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THE FOREST AS A COMPLEX BIOLOGICAL SYSTEM: THEORETICAL AND PRACTICAL CONSEQUENCES

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The first point of the "Manifesto for Systemic Silviculture" is examined. The concept of complex adaptive system is analyzed within the current scientific debate and theoretical and operational consequences in the field of silviculture and forest management are discussed.

The "classic paradigm" in natural resource management has treated population, community and ecosystem dynamics as if they were functioning in a static environment following predictable trajectories. The last decades of the 20th century have seen the birth of hypotheses on ecosystem functioning that have evidenced that they are complex systems, characterized by nonlinear and unpredictable changes and modifications. Systemic silviculture and management, by considering the forest a complex and adaptive biological system, integrate these assumptions into analysis, methods and operational procedures which are coherent with this concept. With systemic silviculture, management proceeds following a co-evolutionary continuum between human intervention and the system's reaction.

It is concluded that a cycle is over, that of the forest considered as an instrumental entity which can be managed according to predefined models to answer specific aims: history has clearly shown that over two centuries of efforts to make forest ecosystems predictable have transformed forests into plantations and silviculture into tree cultivation for wood production.

Key words: systemic silviculture; complexity; forest management; command and control approach.
Parole chiave: selvicoltura sistemica; complessità; gestione forestale; comando e controllo.

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THE FOREST: MUCH MORE COMPLEX THAN WE THINK

The first point of the Manifesto for Systemic Silviculture states: "The forest is a complex biological system and, like all living systems, it is an entity with intrinsic value and rights which must be protected and maintained".

I will briefly examine the concept of complex adaptive systems in the current scientific debate: my aim is to concentrate on the logical connections between the new complexity paradigm, theoretical aspects and operational consequences in the field of silviculture and forest management. I will try to analyze one question in particular, i.e. the fact that in the complexity paradigm forecasting power is weak, particularly at the stand level. I believe that this is the most difficult change to accept because of the reductionist and mechanist imprinting which characterizes our education system in general and the forestry paradigm in particular. In my opinion, this is also the crucial point to the debate on how both natural and socio-economic systems will react to the anticipated climate change and what we need to do to confront this change.

Until most of the last century, natural resource utilization has referred to what ecologists have termed the "classic paradigm" (MEFFE and CARROLL, 1997). This paradigm has treated population, community and ecosystem dynamics as if they were functioning in a static environment that follows predictable trajectories. Scientific interest has concentrated on defining linear laws that regulate relationship between birth rate, death rate and somatic growth (HILBORN *et al.*, 1995). According to this view of reality, until exploitation rate does not exceed regeneration rate, the resource will not be consumed and we do not need to worry. Thus, within this static and linear view continuity of production depends on the possibility of predicting regeneration rate with great accuracy.

Coherently with this paradigm, silviculture and forest management have considered the forest as the sum of individual trees which can be organized spatially and temporally to answer management requirements. Both of these disciplines have pursued this forest arrangement through cultivation techniques aimed at guaranteeing stand regeneration (the silvicultural system) on the one hand, and by planning silvicultural operations in time and space in the attempt of obtaining a maximum, constant and predictable annual production, or more recently, a sustained production of goods and services (HELLRIGL, 1986) on the other hand. The forest has been considered as an instrumental entity.

The vision of nature upheld by this classic paradigm has long been put under criticism. ROBERT MAY, in 1973, introduced the concept of ecological complexity in the famous book "Stability and complexity in model ecosystems". The last decades of the 20th century have seen the birth of hypotheses on ecosystem functioning that have evidenced that they are complex systems, characterized by nonlinear and unpredictable changes and modifications (HOLLING, 1986; PICKETT *et al.*, 1992, LUDWIG *et al.*, 1993; HILBORN *et al.*, 1995; HOLLING and MEFFE, 1996; PERRY and AMARANTHUS, 1997).

In 1998, LEVIN wrote that "Ecosystems, and indeed the global biosphere, are prototypical examples of *complex adaptive systems,* in which macroscopic system properties such as trophic structure, diversity-productivity relationships, and patterns of nutrient flux emerge from interactions among components, and may feed back to influence the subsequent development of those interactions".

LEVIN based his definition of Complex Adaptive System on the work of ARTHUR and colleagues (1997) of the Santa Fe Institute who identified six properties which can apply to any complex adaptive system:
– dispersed interaction;
– absence of a global controller;
– cross-cutting hierarchical organization;
– continual adaptation;
– perpetual novelty;
– far-from-equilibrium dynamics.

From then on there has been a growing interest in using concepts and methods of complex systems science for describing and explaining ecological phenomena. But, according to ANAND *et al.* (2010) despite growing recognition of the utility of CSS in many disciplines, the field of ecological complexity has yet to be widely adopted by ecologists and remains controversial to many.

The idea that a forest must be considered a complex biological system, and that there is the need to change paradigm in the theoretical bases of silviculture and forest management, had been anticipated by what we can now truly define as the "Italian school of silvosystemics", originated from an intuition of CIANCIO (1992) and which was established with the formal definition of systemic silviculture in the book "The forest and man" (CIANCIO, 1997; CIANCIO and NOCENTINI, 1997). At the time this book was published, it received little attention or negative reviews (e.g. MALCOLM, 1999). More recently, in the book "A critique of silviculture: managing for complexity", PUETTMANN, COATES and MESSIER (2009) analyse the development of silviculture and forest management in the light of the complex adaptive system theory. These authors strongly support the idea that it is time to overcome the reductionist paradigm which has characterized and still characterizes research and management in silviculture and move towards managing forests as complex adaptive systems. The authors, in their critique of traditional silviculture, use practically the same arguments that we used in 1997. Maybe the times were not ripe then for this profound paradigmatic change, but it is now gaining an increasing support worldwide.

THE FOREST: NEITHER COMPLETELY PREDICTABLE NOR COMPLETELY RANDOM

If we accept the fact that the forest is a complex biological system, thus overcoming the reductionist and mecanicist view, then we must accept the fact that forest ecosystem's organization and reactions follow processes which are neither totally predictable nor totally random (ANAND *et al.*, 2010).

This brings us to consider our relation with the concept of the future. In forestry, from a scientific and operational perspective, the future has always been considered as practically unchangeable, at least concerning the main factors influencing forest productivity and stand development. In practice this has been translated into the definition of the "best" structure, composition and organization of the forest for fulfilling management objectives. The following step is to translate this forest model in silvicultural prescriptions within "closed" plans. In this view, forest ecosystems are considered as systems which can be totally understood in their functioning and thus shaped so that future results meet management aims. This implies faith in the fact that ecosystems react to cultivation in a predictable and linear manner.

This way of thinking is a clear example of what HOLLING and MEFFE (1996) have defined as "command and control" approach, which implicitly assumes that that the problem is well-bounded, clearly defined, relatively simple, and generally linear with respect to cause and effect". But HOLLING and MEFFE also point out that "when these same methods of control are applied to a complex, nonlinear, and poorly understood natural world, and when the same predictable outcomes are expected but rarely obtained, severe ecological, social, and economic repercussions result." Furthermore "A frequent, perhaps universal result of command and control as applied to natural resource management is reduction of the range of natural variation of systems – their structure, function, or both – in an attempt to increase their predictability or stability" (HOLLING and MEFFE, 1996).

When we have become aware that the future might also rapidly change following climate change, the reductionist approach of forest management has lost another of its strong points: a certain and predictable future. COREAU *et al.* (2009) have pointed out, citing IBANEZ *et al.* (2006), that in studying future development of ecosystems, complexity in ecology often leads us to either simplify the system (by choosing a particular mechanism or part of the system) or to aggregate data from different sources and scales in a single, complicated quantitative model. This may be satisfactory when the main objective is to increase our understanding of current functioning and dynamics, but is less useful to study futures, where we need to emphasize what is not known (BELL, 2003). COREAU *et al.* (2009) further point out that "studying the future leads us to take a standpoint beyond the limits of predictive models that cannot in theory be used outside the range of parameters and conditions for which they have been built (PEARSON *et al.*, 2006)".

It is important also to remember that a detailed knowledge of autoecological processes cannot be simply aggregated to represent an entire ecosystem (HOLLING, 1992). Ecological systems are complex, often unique, and currently unpredictable beyond limited generalities (MEFFE and CARROL, 1997).

KAY and REGIER (2000) also point out how the premise of the conventional approach to ecosystem management is that it is possible to predict and anticipate consequences of decisions, a sort of "anticipatory management". This means that "Once all the necessary information is gathered to make scientific forecast, the "right" decision can be made. This approach is simply not valid when dealing with complex systems. Given the limitations imposed by complexity, management and decision-making strategies must focus on maintaining the capacity to adapt to changing environmental conditions". According to LEVIN *et al.* (1998) the key to resilience in any complex adaptive system is in the maintenance of heterogeneity, the essential variation that enables adaptation.

Simplified structure and composition of forest ecosystems managed with a command and control approach are exogenous, they do not derive from endogenous processes, and therefore make these systems fragile, more vulnerable to stress, such as parasites, climate changes, etc. and thus more prone to collapse by being unable to respond in an adaptive way.

All this points out how risky it is to continue on this road, now that we are aware that (1) the future is neither certain nor exactly predictable and (2) forest ecosystems are complex adaptive systems interacting with complex socio-economic systems.

KAY and REGIER (2000) suggest changing to a non-normal science, where monitoring, i.e. "the activity of observing the human and natural systems and synthesizing the observations together into a narrative of how the situation has actually unfolded and how it might unfold in the future" is the basis for governance and management, i.e. the continuing process of "learning, revisioning and adapting human activities so that human and natural ecosystems co-evolve as a self-organizing entity with integrity".

COMPLEXITY, INDETERMINATION AND SYSTEMIC SILVICULTURE

Systemic silviculture and management by considering the forest a complex and adaptive biological system, integrate all these assumptions into analysis, methods and operational procedures which are coherent with this concept (CIANCIO and NOCENTINI, 2000; 2011).

Systemic silviculture does not refer to a specific stand structure: the forest is considered as "a-structured", because its structure cannot be defined *a priori*: structure is a consequence, intrinsically unpredictable and continually changing in time and space, of the interrelations between silvicultural interventions and the system's reactions.

The application of systemic silviculture necessarily leads to a change in classical forest management (NOCENTINI, 2005). With systemic silviculture, the adaptive approach is fundamental and is based on the careful and continuous monitoring of the forest reaction to cultivation. Management proceeds following a co-evolutionary *continuum* between human intervention and the system's reaction which *de facto* excludes the typical finalism of linear processes that lead to the forest's *normalization* (CIANCIO *et al.,* 1994; 1995b).

This approach brings together the essence of two forest management methods which have always been considered at the outskirts of classical forest management: the silvicultural method i.e. determining the prescribed cut compartment by compartment according to silvicultural considerations, without any reference to the "normal forest" model (KNUCHEL, 1953; CIANCIO *et al.*, 1995a), and the adaptive approach which was already present in Gurnaud's control method, even though still tied to the productive vision of the forest (CIANCIO and NOCENTINI, 1994; NOCENTINI, 2005).

The innovative concept of the minimum standing volume, i.e. the minimum volume which should always be present in a forest, together with the rule of always applying cautious, continuous and capillary interventions, fulfill the precautionary principle and thus eliminate risks of major mistakes. Monitoring the reactions of each stand to interventions is the basis for corrections, if necessary, thus adopting a trial and error approach. According to CORONA and SCOTTI (2011), this means shifting methodological focus from *a priori* determination to *a posteriori* assessment which implies a heuristic approach. Thus management proceeds as an experiment: reaction to each intervention shall be monitored using appropriate indicators, not as reference of an optimal state, but as parameters to measure relative change in time (CIANCIO and NOCENTINI, 2004).

CONCLUSIONS

Systemic silviculture originated from the awareness that the reference paradigm for managing natural resources had changed. Maybe this is why it has received so many critiques: as GRUMBINE wrote (1997), new ideas are often seen as a menace to the *status quo*.

We believe that a cycle is now over, that of the forest considered as an instrumental entity which can be managed according to predefined models to answer specific aims. History has clearly shown that after over two centuries of efforts to make forest ecosystems predictable, we have transformed forests into plantations and silviculture into tree cultivation for wood production (NOCENTINI, 2009; PUETTMANN *et al.,* 2009).

One is free to remain in the reassuring, consolidated deterministic and reductionist paradigm, but we must be aware that if we consider this the only reference system for managing forests in a sustainable way, foresters will progressively loose all contact with the other actors playing in the complex world of natural resource management, with the rapid and disastrous disappearance of any professional space (and credibility) for foresters.

I would like to conclude using POPPER's words (1982): we are lucky that the real world is much more interesting and exciting than how reductionist philosophy imagines it.

RIASSUNTO

Il bosco sistema biologico complesso: ricadute teoriche e applicative

Viene analizzato il concetto di sistema complesso adattativo nel contesto dell'attuale dibattito scientifico e si esaminano le conseguenze scientifiche e operative nel campo della selvicoltura e della gestione forestale.

Il paradigma classico per la gestione delle risorse naturali ha trattato le dinamiche delle popolazioni, delle comunità e degli ecosistemi come se avvenissero in un ambiente immutabile e secondo traiettorie prevedibili. Gli ultimi decenni del ventesimo secolo hanno visto la nascita di ipotesi sul funzionamento degli ecosistemi che hanno evidenziato come questi siano sistemi complessi, caratterizzati da cambiamenti e modificazioni non lineari e imprevedibili. La selvicoltura e la gestione sistemica, considerando il bosco un sistema biologico complesso e adattativo, prevedono analisi, metodi e procedure operative coerenti con questo concetto. Con la selvicoltura sistemica, la gestione procede secondo un *continuum* coevolutivo fra intervento umano e reazioni del sistema bosco.

Ormai si è chiuso un ciclo, quello del bosco visto come una entità strumentale che può essere gestita secondo modelli predefiniti per rispondere a specifici obiettivi: la storia ha chiaramente dimostrato che oltre due secoli di tentativi per rendere gli ecosistemi forestali prevedibili hanno trasformato le foreste in piantagioni e la selvicoltura in arboricoltura da legno.

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