process among many found in nature, whose constituents are in a 'permanent correlative ordering'? In other words, transactional cognitive dynamics is nothing other than an aspect of the dynamics of life, of evolution, conceived as an overall transactional process. Transactional epistemology thus leads to constructing representations of the 'real' in which the 'relations', or, better, the "transactions", between the parts are co-determinant, co-relations, or co-transformants.

We believe that this transactional ontology, which gives full play to the epistemology of Dewey and Bentley, is capable of providing the foundations of a paradigm, that is, a set of ontological, epistemological and methodological propositions, which could be genuinely emergentist. The way that these propositions are formulated below takes into account in particular the work in the philosophy of science of Feibleman (1954) and in ecology of Urban, O'Neill and Shugart (1987), who emphasized the importance of an examination of the three successive levels of integration which, we feel, must be simultaneous.

### Ontological Propositions

\* Nature is made up of transactional systems organized in hierarchies of levels of integration. At each level of integration, each system<sup>10</sup> is characterized by one or several emergent properties that are specific to it, and are thus different from any additional characteristics that result from the coexistence of the lower level systems that make it up.

\* The systems of a given level of integration take part in the functioning of the higher level systems they are part of through their emergent properties. Reciprocally, a system of a given level contributes to the determination of the emergent properties of the lower level systems that make it up.

### Methodological-Epistemological Propositions

\* At each level of integration, the existing systems can only be interpreted by the laws corresponding to that specific level. In particular, these laws must take account of the process giving rise to emergent properties. As a result, it is impossible to limit the study of a system to an inventory of the lower level systems that make it up and their inter-relationships; such an inventory is necessary, in particular to define the additive characteristics of the system, but it is not sufficient.

<sup>9</sup> The only notable exception is that of Hills (1974; see also Phipps, 1985) who attempted to introduce this epistemological perspective in landscape ecology. The attempt was not successful. This is basically because the concept of "transaction" was identified as a particular type of relation existing between the abiotic and biotic compartments of ecosystems (Phipps, 1985, pp. 59-60).

<sup>10</sup> The differentiation between "system" and "level of integration", which may seem irrelevant or perhaps redundant, expresses a real, necessary distinction between entities that more closely correspond to reality (systems) and an abstract category or class (level of integration) that groups these entities.

\* The relations between systems of successive levels of integration have a transactional character: a permanent dynamic of co-determination exists. To understand a system of a given level of integration, at least three levels must be considered. Its own internal processes involve the lower level systems that make it up and that it conditions, while its 'behaviours' can only be understood in relation to the higher level system that it is part of and that conditions it.

\* Research must be approached transactionally, by an iterative process of 'knowing  $\leftrightarrow$  known' with the following *preliminary phases*:

1) The development of a pre-representation of the "central system studied" ( $S_{\odot}$ ), by proposing spatio-temporal limits and the main phenomenological characteristics;

2) The development of a pre-representation of the system from the immediately higher level of integration ( $S_{\ominus}$ ) that  $S_{\odot}$  is part of, which involves the 'identification' of the systems from the same level of integration that are also part of  $S_{\ominus}$ ;

3) The development of an analytical pre-representation of the systems from the immediately lower level of integration ( $S_{\oplus}$ ) that make up  $S_{\odot}$ ;

4) The phenomenological definition of the transactional processes linking the system from the intermediate level of integration to the systems from the higher and lower levels. These processes make it possible to determine the emergent properties of  $S_{\odot}$ , and at the same time give an initial picture of its functioning;

5) The determination of the transactional processes  $S_{\oplus} \leftrightarrow S_{\odot}$  that potentially are the most dependent on the transactional processes  $S_{\ominus} \leftrightarrow S_{\odot}$ .

\* In the *later phases*, research must attempt to analyze the "transactional ensemble" made up by the systems from the three levels of integration. Epistemologically, it is postulated that, as these systems each have a high reality value, they represent a "minimum transactional ensemble", in the sense that only a pre-representation using three levels of integration is likely to provide an effective explanation. Even so, developing such a pre-representation does not guarantee that the pre-representations of each system a priori provide equally thorough explanations. It is only a posteriori, during the iterative evolving process of research that they eventually prove to provide more heuristic value, acquiring this gradually through the transactional dynamic of 'knowing  $\leftrightarrow$  known'. The heuristic value of each pre-representation is thus not intrinsic, but depends on how well the pre-representation of the minimum transactional ensemble being studied corresponds to the initial reality. There will be steady progress in research if it can steadily enhance the explanatory power of the pre-representation of the minimum ensemble and of the pre-representations of the systems at each of the three levels. The problem is thus to understand how to evaluate the suitability of the structural breakdown proposed by the pre-representations relative to the actual organization of the real systems. A better solution to this problem will probably emerge when an operational content for the concept of emergent property has been found. Indeed, in accordance with the first ontological proposition, any real system must be identifiable by the possession of a particular set of emergent properties.

The reductionism-holism debate centers on the idea that genuine emergent properties are not reducible to purely additional or "collective" properties (see in particular Salt, 1979). But no determinant criterion has been proposed to make it possible to positively define an emergent property. A transactional approach to reality should lead to significant advances. We propose to define as an emergent property of the central 'system' of a study a property transactionally co-determined by one or

more systems of the encompassing levels of integration that make up the system studied. At the same time, it is co-determined by the 'system' of the higher level of integration in which the central 'system' of the study is a component. In other words, an emergent property is a process that arises from the (ontologically) intermediate system that is functionally significant vis-à-vis the specific dynamics of the higher level system. Research must thus try to detect and characterize the transactional dynamics taking place between systems of different levels of integration, i.e., the process 'coordinating' the dynamics of these systems in a reciprocally determined way.

## 5. CONCLUSIONS

Some of the works most representative of ecosystem ecology and landscape ecology propose systemic approaches that purport to be holistic, which center on the concept of emergent property. The ontological holism of the Odum brothers is one of the most characteristic examples. Taking off from the concept of the ecosystem, landscape ecology is presented as a transposition of this holism to what is more or less explicitly considered by some authors to be a level of integration that is hierarchically superior to that of an ecosystem. However, in the actual conduct of research, the ontological position is dropped: epistemologically, *stricto sensu*, researchers do their work as if they accept that the explanatory laws for a given level of integration can be analyzed based entirely on an understanding of the laws corresponding to lower levels of integration. Methodologically, they apply approaches that are based exclusively on additional-analysis. The holism of ecologists in fact amounts to a "reductionist systemism" according to which the interpretation of a system can always, and only, be sought by developing a sufficient understanding of the systems of lower levels of integration. However, the continual recourse to the concept of emergence, and more globally, of holism, clearly reflects a feeling that the reductionist approach is unable to give full expression to ontological reality. Even so, despite conceptual advances in the work of authors like Feibleman, Ashby, Allen, O'Neill or Urban, an emergentist paradigm capable of providing ecology with any real explanatory power has never emerged.

Drawing inspiration from the epistemology of Dewey, we have attempted to show the interest of transactional ontology for developing methodological and epistemological propositions capable of helping develop a genuinely holistic paradigm. Of course, these are only guidelines, which need to be deepened and criticized. But by pointing out that the fundamental fact is the existence in reality of a general evolutionary dynamic that involves co-determinant processes at every level of organization and between all these levels, the transactional approach shifts the ground completely in the reductionism vs. holism debate. In actuality, no property can be purely additional, and thus understood simply by the analytical approach, because any process that is internal to a system of a given level of integration is directly or indirectly involved in co-determinant transactions with systems from the higher level. Thus, it may well be the case that apparently collective or additional properties cannot truly be understood except by an iterative process of 'knowing ↔ known' that gradually reveals their nature as part of transactional reality. Collective properties may thus be poorly understood emergent properties. In this context, holism would become the basic way to understand reality, and no longer an utopia for scientists irrationally opposed to reductionism. If this does come about, ecologists, with their awkward

efforts to develop a consistent holism, would have laid the basis for a major epistemological revolution. And if it does not happen, then their epistemological failure would at least have had the useful result of definitively demonstrating that emergentism is a false ideal.

### ACKNOWLEDGMENTS

We are most grateful to Richard T.T. Forman and Michel Godron for their advice and useful comments.

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## APPENDIX

## REDUCTIONISM

## EMERGENTISM

ONTOLOGICAL LEVEL  
(world view)

## ONTOLOGICAL REDUCTIONISM

—maintains that all biological phenomena are based on physico-chemical entities and processes.  
 —maintains that the laws of physics and chemistry are applicable to biology.  
 —is generally in agreement with atomism (Leucyppus, Democritus, Pythagoras, Epicurus, Lucretius, Gassendi, Descartes) according to which the basis of reality is composed of irreducible and distinct atoms of a fixed spatio-temporal amplitude.

## ONTOLOGICAL EMERGENTISM

—maintains that all biological phenomena are based on physico-chemical entities and processes  
 —maintains that each level of organization requires laws appropriate to that particular level, since it is characterized by the acquisition of new **emergent properties** which increase its **complexity**.  
 —is generally in agreement with a “relational” view of reality (Holism) which can be either radical or moderate in form.

## RADICAL

—maintains that the characteristics that define the entities which make up the universe are determined by the sum of the relationships which exist between them.

## MODERATE

—maintains that the characteristics that define the entities which make up the universe are determined by only some of the relationships which exist between entities (organism, organism-environment).

**METHODOLOGICAL LEVEL**  
(research strategies)

—It is **necessary** to consider two levels of organization [i.e. the level which contains the fact to be explained (explanandum) and the level which contributes to determining the explanatory terms (explanans)].

—**At least three levels** of organization should be considered, and the modifications which determine the emergent properties at least should be monitored in real time.

**RADICAL**

—maintains that the properties of a given integrative level can be predicted from a study of its constituent parts and relationships between constituent parts (a priori reduction).

—accepts additional analysis (according to which the whole is equivalent to the sum of its parts) and partial analysis.

**RADICAL**

—considers both additional and partial analysis invalid. Emphasizes the analysis of top-down transactions.

**MODERATE**

—maintains that the properties of a given integrative level cannot be predicted, but may simply be explained from a study of its constituent parts and the relationship between constituent parts (a posteriori reduction).

—accepts all forms of analysis.

**MODERATE**

—considers additional analysis invalid, but accepts partial analysis. This must be completed with analysis of the higher level.

**EPISTEMOLOGICAL LEVEL**  
(relationships between the theories of different levels of integration)

—maintains that the theories and laws belonging to a particular level of organization may be reduced to laws belonging to a more fundamental level of science.

—disputes that there are areas of science of which other levels can be reduced.

—maintains that a transformation in any given area of science may determine changes in all others.