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SYSTEMIC SILVICULTURE, ADAPTIVE MANAGEMENT AND FOREST MONITORING PERSPECTIVES

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Systemic silviculture can be framed as an approach in which management practices are conceived as learning experiments. In the light of this, effective and efficient monitoring processes are required in order to inform and support the management taking explicitly into account the many system components, their interactions and its nonlinear behavior, a characteristic that determines important limitations with regard to the value of predictions. In order to evaluate evidence and turn data into decisions, monitoring effectiveness and efficiency encompass adequate statistical methods and tools for acquisition, processing and analysis of information from different sources. The present note highlights some key contributions on which to engage the development of forest monitoring under such a perspective.

Key words: sustainable forest management; complex systems; decision making; heuristic approach; uncertainty; causality.

Parole chiave: gestione forestale sostenibile; sistemi complessi; processi decisionali; approccio euristico; incertezza; causalità.

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FROM FORECASTING TO MONITORING

Sustainable forest management is quite a delicate task since it calls for the search of an harmonic composition of ecological, economic and sociocultural instances. This, contextualized within ever changing environmental and social values, leads to uncertainty and controversy on how to best manage toward moving goalposts.

Classical forest management, dominated since long by the reductionistic paradigm, is founded on two basic principles: (i) perpetuity of the forest based on the equilibrium between standing volume, standing volume increment and allowable cut; (ii) constrained optimisation of commodities (marketable or not). The latter, basically output-oriented indication, has led to simplifications of forest ecosystem structure and composition. Albeit the fundamental contribution of classical theory to forest preservation and to the development of forestry should not be undervalued, the development of applied ecology has highlighted how dangerous simplifications may be for ecosystems' functionality.

Its limitations and drawbacks have gradually outfit classical forest management from sustainability prospects: to this end, a significant paradigm shift is required to appropriately deal with complex living systems like the forests. Systemic silviculture (CIANCIO and NOCENTINI, 1997, 2004, 2011) grasps this challenge as it assumes as fundamental management goal the search for the functional efficiency of the forest ecosystem. In such a perspective: (i) the forest is perceived as an entity with intrinsic value; (ii) it is necessary to go beyond the management framework grounded mainly on the simplistic equilibrium between standing volume, standing volume increment and allowable cut; (iii) silvicultural practices are guided by an adaptive approach, based on trial and error, rather than on so-called normalisation schemes.

In principle, classical silvicultural practices aim at forest regeneration with a predefined model in mind. The aim is to develop so-called regular structures with normalised stocking, increment and age or diameter distribution, for even-aged and uneven-aged forests, respectively. In both cases, silvicultural practices try to enforce a model as if forest ecosystems could be governed by controlling a few key variables; other aspects are practically ignored and classified as casual effects. Yield tables, and the corresponding norm for uneven-aged forests, are the main expression of the classical idea that, in principle, by managing forests precisely following such optimal schemes, forest growth will probably match managers' expectation (CORONA and SCOTTI, 1998). This paradigm inherently assumes that: (i) forest ecosystems react to the management in a predictable manner; (ii) it is then expedient to anticipate predicted consequences of decisions (i.e. anticipatory management, *sensu* KAY and REGIER, 2000: once all necessary information is gathered to make a scientific forecast, the "right" decision can be made) (NOCENTINI, 2011).

Such an approach is simply not valid when dealing with complex systems. Actually, a vast bulk of evidence from operational forest stand management shows that predicted outcomes are rarely achieved, at least as far as forests of natural origin are concerned. LEVIN (1998) stresses that ecosystems are prototypes of complex adaptive systems, in which the macroscopic properties of the system (e.g. trophic structure, diversity-productivity relationships, patterns of nutrient flows) emerge from interactions between components, and can feed back to influence the development of these interactions. Only hypotheses can be drawn about the effects of management practices. Forest functioning and structure, and distinctively forest reaction to management measures, are neither completely predictable nor completely random (ANAND *et al.*, 2010): distinctively, like many complex biological systems, forests are characterised by multiple feedback links and close dependency on initial conditions, so that the prediction has only a weak power, similarly to what is widely acknowledged in the physics of complex systems (PARISI, 1994).

Under such a framework, management is urged to move from approaches based on forecasting (i.e. the root of the anticipatory management idea) to approaches based on monitoring: focus is not on the prediction of the effect of each intervention but rather on the reaction to it as tracked by relevant indicators. As evidenced, *inter alia*, by KNUCHEL (1953), PATRONE (1979) and CLAUSER (2011), this means to move from a strictly ruled forest planning to adaptive management where, generally, indicators are not intended as reference thresholds but instead as parameters to measure changes over time (CIANCIO and NOCENTINI, 2004).

CONCEIVING MANAGEMENT MEASURES AS EXPERIMENTS

The adoption of an adaptive approach explicitly considers system's unpredictability as a value, as its capacity to react to impacts, and requires learning from system reactions to support its resilience. As mentioned, systemic silviculture aims at preserving the internal organisation and feedback relations of forest ecosystems. Nonetheless, human intervention, artificial by definition, impacting on the structure of forest stands, provokes a certain level of stress in the system (ROGERS, 1996). Artificial impact needs to be constrained within the limits of forest ecosystem resilience. Understanding that natural systems are able to preserve their internal organisation, withstanding even major structural modifications, could help finding key elements for management action. Shifting methodological focus from a priori determination to a posteriori assessment implies a heuristic approach or a system theory of trial and error. Successive forest transformations resulting from human interventions, whether of structural or marginal nature, need to be observed and interpreted considering the complex interactive relations linking management subjects (the forest and man).

The overall goal is not to maintain an optimal condition of the resource (a concept that becomes meaningless under ever changing environmental and socio-economic contexts) but to develop an optimal management capacity. This is accomplished by: (i) trying to maintain ecological resilience, so that the system is able react to stresses; (ii) generating flexibility in institutions and stakeholders' expectations, to allow for the management be adaptive when external conditions change.

Adaptive management systematically integrates results of previous interventions to iteratively improve and accommodate change by learning from the outcomes of experimented practices (MCDONALD-MADDEN *et al.*, 2010). However, application of monitoring, disregarding any methodological approach to explore the consequences of alternatives, may raise relevant problems: heavy reliance on managers' experience and wisdom inherently and unreliably assumes that management conditions are stable over time. On the contrary, management options can be properly designed to enhance learning. Such an approach requires exploring, by means of experimental design and protocol, the effects of alternative interventions on key response indicators and designing monitoring schemes in a way that provides reliable feedback over appropriate time frames and spatial scales (PUETTMANN *et al.*, 2009).

Summarizing:

– systemic silviculture poses the challenges to work with interventions dependent on the peculiar conditions of the ecosystem at hand and to safeguard the functionality of the system: in the light of this, monitoring has to inform state-dependent management, taking explicitly into account the multiple components of the system, the countless interactions and its nonlinear behavior that implies weak predictions;
– systemic silviculture can be framed within an approach where management practices are conceived as learning experiments; differences between how the future actually unfolds and how it was hypothetically envisioned are seen as opportunities for learning: this is in sharp contrast to anticipatory management which sees such deviations as "errors" to be avoided (KAY and REGIER, 2000: much of adaptive management efforts is learning through experimentation rather than focusing on error avoidance);
– monitoring is primarily conceived to support the evaluation of the experimental evidence and turn data into decisions using suitable tools for collecting, processing and analysing (i.e. multiple methods of statistical analysis) information from a variety of sources.

METHODOLOGICAL CHALLENGES

Under the proposed perspective, forest monitoring distinctively aims to: infer causality; incorporate and value uncertainty (i.e. to make decisions in the presence of it); look for full-scale testing; look for multi-scale assessment.

i) *Infer causality*. The difficulty in inferring causality factors from changes observed in monitored attributes is largely known. A key issue to this end is to introduce question-driven monitoring approaches; although it may seem facetious, many monitoring activities are initiated without having a clear idea of what is the point of monitoring. Thus, focused questions are needed for monitoring be more directly supportive in the identification and assessment of mechanisms influencing changes in ecosystems. From a practical point of view, this means moving from implementation monitoring (i.e. a procedure-oriented approach: have the management guidelines been implemented correctly?) or effectiveness monitoring (i.e. a performance-oriented approach: are the management activities producing the desired effects?) to corroboration-oriented monitoring that focuses on hypotheses about the mechanisms influencing changes in ecosystems.

ii) *Incorporate uncertainty*. In anticipatory management the so called best estimate approach is usually pursued, deliberately ignoring the uncertainties and basing management decisions upon the best prediction of the phenomena of interest. Sometimes a qualitative approach is sought, taking uncertainties into account, but only qualitatively or crudely: for instance, using ecological uncertainties to justify a status quo preservation option; or using a qualitative approach to justify extreme pessimism about the response to a management action; or, furthermore, using uncertainties qualitatively to justify a moderately pessimistic outlook and to implement a conservative approach to management; or, on the opposite, using uncertainties qualitatively to justify an optimistic view of how systems will respond to management (either unnecessarily restrictive or excessively lenient measures) (PETERMAN and PETERS, 1998). Under the approach here envisaged, the objectives of monitoring are posed within the iterative process of evaluating scientific hypotheses, possibly framed by statistical inference (SCHREIBER *et al.*, 2004).

iii) *Value uncertainty.* In the conventional reductionist approach of the anticipatory management, data (as a mass) are valued for their inferential contribution, residuals are wastes. In the holistic perspective, data represent individuals, i.e. the uncertainty that "residuals" express brings specificity into evidence and is hence valued as diversity is. For instance, models, typical products of quantitative methods, are the tools allowing researchers to express and use the knowledge that progressively accumulates (CORONA, 1996); the development of these tools is naturally driven by their descriptive/predictive capacity, i.e. by their capacity to reduce or limit the uncertainty concerning system's characteristics/behaviour; on the other hand, models residuals, typical expression of the uncertainty, have much to say: they are not just left-overs, they are opportunities for learning.

iv) *Look for full-scale testing*. The impact of disturbances created by management practices cannot, in general, be deduced from single experimental plots, where neither cultural nor ecological landscape effects might be evident. Successful management of complex biological systems requires full-scale testing. In this respect, suitable statistical sampling designs are of primary concern. Good study design, coupled with the rigour of subsequent statistical analyses of high-quality data, emphasizes the point that forest monitoring needs to be good science (LINDENMAYER and LIKENS, 2010). Distinctively, design determines the kind of statistical inferences that are possible.

v) *Look for multi-scale assessment*. It is clearly beneficial to monitor attributes pertaining to different aspects of forest ecosystems at the same sample points and at the same time so that the information for the different attributes can be related to each other (e.g., this would allow relating the biodiversity dynamics of natural regeneration to changes in landscape metrics as assessed by remote sensing or in the main canopy as assessed by dendrometric field measurements). Hence, the potential to integrate multisource information (e.g. CORONA, 2010) is a key element under the proposed monitoring perspective.

METHODOLOGICAL APPROACHES

Adaptive management requires to measure the initial state of the systems and to monitor trends over time to track system responses to management practices. Management, to be adaptive, is expected to evaluate outcomes and to draw inferences about the causes of changes that are detected in the system, to decide how and when to adjust actions. To this end statistical techniques can provide important insights into both qualitative assessments and quantitative measurements (NYBERG, 1998; NICHOLS and WILLIAMS, 2006).

It is well known that the more control or manipulation is present in an experimental protocol, the stronger the inferences that can be made. While the analysis of observational surveys and designed experiments may be similar, the strength of the conclusions is not. In general, causation cannot be inferred without manipulation (SCHWARZ, 1998). Thus, whenever possible, adaptive management studies should include experimental controls, unbiased sampling and allocation of treatments, as well as the replication of treatments.

However, it is important to recognize that the operational scale and setting may constrain the level of statistical rigour that can be achieved. For instance, it may be impossible to find multiple areas that are sufficiently homogeneous to serve as replicates of operational-scale treatments. In other cases, it may be unfeasible to meet some of the critical assumptions of the classical methods of statistical analysis (e.g. random allocation of treatments, homogeneity of variance, independence of sample variances). In many cases, controlled experiments are impractical or too expensive, and observational surveys are carried out even though the resulting inferences will be usually weaker than those obtained through controlled experimentation. Despite the weaker inferences from non-experimental studies, the same attention must be paid to the proper design of a survey so that the conclusions are not tainted by inadvertent biases (SCHWARZ, 1998).

It should also be stressed that in many cases a proper assessment of forest management practices needs a very long timespan. However, data and circumstances that already exist might serve to circumvent such a constraint, at least up to a certain extent. Distinctively, retrospective and chronosequences studies are alternatives to the prospective ones. Retrospective (e.g. LIKENS, 1985; CARPENTER, 1989; SMITH, 1998; D'AMATO *et al.*, 2011) and chronosequences (e.g. GRIFFITHS *et al.*, 2001; CLAUS and GEORGE, 2005) monitoring offers a compromise, which uses existing data or circumstances. These approaches greatly shorten the time between the inception of the study and the presentation of the results, and reduce the costs as well. Of course, as with any compromise, such studies must be used carefully. Often the results are preliminary, and sometimes do not allow for proper quantitative hypothesis testing. However, by carefully presenting results, designing the study, and being aware of the pitfalls inherent in individual analyses, a great deal of useful information can be obtained. Ultimately, they can be exploited to provide input in two important ways: assessing long-term management actions without waiting until the effect of the action is realized; assessing impacts of natural phenomena that cannot be created for the purpose of a study.

FINAL REMARKS

Designing and applying systemic silviculture involves more than simply transferring theoretical reasoning and research to management problems. Looking forward: forest planning and management strategy should be based on the inspection of ecosystem development, understanding forest resiliency through successive attempts and, hence, identifying proper limits for silvicultural intervention. Scientists can play an important role, but it is local resource professionals, technicians and landowners that are solicited to pursue such a strategy, properly exploiting effective monitoring approaches.

RIASSUNTO

Selvicoltura sistemica, gestione adattativa e prospettive del monitoraggio forestale

La selvicoltura sistemica può essere proposta come un approccio in cui le pratiche di gestione sono concepite quali esperimenti per apprendere. Per agire occorre dunque attivare processi di monitoraggio efficaci ed efficienti, capaci di informare la gestione, tenendo espressamente conto delle molteplici componenti del sistema, delle innumerevoli interazioni e del suo comportamento non lineare, caratteristica che comporta importanti limitazioni nei riguardi del valore delle previsioni. Al fine di enucleare evidenze e ricavarne decisioni, efficacia ed efficienza del monitoraggio comportano il ricorso a metodi e strumenti statistici adeguati per la raccolta, l'elaborazione e l'analisi di informazioni derivate da fonti diverse. La presente nota sottolinea alcuni fondamentali contributi su cui impegnare lo sviluppo del monitoraggio forestale in questa prospettiva.

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