COMPLEXITY SCIENCE GUIDED MANAGEMENT OF FORESTS: VIEWING FORESTS AS COMPLEX ADAPTIVE SYSTEMS IN AN UNCERTAIN WORLD

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The world's forests and forestry sector are facing unprecedented biological, political, social and climatic challenges. The development of appropriate, novel forest management and restoration approaches that adequately consider uncertainty and adaptability are hampered by a continuingfocus on production of a few goods or objectives, strong control of forest structure and composition, and most importantly the absence of a global scientific framework and long-term vision. We argue here that viewing forest ecosystems as complex adaptive system provides a better alternative for both production- and conservation-oriented forests and forestry. We propose a set of broad principles and changes to increase the adaptive capacity of forests in the face of future uncertainties. These span from expanding the sustained-yield, single-good paradigm to developing policy incentives and interventions that promote self-organization and integrated social-ecological adaptation.

Keywords: self-organization, forestry, adaptability, scientific framework.
Parole chiave: autorganizzazione, scienze forestali, adattabilità, quadro di riferimento scientifico.

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1. Introduction

An evolving direction for natural-resource management is to view forests through the lens of complexity science. A major attraction of complexity science is that it provides a conceptual framework to promote the long-term productivity, biodiversity, and adaptability of forest ecosystems and an integrative, multidisciplinary approach to studying the structure and dynamics of forest ecosystems. The various components and processes in a forest are no longer viewed as decoupled entities. Complexity science views forest ecosystems, stands and landscapes as integrated social-ecological systems. It calls for a shift from the pursuit of specific stand-scale objectives toward a more flexible multi-scale perspective that considers site- stand- and landscape-scale processes and their interactions. It acknowledges variability and uncertainty in environmental, biological, economic, and social conditions. Applications to forest management are just beginning to emerge.

Complexity science can aid forest managers and policy makers in understanding how ecosystems respond to change and how management can influence these responses in a dynamically changing environment. Viewing forests as integrated social-ecological systems and then applying complexity science theory to improve their management could be the greatest paradigm shift since the introduction of early forest management theories in the 1800's by German foresters. Traditional forest management was not designed to handle the emerging challenges stemming from the increased uncertainty and rapid pace of social, climatic, and environmental changes in our modern world. The past forestry paradigm viewed forests and the goods and services forests provide as inherently stable and consequently focussed on the notion of an "optimal" forest structure and composition. Nor did it fully recognize the inherent uncertainty of the future and the need to promote adaptability instead of predictability. Uncertainty of future conditions has always been there, but it has become even more important in the last few decades due to the rapid societal, environmental and climatic changes that we are experiencing. And this will accelerate in the future. We now understand that seemingly small changes can sometimes lead to system-scale impacts in forests via phenomena that link processes across scales. Local interactions may trigger the emergence of patterns or processes at larger scales. These dynamics occurring at various temporal and spatial scales are inherently hard to predict since a small changes in the initial conditions of the system or in the external environment (e.g. many mild winters) can get amplified quickly due to the non-linearity of many of these relationships. Long-standing approaches to forest management, especially the notion of "high" predictability, are challenged when viewing forests through the lens of complexity science. When viewing forests as complex systems, the emphasis of management shifts from the traditional view of long-term predictability and sustainability of very specific products to one that acknowledge uncertainty and promotes the adaptability of the forest so as to maintain or increase the overall resilience of forest ecosystems, stands and landscapes. Forest managers now consider and evaluate the short- and long-term viability of specific practices in a framework that minimizes risk and reduces the chance of undesirable future outcomes.

The prediction of the future states of ecosystems, stands and landscapes cannot be made with precision. Non-linear dynamics, feedback between entities at different hierarchical levels, emergence, and constantly changing external drivers or boundary conditions (e.g., environmental variability, climate change, global economy) all contribute to future uncertainty. With this in mind, the tools that we use or develop should incorporate and accept this inherent inability to predict precisely the future and acknowledge that changes or adaptation to known and unknown future conditions are not only something that we must accept, but rather something that has to be promoted and planned from the outset in management plans.

Under this new paradigm, management interventions would not be aimed at reaching a precise objective or goal in the future but instead aim at making sure the system (or the forest) has all of the elements to continue to change and adapt to produce the desirable goods and services in the future. A good analogy would be the education of our children today. Schooling and parenting should not be aimed at producing a specific adult that will do a certain job that we predict will be necessary in 30 years, but rather an very adaptable and resilient individual that will be able to navigate through the complex and increasingly changing world of the future. Given the inherent uncertainty of complex systems, the future of an individual stand (or a regional landscape) should be discussed in terms of scenarios and "envelopes" or ranges of possible future states rather than precise predictions.

One envelope should include all possible future states of the stand for a single scenario, given current knowledge of the system's state and functioning. Stands and landscapes should be evaluated more in terms of how resistant and resilient (or adaptable) they are to future unexpected events than in terms of producing a few well known products or services.

The future of a stand can be conceived in terms of ensembles of likely future system states, given a particular management scenario and external drivers. A series of scenarios may be explored through modeling to ascertain which policies will keep the stand within an acceptable range. The best use of simulation models is to develop and explore future scenarios and to serve as decision support tools by allowing greater insight into the possible responses of the system to proposed policies. Models that represent the local behaviors and interactions of individuals with representations of environmental processes are increasingly being used for scenario building. How is using complexity science to guide forest management different from traditional forest management? There is more involved than choosing or modifying traditional tools or choosing different silvicultural systems. Using complexity science to manage forests requires a new viewpoint, new decision criteria, and new tools. In the past, forest management approaches were generally aimed at optimizing a restricted number of ecosystem components or maintaining certain stand structures by mimicking natural disturbance regimes. Managing forests as complex adaptive systems will require land managers to broaden their focus to assess how practices affect all properties of the system, with a special emphasis to adaptability. There will be greater emphasis on multiple temporal, spatial and hierarchical scales, more explicit consideration of interactions among multiple biotic and abiotic components of forests, the need to understand and expect non-linear responses, and the need to plan for greater uncertainty in future conditions.

2. Actions to implement complexity science guided forest management

- Replace the sustained single good or objective-yield paradigm with one that integrates risk/flexibility/adaptability into scenarios of sustained provision of various goods and services. This is a core action needed to allow the complexity science management paradigm to move forward.
- Promote self-organization and adaptability. Focus on building adaptive capacity by managing for specific species and functional diversity in an ever-changing biological and social environment. Functionally diverse, mixed-species stands support species with different biotic and abiotic sensitivities and recovery mechanisms following disturbances, thus ensuring the ability of ecosystems to self-organize, increasing their adaptive capacity.
- Manage at multiple scales with explicit linkages among all levels. Viewing management effects at different organizational levels and recognizing interactions among them will provide insight into potential positive or negative effects on self-organization pathways.
- Plan and assess interventions across a range of spatial and temporal scales, e.g., from plant neighborhoods to landscapes. Greater attention must be paid to maintaining variability in stand structures and tree species compositions at different spatial scales and across all temporal (or successional) stages of forest development. Explicitly work with interactions among species to promote productivity.
- Measure success at the appropriate temporal and spatial scale. Question if current procedures are properly capturing success.
- Plan and develop long-term scenarios and work with envelopes of possibilities and alternate futures using new analytical tools and models that specifically acknowledge the prevalence of highly uncertain social, economic, climatic, and ecological conditions.
- Allow social-environmental systems to self-organize and adapt to novel biological, environmental, and social conditions. Avoid general top down rules. Promote an approach where interventions are minimized and aimed at facilitating bottom-up developments, inherent to complex systems, to maintain adaptive capacity while providing desired goods and services.
- Monitor to determine actual conditions. Focus monitoring on more than average conditions.

Explicitly include aspects of variability. Include information about feedbacks and thresholds (establish how close and the direction of movement toward or away from critical threshold). Sample at multiple scales in space and time. Identify and monitor key linkages between interacting agents and the external environment that may cause undesirable outcomes. Adapt monitoring protocols as necessary to incorporate new requirements or to better meet the needs of scientific analyses. Overall purpose is to determine if management intervention is required.

- Increase involvement of local communities and stakeholders to ensure that future forests are better aligned with the needs and preferences of local people.

3. Background information on important concepts

3.1 Complexity science and complex systems

Complexity science has a strong conceptual foundation that is based on work in numerous fields. It is not a discipline per se, but a set of theoretical frameworks that can apply to biological, economic, social and political problems and challenges.

A complex system is adaptive when individual components are constantly reacting to one another and outside influences, thus continually modifying the system and allowing it to adapt to altered conditions. Forests are different from strictly physical and chemical complex systems because of their ability to self-organize and change over time.

Forests have ecological attributes - such as diversity, cross-scale interactions, memory and environmental variability - that make them not just complex, but also adaptive systems. Although there is no universally accepted definition of a complex system, most researchers would agree that a complex system (1) is composed of many interacting components and (2) has structure and dynamics that are the collective result of these interacting components and are thus difficult to analyse or describe using only one scale or resolution. Complexity science provides a trans-disciplinary framework to study complex systems characterized by (1) heterogeneity, (2) hierarchy, (3) self-organization, (4) openness, (5) adaptation, (6) memory, (7) non-linearity, and (8) uncertainty.

Forests are heterogeneous, highly dynamic and contain many biotic and abiotic elements that interact across different levels of organization with various feedback loops. Changes in forest dynamics are driven by bottom-up linkages and interactions that bridge temporal, spatial, and hierarchical scales. Forests are subject to continual change. Their states will change with changing external or internal drivers. We now understand that these dynamics can be non-linear and are typically far from being in equilibrium, such that the response of the system may not be proportional to a disturbance or management intervention. Forests should be viewed as being composed of systems made up of systems. This conceptualization is fundamental to understanding and interpreting their dynamics. It provides a framework with which to explain many examples of emergence as well as the potential for interactions between processes and entities across hierarchical, spatial, and temporal scales. This framework acknowledges that the geophysical environment is not a fixed background but rather structures, and is structured by, human and ecological processes.

Complex systems are not well understood using the classical or Cartesian modes of thinking used in reductionist or determinist science. Reductionist science focuses on the study objects by investigating individual components in isolation. In contrast, complexity science suggests that a system can be better understood or managed by focusing on the interactions among the various components of the system.

3.2 Adaptive capacity

Adaptive capacity refers to the ability of the system to modify its structure and composition under changing social and ecological conditions without losing its essential functions. In a forest restoration and management context, this may be the ability of forests to respond to changing host-pest interactions and climatic conditions, while at the same time continue to provide essential ecosystem services to society, such as wood in a global changing market, and to support habitats for native biodiversity.

The idea of the adaptive capacity of forest ecosystems does not receive adequate attention when the emphasis of environmental policies and “command and control” management is on optimal stand structures and composition or the production of a single good or service (e.g., wood, recreation, or water). In contrast, focusing on maintaining the adaptive capacity of forest ecosystems in the context of rapid and uncertain global socio-environmental changes provides the best assurance that forests will continue to provide a full set of goods and services in a variable and uncertain future, including timber production, carbon storage, water quality, biodiversity, disease regulation, and maintenance of climate and soil properties.

Ecosystems will always adapt, but that shouldn’t be interpreted that all changes or adaptation are socially acceptable. Adaptation is value free and an assessment of resilience may be necessary to decide whether the ecosystem stays within (human defined) limits of environmental quality. Management based on complexity science principles must ensure that forested ecosystems have all of the elements needed, and the redundancy of elements, to be able to adapt while maintaining the important ecosystem services.

RIASSUNTO

Gestire le foreste sulla base della scienza della complessità: considerare le foreste come sistemi complessi e adattativi in un mondo incerto

Le foreste e il settore forestale mondiale si trovano di fronte a nuove sfide biologiche, politiche, sociali e climatiche.

Lo sviluppo di approcci di gestione e ripristino delle foreste appropriati e innovativi e che considerino adeguatamente l’incertezza e l’adattabilità, è ostacolato dal perdurante focalizzarsi sulla produzione di pochi beni o

su pochi obiettivi, dal forte controllo della struttura e composizione delle foreste e, cosa più importante, dall'assenza di un quadro di riferimento scientifico globale e di una visione di lungo termine.
Qui sosteniamo che considerare gli ecosistemi forestali come sistemi complessi e adattativi fornisce una migliore alternativa sia per foreste e attività forestali orientate alla produzione sia per quelle orientate alla conservazione.
Proponiamo un insieme di ampi principi e cambiamenti per aumentare la capacità adattativa delle foreste a fronte delle future incertezze. Questi vanno da espandere il paradigma della produzione massima e costante di un singolo bene a sviluppare incentivi e politiche che promuovano l'autorganizzazione e l'adattamento socio-ecologico integrato.

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