Complexity theory and landscape ontogenesis: an epistemological approach

Almo Farina
Institute of Ecology and Environmental Biology, Faculty of Environmental Sciences, The University of Urbino, Campus Scientifico – Sogesta, 61029 Urbino, Italy
Fax: +39-0722-304265 E-mail: farina@uniurb.it

Abstract: Complexity and landscape have been confronted using an epistemological approach. The complexity paradigm has been described using the Uncertainty Hypothesis (UH), the Inter-domain Hypothesis (IH), and the Connection Hypothesis (CH). The landscape ontogenesis theory that describes three main steps in landscape dynamic: novelties, opportunities and events, has been confronted with the complexity hypotheses using a probability perspective (PP), an energy perspective (EP) and a driver perspective (DP). Novelties have been found consistent with UH and PP, Events with IH and EP, and finally Opportunities are connected with CH and DP. This analysis confirms that landscape ontogenesis paradigm can be incorporated in the complexity theory, and that landscape ontogenesis represents a promising approach to investigate the complexity of meso-level systems like the landscape.

Keywords: complexity theory; ecological drivers; events; landscape ontogenesis; opportunities; probability; uncertainty.

Reference to this paper should be made as follows: Farina, A. (2005) 'Complexity theory and landscape ontogenesis: an epistemological approach', Int. J. Risk Assessment and Management, Vol. 5, Nos. 2/3/4, pp.159–166.

Biographical notes: Almo Farina was Field Assistant to the Zoological Chair at Pisa University from 1976–1979, Teacher of biology at High Commercial School, Fivizzano from 1976–1984 and Director of the Lunigiana Museum of Natural History in Aulla (I) from 1984 to 2000. During the 1990s he was Agent Professor of landscape ecology at Padua University, then Parma University and finally Venice University. From 1992–1995 he was Visiting Professor at the Mediterranean Agronomic Institute, Chania, Greece and in 2000 Agent Professor, Beirut University (Lebanon). From 2000–2004 he was an Associate Professor of Ecology at Urbino University and is now a full Professor.

1 Introduction

In recent years complexity has become a popular concept used in several fields of scientific research ranging from human to natural sciences (Arthur, 1999; Bossomaier and Green, 2000; Cilliers, 1998; Levin, 1999; Lewin, 1992; Manson, 2001; Merry, 1995; Taylor, 2001).
Complexity conceptualisation emerges as a result of an increasing connection between human systems, the discovery of chaotic behaviours in many fields of human knowledge (Cushing et al., 2003; Gleick, 1988; Morowitz, 2002), and also from the new system vision of the world (Laszlo, 1996). The widespread use of computers and their connection to a global net, allows communication (sensu Shannon and Weaver, 1949) to move close to the ‘light speed’ across the planet. Unexpected effects of such globalisation, like the economic crisis of many countries (Coatsworth, 2001), encouraged by a net of ‘selfish’ computers based decision that operates in the financial realm, can be explained only in terms of no linear, adaptive mechanisms. The lack of control of many financial processes is a signal that complexity is appearing on this horizon.

In particular, when the complexity conceptualisation is applied to the ecology, two different problems emerge: the first is represented by the definition of complexity per se, and the second is related to the context in which complexity operates. The two aspects are strictly related, but the first pertains to a philosophical realm, and the second to an experimental perspective.

As recently argued by Li (2004), the research in ecological complexity, although in recent years has made some progresses, is still at a very early stage.

Although the (bio)complexity can be observed in the structure and functions of every organism, ecological systems (sensu latu) are generally considered the best candidates to study and evaluate complexity. Every system that has no goal functions, and is outside, the logic of the auto-regulative and auto-repairing (autopoietic) machine (sensu Maturana and Varela, 1980) has ambiguous (complex) behaviour.

Recently Bradbury et al. (2000) have considered the ecosystems as complex systems but, when the chorological dimension is considered, moving from the ecosystem to the landscape realm, the complexity seems to increase (Maurer, 1999, p.24).

In particular, the ontogenetic processes, by which a landscape evolves (sensu Farina and Hong, 2004), seem good candidates to explain important characters of the ecological complexity.

The goal of this contribution is to find epistemological convergences between the ecological complexity theory and the landscape ontogenesis theory, in order to formulate a common paradigm and, in this way, to contribute to reinforcing the theoretical basis for a science of landscape.

2 The emergence of the complexity

Different hypotheses can be presented to explain the emergence of the complexity, and considering that to investigate the complexity, a plethora of mental constructs (Loehle, 2004; Wu and Marceau, 2002), ranging from neurosciences to genetic, through biological and social sciences, has been created, I have selected three hypotheses that have a very broad meaning:

1 the uncertainty hypothesis (UH)
2 the inter-domain hypothesis (IH)
3 the connection hypothesis (CH).
2.1 The uncertainty hypothesis (UH)

According to this hypothesis, complexity is a concept connected with the unpredictability of the phenomena and such uncertainty reduces the possibility for a system to couple with another system. For instance, a snow patch on the mountains of the Mediterranean region has no chance of surviving the hot summers of the present time climate, but the shape of the dissolving patch and the rate of melting cannot be predicted, for instance on a daily basis. Vegetation has no possibilities to link into a spatially explicit and co-evolutionary matrix, its growing processes with snow melting.

When a system experiences uncertainty, the information accumulated in a permanent memory cannot be applied and the possibility of ecological surprises is very high. The system moves from linear to nonlinear reactions. Uncertainty creates new conditions in which the system develops, recovers or adjusts strategies. To face the uncertainty, a system can use only a narrow range of its redundant functions. In other words, complexity means uncertainty and this creates new possibilities of stochastic arrangement of patterns and processes.

According to this vision we could describe systems like rivers or forests in terms of unpredictability. The point is whether uncertainty is connected with phenomena like species richness or turnover, and community coalescence (Tilman et al., 1996).

2.2 The inter-domain hypothesis (IH)

According to this hypothesis, complexity consists into the mechanism by which a domain (sensu Farina et al., 2004a), communicates with other domains. To do this a domain must have a code able to convert patterns and processes that have peculiar intra-domain characters. In such a scenario, complexity is represented by the mechanisms acting to assure communication between different systems (Barbieri, 2003). Codes and related mechanisms are the expression of such complexity. According to this vision complexity is the emergence of natural codes that allow a system to communicate with a system located in another spatio-temporal or organisational domain. This hypothesis is very stimulating and has been at longer adopted by many ecologists (Allen and Hoekstra, 1992; Allen and Starr, 1982; O’Neill et al., 1986). When we study the scalar relationship between systems we apply the paradigm of complexity as emergent property of the inter-system coding. Complexity in this case is a synonym of the language that connects different systems and is represented by coding mechanisms necessary to transfer energy, information (sensu Stonier, 1990, 1996) and organisms across neighbouring systems.

2.3 The connection hypothesis (CH)

The present time world is becoming more and more connected. This means that energy and information turnover are growing. This has several consequences on the homeostasis of the systems and their survivorship. It means a very rapid exchange of information among the systems and this can disrupt the insulation required by a system to self-maintaining. We recognise that connections are important for
maintaining a system, but a system exists only if self-regulating (autopoietic, sensu Maturana and Varela, 1980) units persist. If we increase connections, processes inside the units can degrade their inherent structures for too much information received and not precisely allocated, and the entire system can collapse. More information is intercepted by a system and more sink reactions are expected. The overflow of information reduces the speed of reaction and expands the possibilities of unpredictable results. Using a metaphor, we could assimilate the processes of the organising systems to the stationary movement of sea waves and the emergence of connection to the translatory movement of such waves. Translatory movements disrupt the regularity of the stationary waves. In the same way, the connection between units reduces the stationary, autopoietic state of such units, creating, in such a way, a complex unstable status (see also Ulanowicz (1997)).

3 The landscape ontogenesis

The landscape ontogenesis theory is a paradigm that tries to explain how landscapes develop structures and functions (Farina and Hong, 2004). According to this theory three main steps, that are named respectively: novelties, opportunities and events, are responsible for the structures and the processes that are recognised in the landscapes. Novelties represent the disturbance step that significantly modifies structure and processes of a system. After a novelty the system reorganises itself through opportunities. From opportunities, later, emerge the events that create the observed patchiness of the landscapes. Every step also has a different probability of occurrence, a different energy requirement and distinct drivers. These three different attributes are discussed as perspectives to interpret the ecological complexity.

3.1 The probability perspective (PP)

Probability of a certain occurrence is very low for novelties, but quite high for the opportunities. Events show intermediate values. Every process that occurs at low frequency, produces into the system a ‘surprise’ effect and this surprise means that such an occurrence is unknown by the (ecological) memory of the system. A tornado or a large flood can create surprise into the systems. Such a ‘surprise’, translated from a metaphorical language to an ecological language, means that the system has no possibilities to prevent or to accommodate the processes produced by such an occurrence. On the other side, opportunities are phenomena which are very frequent and expected by the system. The system has the necessary (ecological) memory and can, consequently, react. For instance, a viral flu is a very common disease in human societies and our immune system has all the necessary information to counterattack. Opportunities are the chance for every species to develop adaptative mechanisms. The ecological succession is strictly a process inside the ‘family’ of the ecological opportunities.

Events have an intermediate probability of occurrence. Such a probability is the consequence of the opportunity process. When inside an opportunity domain, spatial heterogeneity emerges, the borders between the incoming patches can generate a ‘membrane effect’ that contributes to further differentiating the system.
3.2 The energy perspective (EP)

Novelties occur after an extraordinary input of energy coming from outside the system. For instance a landslide or an avalanche can produce the destruction of existing vegetation at the bottom of the valley. Energy accumulated at the top of the valley is quickly released and the resistance of the entire system annihilated. It seems a general rule, that when extra energy is injected into a system, such a system reacts by a deep rearrangement of the internal structure and often suffers by such dramatic transformations. A forest can be completely destroyed by a windstorm and substituted by shrublands. The same effect is also observed when energy is subtracted. For instance a dam can destroy natural dynamics in both the directions along a river, or an artificial drainage can transform a marshland into arable fields cancelling most of the biological and ecological diversity.

When energy is transferred inside a system by interacting organisms, such energy concurs to the opportunities. In other words, opportunities are created by the rearrangement of energy inside a system. For instance, plants able to fix the nitrogen can transfer through the root system such additional nutrients to other plants. Symbiotic relationships can provide food or refuge for collaborative species.

When an energy gradient is created inside a patch by opportunities, such a gradient influences the neighbouring patches along a border that is called the ‘ecotone’. Events manipulate energy in such a way and become important processes influencing the shape of every ecological mosaic.

3.3 The driver perspective (DP)

According to this perspective, three different types of drivers are responsible of the landscape ontogenesis. At the novelty level, the drivers are external to the system; generally such drivers have a scale of action many times larger than the interacting system. For instance, a windstorm occurs over a large geographical area, many times greater than the scale at which a single tree is pulled down.

At the opportunity level, drivers that are internal to the system, have a scale very close to the scale of the system in which they operate. But, in this case, it is the number of drivers that makes the difference. A plethora of drivers act contemporarily on a local scale creating a thick net of energetic and semiotic relationships. They are strictly linked to each other. For instance, the complexity of the coral reef is the result of several organisms that are interacting using a continuous coding process.

At the level of the event the drivers are located along the ecotones and operate at an interconnecting level, linking emergent processes from both sides of the adjacent patches.

4 Connecting complexity and landscape ontogenesis

When a system is observed at a very detailed scale (microscopic view) or at a mega-scale, a universe of quasi-linear relationships appears. But if we move at an intermediate scale, linearity and predictability are vanishing, substituted by nonlinearity and unpredictability. Based on the precedent argument, a landscape can be considered a complex meso-system in which deterministic local processes
interact with probabilistic phenomena, when the scale of temporal and spatial resolution is expanded.

Landscape is not an easy subject for ecologists who must share the conceptualisation of this entity with architects, policy makers, developers, artists and intellectuals, but, at the same time, landscape has many characteristics that are favourable to testing the ecological complexity theory. In fact, landscape is both a conceptual and a physical entity (Farina et al., 2004b; Naveh, 2003), has multi-scalar properties, is easily delimited from a geographic point of view, and definitively, is a tangible entity (Forman and Godron, 1986).

After the presentation of the three perspectives by which we have formalised the landscape ontogenesis (Farina and Hong, 2004), the main question that could arise at this point should be based on the assumption if the three ways to intercept and to describe the complexity (The Uncertainty Hypothesis (UH), the Inter-domain Hypothesis (IH) and the Connection Hypothesis (CH)) might be consistent with the landscape ontogenesis paradigm, described using the three distinct perspectives (Probability Perspective (PP), Energy Perspective (EP) and Driver Perspective (DP)). In addition, as reported in Table 1, every ontogenetic step shows a selected specificity with the complex hypothesis. Novelties appear extremely sensitive to the pair UH–PP. Events show the most peculiar position in the couple IH–EP, and finally the opportunities find the more distinct attribute when CH is coupled with DP. It is remarkable that every ontogenetic step can find a paradigmatic explanation with each of the complex hypotheses, but each ontogenetic step shows more consistency with specific hypotheses.

### Table 1  Relationship between three complexity hypotheses and the landscape ontogenesis perspectives

<table>
<thead>
<tr>
<th>Complexity</th>
<th>Landscape ontogenesis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Probability perspective</td>
</tr>
<tr>
<td>Uncertainty hypothesis</td>
<td>Novelties</td>
</tr>
<tr>
<td>Interdomain hypothesis</td>
<td></td>
</tr>
<tr>
<td>Connection hypothesis</td>
<td></td>
</tr>
</tbody>
</table>

5 Discussion

The three main steps of the landscape ontogenesis are converging toward the complexity hypotheses and this confirms the value and the importance of the ontogenesis approach to study patterns and processes in the landscape. This fact seems, at first sight, too speculative, but looking closer, it is possible to see how landscapes behave under the umbrella of complexity. It seems clear that the behaviour of such systems cannot be explained using linear relationships, but that we must consider many variables. The applications of such a theory into the field of landscape management are evident.
When we consider the landscape only as a mosaic of patches of different composition and behaviour we have over-simplified the system. Landscapes are entities with a complex behaviour when considering energy, drivers or probability of occurrences. The human use of landscape, at least in the past, was based on the maintenance of stability into the spatial configurations (Farina, 2000). Today, it does happen the opposite: landscapes are frequently disturbed and change their structure and self-regulating dynamics very quickly, losing emergent properties such as redundancy and resilience. Often these changes can be classified as novelties and the repetition in a short time of such a step reduces the possibilities for the ontogenetic mechanisms to behave adequately.

Humanity is increasingly influencing the ontogenesis of landscapes by introducing extra energy from fossil fuels and extra information from digital nets. This excess of energy and kinetic information (sensu Stonier, 1990, 1996) has no possibilities to be converted in structured information and degrades quickly into an entropic status, as argued by Rifkin (1981). However, other human-induced disturbances are more subtle and hidden, like the modification of process timing that alters the probabilities of occurrence of phenomena or reduces the role and functioning of drivers.

Research in landscape ontogenesis seems a promising field that conjugates the complexity paradigm with the more advanced vision of the landscape science. This opens epistemological perspectives up to a better understanding of the intricate nature of the ecological processes, under a context of growing uncertainty.

References


