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Discussion Paper

THEORY AND MODEL OR ART AND TECHNOLOGY IN ECOLOGY

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ABSTRACT

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Ecology is the science of the 'house'. This paper will compare the difference between working with the 'house' in a technological or in an artistic manner and address the question of the alternative approaches to the science of ecology embodied in the terms theory and model.

It will be argued that modelling can serve to illustrate particular situations just as technology is used when building a specific house. However, modelling cannot contribute to our idea of what a house is. Such an abstraction is the art of science which advances our deeper understanding. Because of the complexity of an ecosystem, it is unlikely that we can find system properties by fitting systems together piece by piece. Such properties are more likely to be found by directly investigating the system as a whole. We therefore plead that more attention should be given to abstract theories about ecosystem functioning rather than to modelling it.

A guidance in looking for ecological theories can be the 'physics envy'. But we should not envy the physicists the accuracy of their theories, which certainly is not there all the time, but the beauty of the power in the simplicity of their theories. It is time that art and beauty become elements in ecological research as well.

INTRODUCTION

Ecology is the science of 'the house'. But how do we as ecologists relate to out house? Are we like construction engineers who mainly care about getting the house built, or like artists who try to capture the essence of the house in our paintings? Both aspects contribute to our use and conception of a house, but they do not contribute equally. Similarly, theory and model provide two

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aspects to the advancement and application of ecological understanding. The model (technology) can synthesize and apply the existing knowledge whereas theory (art) contains the analysis which can generalize and transcend existing knowledge. We will be using the term ‘synthesize’ mainly in the restricted sense of meaning putting together and not with the Hegelian implications of creating something new.

The aim of this paper is a plea for more artistry and less construction-engineering or more science and less modelling in ecology. Certainly, as the history of ecology shows (e.g. McIntosh, 1985), we are not the first to ask for more theory. However, earlier pledges have mainly been to replace empiricism with theory (e.g. Levin, 1981; Fagerström, 1987; Loehle, 1988) whereas we want to see modelling replaced by theorizing. With the everyday increasing capacity of computers and simulation programmes, modelling will soon be on every scientist’s desk. This makes it still more important to now and then stop to consider what science should be about. Our conviction is that ultimately it must be theories formalizing our knowledge.

DUALITY OF MODEL–THEORY

Theory and model form two steps in a hierarchy of explanation. The delineation between the two is not always clear-cut but the theory should embody more generality than the model, in particular with respect to its domain of explanation. The model can therefore be seen as a restriction on or particular interpretation/translation of a theory. The step from theory to model can be taken in two ways: (a) translating the theory *into* a model; or (b) translating the theory *through* a model. The first path we would like to call the *E-approach* (for engineering), and the second one the *S-approach* (for scientific). The E-approach is also frequently called ‘modelling’ and is mainly restricted to use in ecosystems ecology, whereas in population ecology the term ‘modelling’ is infrequent. Both uses of model occur in ecosystem analysis but in population ecology model is normally associated with the S-approach. A partial answer to the question: ‘Why are parts of ecology so dominated by the E-approach?’ can be that ecology has yet not severed its umbilical cord to its parent sciences. Ecology is still an endeavour to apply the concepts of these parent sciences to the universe of ecological systems.

The E-approach had its grandeur during the IBP era resulting in some gigantesque model systems where everything is connected to everything else. The main characteristics of the E-approach are: (a) low level of abstraction; (b) reductionism (an attempt to fit together an understanding of ecological systems in a piecemeal manner); (c) extensive use of computers for data analysis and numerical solutions of systems of equations. The second

THEORY

S-approach	**E-approach**
Through	Into
Means	Goal
Analysis	Synthesis
Abstract	Concrete
General	Specific
Analytical	Numerical

MODEL

Fig. 1. Characteristics of the two ways, abstract theoretical analysis and modelling, of connecting theory to model.

approach is and has been the method of physics. Since its point of departure is a mental picture, it starts at a high level of abstraction; variables are 'sorted out' at the beginning and empirical data become less important. Mathematical deduction becomes the main, powerful tool by means of which new and, many times, unexpected relationships can be derived between the variables of the theory-model complex. Art, in this context, enters at two moments; (a) when choosing the model and (b) when, in the process of deduction, making the 'right' approximations. Art in science is then intimately related to level of abstraction.

The partially reductionistic S-approach of physics is, as far as is known, the only one capable of leading to holistic synthesis: the 'primary-school-simple' Newton equations relate two, before 1660, seemingly unconnected pieces of the S-method, namely, the law of free fall of Galileo Galilei and the three laws of planetarian motion of Kepler. In constructing his 'imago mundi', Newton used deduction to derive the central force law from the equations of Kepler, but he also used art and, certainly, in its most sophisticated, quasi-divine, way.

The difference between the E- and S-approaches as defined by the words *into* and *through* might seem small, but we claim it to be fundamental and all-important. These differences are schematically outlined in Fig. 1.

Translating the theory *into* a model means that the model is the *goal* of the activity. When a theory is translated into a model it is with the aim of obtaining something that can be used for some *specific*, often practical, purpose. The model serves to *synthesize* current knowledge about some *concrete* object. Such models will normally apply only to that specific situation. These models also contain a large number of statements about relations, necessitating the use of *numerical* methods to explore the consequences of the models. Changes in model structure or parameters are principally made in order to increase the agreement between outputs from the model and data thought to represent the world the model is mapping.

Translating theory *through* a model makes the model the *means* of the activity. This is done to obtain information about the internal properties of the theory. The outcome of such exercises are checks on the consistency of the different parts of the theory or statements about relations between variables in the theory. The models used are generally of an idealized character. e.g. an ideal crystal, and do not pertain to any specific situation but try to relate to the *general*. The emphasis is on the *analysis* of the *abstract* properties of the theory. The analysis is preferentially done *analytically* and modification of the model is an important instrument to bring forward generic properties of the theory.

Since our ultimate goal in science is the synthesis (in the Hegelian sense!) of our knowledge into a theory, the central issue is rather the inverse problem of what we have discussed so far: How to go from model to theory? In a case like ecosystem ecology, where theories are of low quality and cover only limited areas of the universe of discourse, exercises with models can help to improve the quality and extension of theory (exploratory modelling; Taylor, 1989). However, it is only through the use of models in the S-approach that this can be achieved. Modelling, as well as empiricism, leads to the perception of nature as a series of specific cases, and inferring theories from the specific involves all the problems of induction (Popper, 1972). Our thesis is that, in order for ecology to reach the holistic stage of a mature science, it is imperative first to shift from the E- to the S-approach.

DUALITY OF REDUCTIONISM–HOLISM

Intrinsic to the philosophy of modelling is that in order to have an accurate description of a system it is necessary to describe all the connections within the system. Such a view is not new but can be traced far back in the history of natural sciences: "All Bodies have some Dependence upon one another, and ... every distinct Part of Nature's works is necessary for the Support of the rest; and ... if any one was wanting all the rest must consequently be out of Order." (Bradley, 1721; cited in Egerton, 1973). Yet, we believe that those concerned with the functioning of ecosystems are convinced that it is actually only a few interactions that dominate and define the system. For example, the understanding of the determinants of water and nutrient transport is a major concern in ecosystems ecology. Even deleting a majority of the species in the ecosystem could mean only small changes in these respects, although from the community point of view the system is drastically changed. Properties of this kind are what Brown (1981) termed ‘capacity rules’. It is in the search and finding of such rules that ecosystems ecology matures into a science of its own.

It is also evident from another point of view that ecosystem ecologists do not care about a large number of interactions in their systems. In only a few cases are more than one trophic level, the autotrophs, regarded. Herbivores may sometimes be included but carnivores are almost entirely left out. Although decomposition and mineralization are important processes in nutrient turnover, the biology of the detritivores is rarely central, at least not explicitly. It seems to us that the exclusion of a number of processes conforms with a hierarchical approach (O’Neill et al., 1986) focusing on a narrow range of frequencies in time and space.

The suggestion to look directly at the system level rather than performing a synthesis from the parts is not a rejection of reductionism as a philosophy. Nor does it imply a belief in some superproperties of the system (e.g. the ecosystem as a superorganism in the sense of Clements), i.e. properties not inherent in its parts, although such a perspective is sometimes suggested (e.g. Ulanowicz, 1986). It is only a questioning of the practicability of reductionism with our current understanding. It seems to us that there is as yet only one good case where higher level properties have in an extensive way been derived in a strict, formal way from lower-lying levels and that is thermodynamics derived from statistical mechanics. In all other cases higher-level properties are at best shown not to conflict with the lower-level properties.

The following example demonstrates that it is not trivial to synthesize a larger system from its pieces and infer the system properties from the properties of the parts. Consider a system consisting of two boxes, X_1 and X_2. Each box is drained by two flows following first-order kinetics. If box 1 is operating separately, it is described by the equation:

$$\mathrm{d}X_1/\mathrm{d}t = -k_1X_1 - k_{21}X_1 = -(k_1 + k_{21})X_1 \qquad (1)$$

and similarly for X_2. The time constant for box 1 is then: $(k_1 + k_{21})^{-1}$, and for box 2, $(k_2 + k_{12})^{-1}$. Assume for simplicity that $k_1 + k_{21} = k_2 + k_{12} = k$. When the two boxes operate as a system, one of the flows from each of the boxes is directed to the other box, giving for box 1 the equation:

$$\mathrm{d}X_1/\mathrm{d}t = -k_1X_1 - k_{21}X_1 + k_{12}X_2 \qquad (2)$$

and similarly for box 2. It is now easy to show that the time-constants for the system are $[k \pm (k_{21}k_{12})^{1/2}]^{-1}$. These time-constants can be very different from those of the constituent parts. Our way of looking at the whole-system behaviour can therefore be entirely different from the way we look at the parts. For example, the whole system will respond to different frequencies in the environment than will the parts. If we want to understand the system as such and derive properties that are valid at the system level, we might be better off starting directly at the whole-system level, forgetting about the properties of the individual parts in isolation.

The discussion on the relation between reductionism and holism in ecology is ongoing and likely to continue for a long time, as the reports from the symposium Holism and Reductionism in Ecology at the 4th International Congress of Ecology show (Lidicker, 1988; Flanagan, 1988; Redfield, 1988; Wiegert, 1988; Wilson, 1988). What we would like to stress in this context is the value of being able to switch between the reductionist and holistic views, but that it seems to us that the reductionist view has now been dominating ecosystem ecology for so long that progress is likely to be achieved by a shift in emphasis. This is an application of the Hegelian thesis-antithesis-synthesis scheme.

EPILOGUE

It is sometimes claimed that there exists a 'physics envy' in biology. This envy is normally directed towards the accuracy and reproducibility with which physical systems can be studied. However, we believe that envy towards physicists should be directed to another aspect. We should envy the physicist the beauty of their theories. With a very small number of very powerful theories given in very condensed statements (e.g. the Schrödinger equation; $i\hbar\, \partial\psi/\partial t = H\psi$) the physicist can start explaining the physical world. The beauty of these theories resides in the powerfulness of the simple. It is said about Dirac that his choice of equation to generalize the Schrödinger equation to relativistic mechanics was not based on any sophisticated physical argument but because one equation was more beautiful than another. We would like to see ecologists use similar criteria to guide them towards useful theories in their domains.

It is also important not to confuse mathematics with computers. Suppose today's computers had been available in the days of Kepler. How much easier had it not been for the astronomers of those days to make complicated computer programs to calculate the epicycles perceived by Appolonius, predicting, certainly with high accuracy, the movements of the planets. Tycho Brahe was astonished by the accuracy with which predictions could be made with the Ptolemaic astronomy. Would it then have been possible to shift to a heliocentric world using the simple laws of Kepler if these had been found less accurate, as is likely to be the case with, e.g. Mercury, the movement of which could not be properly explained until the beginning of this century when Einstein had developed general relativistic mechanics? This should teach us that we should not expect to reach understanding from prediction and that understanding is genuinely qualitative whereas prediction is quantitative. The failure of a prediction can be illustrative in this context. One of the most powerful predictive models is certainly the so called standard model connecting properties of elementary particles. When used in elementary particle physics it can interpret and predict the results of an enormous range of particle physics experiments (Abbot, 1988). Unfortunately, when the model is used to predict the energy of the vacuum it does it with a 'slight' discrepancy of 10^{46}! So, how safe is the sanctuary 'good agreement between data and model'?

Physics consolidated in Greece and it was beneficial that, lacking computers, the old Greeks started making mental pictures of the world. The inverse is, perhaps, the curse of ecology. There is no recipe on how to make theories (Bunge, 1967). Perhaps a simple prescription goes as: (a) develop a mental picture of the 'universe' under consideration — the problem — embracing the smallest possible number of variables (one or two); (b) deduce all the possible consequences from your theory; (c) if some deduced result contradicts some event of experience then increase the number of your variables by one; (d) repeat the process.

If we are to advance the ecological understanding, we think it is time to start thinking of ecosystem properties as such and see these as theories of ecosystems rather than trying to erect complicated model constructs. It is time that beauty gets a place also in the ecological thinking.

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