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Managing forests in a changing world: the need for a systemic approach. A review

Susanna Nocentini[1*], Gérard Buttoud[2], Orazio Ciancio[3] and Piermaria Corona[4]

[1]*University of Florence, Department of Agricultural, Food and Forestry Systems, Florence, Italy* [2]*University of Tuscia, Department of Innovation in Biological, Agro-food and Forest Systems, via San Camillo de Lellis, 01100 Viterbo, Italy* [3]*Italian Academy of Forest Sciences, Piazza Edison 11, 50133 Florence, Italy* [4]*Consiglio per la ricerca in agricoltura e l'analisi dell'economia agraria. Research Centre for Forestry and Wood, viale Santa Margherita 80, 52100 Arezzo, Italy*

Abstract

Aim of study: The paper is a scientific commented discussion with the aim of defining a framework which allows both a comprehensive vision of forest dynamics, as well as an adaptive management approach and policy procedures more suited to a changing and inherently unpredictable world.

Main results: We identify the main challenges facing forestry in relation to recent developments in forestry thinking, i.e. the paradox of aiming at sustainability in a changing environment, a shifting perception of the relationship between ecological and social systems, the recognition of forest ecosystems as complex adaptive systems, the need for integrating the social and ecological dimensions of forestry into a single framework, and the growing awareness of the importance of the ethical approach to the forest. We propose the concept of "systemic forestry" as a paradigm for better understanding forest dynamics and for guiding management and public actions at various levels. We compare the systemic approach with different silvicultural and forest management approaches which have been proposed in the last decades.

Research highlights: Our analysis shows that a systemic approach to forestry has five main consequences: 1. forestry is viewed as a part of landscape dynamics through a multi-sectoral coordination, 2. the logic of action changes from norm to process, 3. conservation is a dynamic search for resilience, 4. multi-functionality is achieved through a multi-entries approach integrating ecological, social and economic components of sustainability, 5. forestry institutions are reframed to address the issue of changing interactions among actors, 6. a change in the ethical approach to the forest is needed.

Keywords: adaptive forest management; systemic silviculture; social-ecological systems; forest governance; landscape approach.

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Correspondence should be addressed to Susanna Nocentini: susanna.nocentini@unifi.it

Introduction

Sustainable forest management has been and still is a central objective and a recurrent slogan in forestry. Since the birth of forestry as a science, the ideal of "sustained yield", i.e. maintaining a continuous flow of goods and services from the forest, has occupied a central place in forestry thinking (Ciancio & Nocentini, 1997; Puettmann *et al*., 2009). This way of thinking anticipated the recent view of sustainability, which assumes that there are desirable states for ecosystems, *e.g.* managed forests, that humans can maintain indefinitely.

The raising awareness that "we must face the impossibility of even defining — let alone pursuing — a goal of ''sustainability'' in a world characterized by extreme complexity, radical uncertainty, and unprecedented change" (Benson & Craig, 2014) is pushing towards a shift in the discussion on forestry not only from a scientific and technical point of view, but also from a policy perspective.

Forestry is now facing a paradox which consists in aiming at sustainability in a changing environment and in a shifting perception of the relationship between ecological and social systems (Von Detten, 2011).

Here we present a scientific commented discussion with the aim of defining a framework which allows both a comprehensive vision of forest dynamics, as well as an adaptive management approach and policy procedures more suited to a changing and inherently unpredictable world. We propose the concept of "systemic forestry" as a reference paradigm for better understanding forest dynamics and for guiding management and public action at various levels.

Viewing forests as a social-ecological systems: understanding complexity

Natural systems and social systems are complex systems in themselves (Berkes *et al.*, 2003). The term social-ecological system (SES) was used by Berkes & Folke (1998) to emphasize the integrated concept of humans-in-nature and to stress that the delineation between social and ecological systems is artificial and arbitrary (Folke, 2006). SESs are composed of (1) biotic agents ranging from microbes to plants to humans, each with a different degree of information-processing capacity; (2) a set of allowable actions related to their physical or behavioural characteristics; and (3) a physical substrate that includes chemicals, light, and water. The interactions among these agents and their interactions with the substrate generate dynamic social-ecological systems.

In a complex SES, subsystems such as resources, users and governance systems are relatively separable but interact to produce outcomes at the SES level, which in turn feed back to affect these subsystems and their components, as well other larger or smaller SESs (Ostrom, 2009).

Complex adaptive systems theory has been suggested as a means for better understanding forest ecosystem functioning and shaping more effective management approaches (Ciancio & Nocentini, 1997; Puettmann *et al.*, 2009; Ciancio & Nocentini, 2011; Messier *et al.*, 2013) According to Messier *et al.* (2013), forest ecosystems exhibit all the characteristics of complex adaptive systems because they are heterogeneous, highly dynamic and contain many biotic and abiotic elements which interact across different levels of organizations with various feedback loops. Forests are non-linear systems, highly sensitive to initial conditions, which makes precise predictions about their future behaviour very difficult. They also show a hierarchical organization: elements at different levels interact to form an architecture that characterizes the system (Filotas *et al.*, 2014).

Forest ecosystems are open to the outside world exchanging energy, materials and/or information. Forest ecosystems' components and processes interact with each other and with the external environment in many different ways and over multiple spatial and temporal scales (Messier *et al.*, 2013).

The need for taking into account the social and economic issues in forest management is not a new concept, but in practice this has usually been translated into adjusting management so as to shape forests to respond to these issues. Thus, the traditional forestry vision still interprets social and ecological components of forest dynamics as inhabiting fundamentally separate domains (Filotas *et al.*, 2014).

Instead, interactions with the social and economic systems, such as industries, governments, local communities, and other users of forest products and services together with their cultural backgrounds (Filotas *et al.*, 2014) form an integral part of forests. This is a particularly relevant issue for managed forests which have been, are and will continue to be profoundly impacted by changes in the social and economic systems, while at the same being themselves drivers of change in these systems, *e.g.* forest degradation as a cause of poverty, or, at the other extreme, mature, diverse and socially attractive forests in parks and nature reserves as factors of economic development (*e.g.* Hein, 2011).

Similar to the environmental components, the social, economic and policy elements of the social-ecological system formed by forestry can be assessed at various levels, so that the broader "landscape", defined on a social and/or environmental basis, where forests and forestry are just a part, and whose boundaries and size may change depending upon the issue, constitutes the right level to which forest management, policy and governance issues must be addressed.

All these considerations point out the need for integrating the social and ecological dimensions of forestry into a single framework.

Multifunctionality: an integration of different subsystems

In the conventional forest management approach, multifunctionality, i.e. the provision of multiple goods and services to society, has been based on the "wake theory" which states that if forests are efficiently managed for wood production, then all the other forest utilities will follow (Dietrich, 1941; Kennedy & Koch, 2004). Dynamics and reactions from other interacting systems have been ignored and the consequences have often been and still are harsh conflicts (*e.g.* between wood production, landscape and nature conservation, recreation and related stakeholders). In addition, recent examples show that societal preferences and values can change drastically in a relatively short time radically altering the social environment for forest management (Johnson & Swanson, 2009; Seidl & Lexer, 2013).

When considering forests as adaptive systems interacting with the economic and social systems, the concept of multifunctionality changes from a sum of different outputs of forest management activities to a set of complex interactions between various sub-systems.

The resilience of forests as social-ecological systems

Resilience of social-ecological systems has been defined as the capacity of the system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks (Walker *et al*., 2004). However, during adaptation a system can undergo major reorganizations: it can still sustain major functions but it may lose its identity (Gunderson & Holling, 2002).

According to Walker & Salt (2006), adaptability is the capacity of actors in a system to influence resilience, to avoid crossing into an undesirable system regime, or to succeed in crossing into a desirable one. In a social ecological system, this amounts to the capacity of humans to manage resilience (Walker et al., 2004).

This leads to consider forest adaptation to disturbances as a dynamic process which involves the system's resilience and flexibility, not only from the ecological point of view but also from the social-economic one, i.e. concerning both the provision of forest goods and functions and the relation with society's value system.

According to Levin (1998) the key to resilience in any complex adaptive system is in the maintenance of heterogeneity, the essential variation that enables adaptation. Conventional forest management, aimed at maximizing wood production and based on a command & control approach (Holling & Meffee, 1996), has simplified the structure and composition of forest ecosystems (Puettmannet al., 2009; Nocentini, 2011). This simplification, reducing response diversity (*sensu* Elmqvistet al., 2003, and Mori et al., 2013), makes these systems fragile, more vulnerable to stress, such as parasites, climate change, etc. and thus more prone to collapse because unable to respond in an adaptive way.

Forestry decisions as a product of interactions among actors

In forestry, an increasing part of decisions emanates from a series of interactions between actors that engage with/ and react to/ one another.

Any decision-making procedure has to cope with these interactions, addressing the following questions: (i) who/what interacts?; (ii) what drives or shapes the interactions (global context, actors' interests, values, perceptions, knowledge and resources)?; (iii) what are the mechanisms/pathways of interaction (networks - see Bodin & Tengö, 2012, communities, communication patterns)?; (iv) what is the character of the interactions (competition, coordination, cooptation)?; (v) what are the effects of interactions (stringency or homogenization)?; and (vi) how do interactions change over time?

Those social/institutional interactions permanently interfere with the ecological changes, giving the whole system a dynamic that is constitutive of what is called forestry, and resulting in an instability which the actors tend to reduce or master (Gunderson &Holling, 2002). Although whilst doing so, they introduce new perturbations leading to new feedbacks defining new demands for change (Armitage & Plummer, 2010).

Changing the paradigm of forest management

Forest management has long been dominated by the reductionist and mechanist paradigm founded on two basic principles: (i) perpetuity of the forest based on an equilibrium between standing volume, standing volume increment and allowable cut; (ii) constrained optimization of productions (marketable or not).

This forest management paradigm considers population and ecosystem dynamics as if they were acting in an invariable environment and according to predictable trajectories. In such an approach, silviculture aims at controlling natural processes, and cultivation methods try to obtain forest regeneration according to a predefined stand structure model: even-aged or uneven-aged. Forest management tends towards a regulated distribution of age or diameter classes (Ciancio & Nocentini, 1997; Puettmann *et al.*, 2009). This means that silviculture acts as if forest ecosystems could be governed by controlling a few key variables, while other aspects are practically ignored and classified as casual effects. In this approach forest ecosystems are supposed to be totally understood in their functioning and thus shaped so that future results meet management aims (Nocentini, 2011; Wagner *et al.*, 2014). Yield tables for even-aged stands, or norms 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 & Scotti, 1998). This paradigm inherently assumes that: (i) forest ecosystems react to management in a predictable manner; (ii) it is then expedient to anticipate predicted consequences of decisions (i.e. anticipatory management, *sensu* Kay & Regier, 2000: once all necessary information is gathered to make a scientific forecast, the "right" decision can be made).

Undoubtedly, in former times this approach has contributed to regulate forest exploitation and slow down forest destruction. But classical silviculture and management, with the aim of predicting regeneration rate and producing a constant yield of merchantable wood, have in practice transformed complex ecosystems into simplified systems. Examples of forest stand simplification in the past centuries are the conversion from mixed forest types (*sensu* Barbati *et al*., 2014) with prevailing hardwoods to prevailing conifer forests to foster commercial timber production in Central Europe, or the conversion of mixed forest types with prevailing conifers into hardwood coppices to foster fuelwood production around villages in the Italian Alps and Pre-Alps.

Successfully managing a forest to maximize production of a service (or set of services) may lead to a less resilient and more vulnerable system, not only from the ecological but also from the institutional perspectives (Rist & Moen, 2013).

Actually, a vast bulk of evidence from operational forest stand management shows that predicted outcomes are rarely achieved, at least for naturally originated forests (Puettman *et al*., 2009; Messier *et al*., 2013). Already in 1993, Mladenoff & Pastor wrote that classical silviculture is based on a short term perspective and on a paradigm which considers the forest as being in a constant state and with a constant production. They concluded that, with a full appreciation of the natural complexity of forested landscapes, these assumptions become untenable because processes appear linear and states appear constant only over a limited spatial and temporal field: thus, foresters must shift their emphasis from maintaining the forest in a given state to maintaining particular processes, and change from concentrating on trees to concentrating on the ecosystem.

Summing up, the acknowledgement that the forest is a complex, biological, adaptive system has changed the reference paradigm in forestry: from a logical, rational, analytic and reductionist way of thinking, based on the mechanistic view of nature and aiming at the normalization of natural resource exploitation, to a way of thinking which is intuitive, synthetic, holistic, based on the complexity of forests as social-ecological systems and aiming at supporting their overall resilience and adaptive capacity.

The issue of low predictability

When dealing with complex adaptive systems only hypotheses can be drawn about the effects of management practices (Anand *et al.*, 2010). Forest functioning and structure, specifically forest reactions to management, are neither completely predictable nor completely random: like many complex systems, forests are characterized by multiple feedback links and close dependency on initial conditions, so that prediction has only a weak power and there is always a high degree of indetermination.

Prediction reliability is conventionally considered an essential feature when applying models as quantitative tools in forest management. Under this view, forest ecosystem processes (*e.g.* growth, regeneration, succession) are supposed to be fully predictable and, thus, can be manipulated so that forest responses to silvicultural treatments meet management expectations.

As far as natural and semi-natural forests (*sensu* http://glossary.eea.europa.eu) are concerned, even for the simpler volume or increment forecasting, the predictive power of models is so dramatically limited by structurally unpredictable events to be practically constrained to theoretical productions. For example, De Champs (1985) in the French Massif Central observes that, with 80-100 year rotation periods, each stand usually experiences one or more catastrophic events in the course of its life cycle. Wind breaks, ice storms, diseases, drought, forest fires, pollution, dieback, etc. are examples of phenomena that cannot be considered as having marginal effects on stand development in natural and semi-natural forests. A vast bulk of evidence from literature (*e.g.* Mueller-Dombois, 1987; Rogers, 1996; Rinaldi, 2012; Mitchell, 2013; Barbati *et al*., 2015; Nagel *et al*., 2016) and practical experience highlight that moderate-to-severe disturbances, both natural and human-caused or human-induced, recur relatively frequently in such forests, falling within the spectrum of chronic and acute effects that stochastically drive ecosystem patterns and processes.

Since the nineteen seventies there has been a growing effort in developing the modelling approach to growth-and-yield studies. Conventional yield tables have been criticized and there have been great advancements (Pretzsch, 2009; Weiskittel *et al*., 2011), *e.g.* in the development of process based models (Mäkelä *et al*., 2000). The current portfolio of advanced modeling techniques is wide and also focused on complex systems, so that hypothetical indications on future states of forest stands and landscapes can be actually provided over a wide range of conditions (*e.g.* García, 1994; Kimmins *et al*., 1999; Saltelli *et al*., 2000; O'Hara *et al*., 2001; Haeussler *et al*., 2013), and robust statistical tools, like *e.g.* Bayesian model averaging (*e.g.* van Oijen *et al*., 2013), have been developed to better assess the uncertainty of model predictions.

But what is attainable even by these advances is just hypothetical accuracy and uncertainty assessment, since modelling basically assumes that no other factor has an influence on the modelled phenomenon at hand beside those considered by the model itself. When the variables of a model (or of a set of models) are identified in relation to the observed properties of the phenomenon, many aspects of the phenomenon itself are reduced to only one or few variables or not even represented in the model at all. How then can it be said that "the model is a model of that phenomenon"? This is constrained by a list of assumptions which specify the model and allow for the logical connection between the model and reality. But no list of assumptions can ever be complete: there is no way of excluding the possibility that some disturbing factor, other than the ones explicitly considered, might have an influence. And this is even more evident under the acknowledgement that no stationary state can be claimed for environmental conditions. Only if this list is complete we can be sure that the model is a model of the phenomenon at hand. Thus, a blanket assumption must be implicitly incorporated in the construction of a model: "no other disturbing factor is operative" (Doucet & Sloep, 1992). Of course, this is a problematic assumption since there is no way of guaranteeing its truth! This is the reason of the practical poor usefulness of the anticipatory approach based on model forecasting (Kay & Regier, 2000) for the management of natural and semi-natural forests where the effects of disturbing factors is never negligible, as above stressed.

While "models may be deficient instruments for the reduction of uncertainty as to future system behaviour" (Haag & Kaupenjohann, 2001), they may serve heuristic and theoretical functions and may outline the space of possible behaviour. Distinctively, they may contribute to operational guidelines by supporting field management with the objective of performing a few, crucial experiments whose results can eliminate a large number of alternative assumptions, according to an adaptive framework. In the light of this, we acknowledge that a combination of hypothetical-deductive modelling with guided experimentation may help in understanding certain aspects of how forest ecosystems function and provide context-sensitive knowledge (*sensu* Haag & Kaupenjohann, 2001), and that the hypothetical ability of models to asses uncertainty under certain conditions has potential uses in management, but this perspective is very different, both conceptually and operationally, from founding the management of natural and semi-natural forests on the alleged full predictability of their development as embedded in the anticipatory management approach.

System analysis for adaptive forest management

Adopting an adaptive management approach explicitly considers the system's low predictability as a value, as its capacity to react to impacts, and requires learning from system reactions to support its resilience. Silvicultural interventions, artificial by definition, impacting on the structure of forest stands, provoke a certain level of stress in the system (Rogers, 1996): artificial impact must be constrained within the limits of the forest ecosystem's resilience. Understanding that natural systems are able to preserve their internal organization, withstanding even major structural modifications, helps finding key elements for management. Shifting methodological focus from *a priori* determination to *a posteriori* assessment implies a heuristic approach or a system theory of trial and error. In this we agree with Von Detten (2011) that "incremental and adaptive management strategies directed towards feedback mechanisms and reflexive learning processes seem the proper way to cope with an undetermined future and the problems of risk, uncertainty, ignorance and indeterminacy". Thus, successive forest transformations resulting from human interventions, whether of structural or marginal nature, must be observed and interpreted considering the complex interactive relations linking the management subjects (forest and humankind).

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 (Corona, 2016). This means moving from a strictly ruled forest planning to adaptive management where, generally, indicators (*e.g.* regenerative success, net annual increment, or the proportion of healthy individuals) are not intended as reference thresholds but instead as parameters to measure changes over time (Ciancio & Nocentini, 2004; Corona *et al.*, 2011).

Using sets of criteria and indicators has become a common way to evaluate aspects of sustainable forest management, and several approaches used for certification issues, assessment of forest conditions or adaptability to climate change are described in the scientific literature (*e.g.* Brang *et al.*, 2014). However, forest management is not just an ecological, silvicultural or harvesting issue, because there is a network of ecological, technical and socio-economic aspects which increases problem complexity. Within a system analysis approach, indicators should allow referring to the context of forest management, measure the quantity and quality of the actions taken and the feedbacks of the forest system to these actions.

Systemic silviculture

The consequence of the change in paradigm has been the proposal of a systemic approach in silviculture and management, with the definition of "systemic silviculture" (Ciancio & Nocentini, 1997; Nocentini & Coll, 2013). With systemic silviculture management strategies are based on an adaptive approach and continuous monitoring of the reactions of the forest to silvicultural interventions. Management proceeds along a co-evolutionary continuum between human intervention and reactions of the system, which *de facto* excludes the typical finalism of linear processes which leads to the normalization of the forest (Ciancio *et al*., 1994, 1995).

Compared to other recent alternative forest management approaches which have been proposed during the past years in various parts of the world (Puettmann *et al*., 2015), such as close-to-nature forestry (Jacobsen, 2001), variable retention forestry (Lindenmayer *et al*., 2012) or ecosystem management (Grumbine, 1994), systemic silviculture takes into account most of the characteristics of forests as complex adaptive systems (Messier *et al*., 2013).

According to Puettmann *et al*. (2009), viewing forests as complex adaptive systems shifts management from the stand level to the landscape level. But because systems have a different behavior at the different scales which interact in complex ways, the stand level is also relevant from the silvicultural point of view. When dealing with management, the "regulated forest" is the reference model of the conventional normalizing approach, i.e. a sum of forest compartments where the silvicultural intervention in each compartment is defined by the general model, in a top-down approach; the aim is to "homogenize" composition and structure in each compartment, thereby conceptualizing stands of trees as uniform management units (Puettmann *et al*. 2009) and stands are actually "the building blocks of sustainable, regulated forests" (O'Hara & Nagel 2013). On the contrary, with the systemic approach each stand is treated according to its own specific characters. In this sense we agree with O'Hara & Nagel (2013), that there is an ecological basis for stands in that disturbances, and we add, natural self-organizing processes in a forest, may form discrete stand structures or uniform groups of contiguous trees. With the systemic approach silviculture does not aim to homogenize these differences within a compartment, but tends to follow and adapt interventions to the response of each stand.

In other words, there is no set rule or recipe which can be applied uniformly to the different parts of a forest, only a detailed analysis of the characters of each stand can show how to manage the whole forest. In this approach management must proceed cautiously so that the reactions of the system can be analysed and management adapted so as to take these reactions into account. The landscape level becomes a useful scale from which to analyse the reactions of the forest as a whole.

This relation between the different scales of forest management (from the stand to the landscape) is also determining in defining the adaptive approach of systemic silviculture. Adaptive management of natural resources is not a novel concept (Holling, 1978; Walters & Holling, 1990). The adaptive approach applied to forest management has been discussed by several authors, although with different meaning. Bormann *et al*. (2007) have defined adaptive management as a systematic and iterative approach for improving resource management by emphasizing learning from management outcomes. This requires exploring alternative ways to meet management objectives, envisioning the outcomes of alternatives based on what is known, implementing one or more of these alternatives, monitoring to learn which alternative best meets the management objectives, and then using results to update knowledge and adjust management actions (Borman *et al*., 2007). This type of approach has been usually suggested, and in some cases applied in large scale planning programs (*e.g*. the Forest Ecosystem Management Assessment Team, FEMAT, 1993). "Adaptive forestry" as discussed by Bolte *et al*. (2009) has instead a very different meaning, i.e. management that specifically aims at adapting forest ecosystems to climate change in order to achieve management goals, maintain desired forest ecosystem services and reduce the risks of forest degradation.

The adaptive philosophy of systemic silviculture refers to the concepts outlined by Borman *et al*. (2007), but scales down this approach also to the forest stand level, where each recurring silvicultural intervention is based on an assessment of the reactions to the preceding one. By focusing on learning from the managed system at the silvicultural level enhances local variability thus avoiding to stifle flexibility at one of the relevant scales for forest ecosystem functioning. On the other hand, as pointed out by Messier *et al*. (2013), "accepting less 'control' at the stand scale provides foresters with more flexibility to accommodate self-organization and thus greater ecosystem adaptability at landscape or regional scales".

The problem of cross scale interactions leads to the concept of emergent properties which characterize the behavior of complex system. Emergent properties are ecosystem features that can be assigned only to certain levels of a hierarchy and are functional attributes that do not form simple additive hierarchies, i.e. there is an additional quality created by the interactions within the system that makes 'the whole more than the sum of the parts' (Müller *et al*., 2000). Well known examples are those of the age-related decline in forest growth (Smith & Long, 2001) or the albedo effect from interconnected crowns (Ponge, 2005). Müller *et al*. (2001) have also pointed out that, since emergent properties are always consequences of self-organizing processes, emergence is directly linked with the principle of ecosystem integrity and many emergent properties are suitable indicators for it. A hypothesis that should be further investigated is the use of emergent properties as indicators for monitoring the forest reaction to management (see *e.g*. Müller *et al*., 2000).

Finally, systemic silviculture considers the forest an entity with *intrinsic* value (Ciancio & Nocentini, 1997; Ciancio, 2011), shifting from the anthropocentric-ecocentric dichotomy to an integrated and respectful perception of the forest-humankind relationship. This means taking into a account the ethical dimension, which has recently been pointed out by Batavia & Nelson (2016) as being critically underdeveloped in the discussion of new approaches in "ecological forestry".

Impacts on policy and governance

Constructing forest policy through a social process

In a conventional framework, the common interest is defined by rationalist norms provided by technical expertise, without consideration of the demands expressed by the users. In forestry, it is even sometimes stressed that the common interest contradicts the social needs, whilst the conservation of the resource on the long run is frequently opposed to the satisfaction of present demands for products. This leads to top-down policies, where the public authority has the role of deciding for the greater good of the community.

Adapting public decision to the dynamics of the system implies not to consider policy as a list of formal measures and means for achieving pre-defined objectives, but as a set of actions taken by a network of interactions between the stakeholders and the public authority. In pluralist societies, the model for policy decision tends to the search for a social consensus between stakeholders and the public, the common interest being defined as a consequence of needs and interests expressed by them. In a systemic view, the public decision consists in an articulation of social interests through conciliation. Policy formulation and implementation are understood as a reflexive governance process, based on the interactions between different actors whereas their demands, positions, reactions and coalitions are being permanently re-constructed through mutual learning.

Whilst the various stakeholders do not share the same views on what needs to be done, the role of the public authority is first to translate those visions, and then to co-ordinate the actions in a public context. This leads to an iterative process integrating bottom-up approaches making policy a participatory process of discussion and negotiation among the various interested parties, which results in decisions compromising the various values expressed by the participants.

This process is different from what is usually defined as Participatory Forest Management: PFM aims at giving more effectiveness to decisions taken by the authority by considering all possible information from stakeholders which can help this authority (one actor deciding; usually the forest administration) to take decisions (theory of government). In this framework, the decision is fixed. In a systemic approach, instead, all various stakeholders interact with each other, and the result of this interaction is a commonly assumed decision; the actor in charge of following-up the implementation of the decision (usually the forest administration) has a role of translator of social demands (theory of governance). In such a framework, the decision is not definitive, because it can be re-discussed following results of management or new developments in stakeholders (Mendoza & Prabhu, 2006; Lawrence, 2007).

Communicative mechanisms instead of regulatory tools

In the conventional vision, the policy tools include legal and technical norms that give the rules of the game to stakeholders considered as subjects, which must comply with the rules. Opposite to this vision, adopting a systemic view of forests and forestry leads to promoting instruments that are linked to the social-economic context of the system, and that are aimed at favouring interactions and communication among actors.

Whilst restrictive regulations and obligations are the basic tools in a context of top-down authoritative policy, support by both public and private bodies to groups and individuals, provided through associations and coalitions, is the means in systemic forestry. This support may be economic (grants, subsidies, low-interest loans, payments for environmental services) and educational (capacity development) as well. Communication plays a central role in systemic forestry instruments and mechanisms for policy and governance. Coalitions and networks, as mechanisms and patterns of formal and informal connection between actors measured by communication or exchange, constitute bridging organizations for effective policy learning (Buttoud, 2007, 2014).

Flexible and adaptive modes of governance are required

The process of forest policy formulation and implementation does not only translate a pre-existent social debate into policy terms: it organizes social and policy debate itself, creating values, but also new demands for change, through reciprocal information flow from the participants. Whilst implementing forest policy is a permanent construction of the facts, governance procedures and mechanisms need to be flexible and adaptive to contextual changes. More than the use of a pre-defined set of criteria and indicators as a normative referent, new mechanisms are needed for follow-up and backstopping in order to facilitate communication and interactions among actors, and make the adaptation of the system possible.

In forestry, the reluctance to change centralized top-down models for decision still opposes strong barriers to such an evolution. More than a shift from normative procedures of government to flexible mechanisms of governance, institutional change in forest policy often leads to new modes of government (and not of governance) integrating in the same conventional framework for decision making some of the changes demanded that are translated or sometimes hidden by the strongest stakeholders' desire to retain their power, usually in favour of conventional policies and market mechanisms (Buttoud, 2011). New policies and modes of governance are brought in a comprehensive manner, through a process comprising inhibition and promotion, where learning is directly linked to power consolidation (Kouplevatskaya-Buttoud, 2009). Therefore, backstopping forest policy implementation is an exercise of permanent adjustment and adaptation. Change of governance, as implied by the development of a systemic forestry, means also governance of change.

Promoting changes in forest management, policy and governance

Practical forest management has many challenges ahead, the first of which is usually advocated to be providing more wood production with less input and less environmental impacts. However, it can be argued that the very major challenge is of theoretical nature in itself. Managing in the face of uncertainty will require a portfolio of approaches, including short-term and long-term strategies that focus on enhancing ecosystem resistance and resilience as well as assisting forest ecosystems to adapt to changes in climate, environment, economy and society

According to Wagner *et al*. (2014), a "maximum flexible" forest may be described, theoretically, by its ability to adapt to any change in the ecological or economic environments. In this view, because ecological functions are the basis for the functioning of systems in a changing environment, they are set prior to economic and social ones. However, the extent to which the economic and social functions might follow depends on many factors, among which the aims and expectations of the different owners are the most relevant.

Forest planning has been primarily concerned with wood and cash flows, i.e. sustainable timber (yield) management. Traditionally, planning and decision making in forestry are performed along a hierarchical framework that consists of a strategic level, a tactical level and an operational level, each covering different spatial and temporal scales. The top of the hierarchy (strategic level) focuses on the long-term planning horizon and large spatial scale or national planning. Strategic planning must be translated to specific tracts of land (*e.g.* a forest estate, a forest concession): the tactical level performs this translation task, the purpose of which is to produce a spatially feasible schedule of management operations that can be implemented in specific areas and on a finer time scale, considering the wood and non-wood products and ecosystem services to ensure. An output from the tactical plan is a set of stands to be further inventoried in detail and passed to the operative planning level.

Each level of this management hierarchy can involve the development and application of optimization models. These models typically aim at exploring management alternatives as well as multi-objective trade-offs. However, this hierarchically-based modelling to support forest planning has critical issues: when decisions taken at different levels are confronted, many differences may appear, and solutions at one level may be inconsistent with the results at another level. It can be also stressed again that, at tactical and operational levels, a current major challenge, at least as far as the management of naturally originated forests is concerned, is to move from approaches based on forecasting (i.e. the root of the traditional anticipatory management idea) to approaches based on monitoring, by accepting that optimization models actually have low ability to effectively support the management of natural renewable resources. And this means again to straddle from a strictly ruled hierarchical forest planning to adaptive management.

Adaptive management is a methodological approach that views practices as if they were experiments to be studied, so that the results from one monitoring inform subsequent decisions (McDonald-Madden *et al*., 2010). To accomplish this, the adaptive management literature advocates that a cyclical approach to management can be adapted as circumstances change and people learn.

Adaptive management systematically integrates results of previous interventions to iteratively improve and accommodate change by learning from the outcomes of experimented practices: 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 & Regier, 2000: "much of adaptive management efforts is learning through experimentation rather than focusing on error avoidance").

In practice, 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 to be adaptive when external conditions change; (iii) maintaining a flexible view of participation (multi-stakeholder participation results in better management plans, and suggests that participatory methods are an effective way of capturing the information and perspectives necessary to manage social–environmental systems).

Relevant steps for adaptive management are reported in pillar textbooks like *e.g.* Salafsky *et al.* (2001). However, adaptive management is not a theoretical exercise. On-the-ground examples and tools for successful adaptive management are still being developed, even in the perspective of a bio-based economy (Corona, 2014), in what is a highly adaptive process of experimentation in many locations around the world (Armitage *et al.,* 2009).

Evolving perceptions in forestry and the systemic approach

The appeal for a change in silviculture and forest management is certainly not new, and a comparison of systemic forestry with the main approaches which have been suggested is useful (Table 1). Recently, Duncker *et al*. (2012) have classified management approaches along a gradient of intervention intensity, suggesting five Forest Management Approaches (FMA) based on the objectives of management and allowed silvicultural operations. In this classification "intensive even-aged forestry" (FMA IV) and "short rotation forestry" (FMA IV) correspond to "Conventional forestry", as used in this paper, which typically emphasizes commodity production and views other objectives as constraints.

Silvicultural approaches which can be viewed as alternatives to conventional forest management have been developed in various parts of the world, but interest in these alternatives has greatly increased in many regions over the last three decades (Puettmann *et al*., 2015). In Europe the attention has focused mostly on Close-to-Nature Forestry (CTNF - *e.g.*, Germany, Switzerland, Slovenia, Italy, ProSilva 2014) or Continuous Cover Forestry (CCF - *e.g.*, UK and Ireland; Wilson, 2013). Due to its origin and wide-spread application, CTNF (including CCF for the purpose of this discussion) cannot be regarded as an approach with a single commonly agreed definition and a well-defined, established scientific basis (*e.g.* Pommerening & Murphy, 2004). According to the classification by Duncker *et al*. (2012), the objective of close-to-nature forestry (FMA II) is to manage a stand with the emulation of natural processes as a guiding principle, economic outturn is important but must occur within the frame of this principle. FMA III (combined objective forestry) assumes that various management objectives can be combined in a manner that satisfies diverse needs, and, generally, economic and ecological concerns play a major role. FMA III includes syilvicultural systems (*e.g.* strip shelterwood, group and uniform shelterwood) which by other authors have been considered as part of a close to nature approach (*e.g.* Brang *et al*., 2014), so here we consider them together (Table 1).

Whereas these definitions reflect an European perspective, a second school of silvicultural approaches originated in Northern America as a reaction to large-scale clearcutting in natural forest ecosystems and its impact on wildlife habitats, visual quality, and other ecosystem functions. Batavia & Nelson (2016) have collectively defined these approaches "ecological forestry", which comprises both natural disturbance based management (Oliver, 1981; Attiwill, 1994; Franklin *et al*, 2002, 2007; Kuuluvainen & Grenfell, 2012) and variable retention harvesting (Franklin *et al.,* 1997, Gustafsson *et al*., 2012, Lindenmayer *et al*., 2012). Harvesting decisions in all these alternative approaches are generally driven by an appreciation of the economic and ecological value of retained trees in terms of ensuring the continuity of ecosystem processes and functions.

According to Bauhus *et al*. (2013), CTNF has been defined by a set of general principles that are derived from the common goal of managing for high value wood production. According to Puettmann *et al*. (2015), alternative approaches aim to maintain or increase the growth potential of the site, thus conforming to traditional sustained-yield paradigms.

The comparison between systemic forestry and CTNF and "Ecological forestry" (Table 1) shows that although there may be some common points (*e.g.* the importance

Table 1. Comparison between "systemic forestry" and other approaches.

	"Conventional" forestry[1]	**Close to nature forestry**[2] **Ecological forestry**[3]	**Resilience thinking**[4]	**"Systemic" forestry**
View of the forest	The forest as a sum of trees	Focus on trees expanding to include soil and biodiversity. The forest as an ecosystem	Forests as complex social-ecological adaptive systems	
Multifunctionality	*Wake theory*: if forests are efficiently managed for wood production, then all the other forest utilities will follow	The production function must comply with conservation of other values (*e.g.* biodiversity). Multiple use forestry based on a sound ecological basis	Focus on maintaining options rather than a particular way of using a resource	Multifunctionality is the outcome of complex interactions between various sub-systems
The Future	High predictability	Predict ecological consequences of management practices	Low predictability - Uncertainty is acknowledged	
Management	Approaches based on forecasting	Management based on knowledge of past disturbance regimes and/or "desired future condition"	To maintain a desirable state (identity), or transform into a more desirable state	Approaches based on monitoring and adaptation of silvicultural interventions to reactions of the system
	Maintain an optimal condition of the resource		Maintain the systems' identity - function, structure and feedbacks	Develop an optimal management capacity
	Strictly ruled forest planning	Planning based on multifunctional optimization models	Maintaining options rather than a particular way of using a resource	Adaptive forest planning
Forest policies and the common interest	Defined by rationalist norms provided by technical expertise		Network of interactions between stakeholders and public authority Social and ecological components of the system are treated as inseparable and strongly linked "social-ecological systems"	
Policy tools	Legal and technical norms give the rules of the game to which stakeholders must comply	Different stakeholder concerns are considered and correctives applied (*e.g.* for biodiversity conservation)	Strongly emphasises adaptive comanagement, as well as adaptive governance Instruments favouring interactions and communication among actors	
Ethical standpoint	Anthropocentric utilitarian ethic Forests as a resource for human exploitation	From anthropocentric to un-explicit attempts to dismantle the dichotomized worldview	(not considered)	Non-antrhopocentric ethic: the forest has intrinsic value Integrated and respectful perception of the humankind/forest relationship

[1] *e.g.* Duncker *et al*. (2012) FMA IV and V, see text for discussion. [2] From Duncker *et al*., 2012; Jacobsen, 2001; Gamborg & Larsen, 2003; Bauhus *et al*. 2013, see text for explanation. [3] *sensu* Batavia & Nelson, 2016. [4] From Rist & Moen, 2013.

of other values rather than just wood production, an attention to the various components of the forest ecosystem), there are many clear differences. We agree with Rist & Moen (2013) that in theory and application forestry is organized around a specific paradigm and a particular set of principles, concepts, generalizations, or assumptions regarding how the system subject to management functions: these have a fundamental influence, among others, on management philosophy, including normative aspects of management, and on how the human-nature relationship is perceived (Rist & Moen, 2013).

One of the main distinctive issues of systemic forestry is precisely the reference paradigm, which for Conventional forest management, CTNF and "Ecological forestry" is fundamentally based on predictability, and the emphasis of management, mainly shaped by technical considerations, is on continuity and stability. Instead, systemic forestry explicitly refers to the complex adaptive systems paradigm, recognizes unpredictability and uncertainty, and shapes forest management and policy decisions on an adaptive co-management approach based upon interaction between actors (Table 1). But the most radical difference is in the human-nature relationship: in Conventional forestry, CTFM and Ecological forestry, the forest is finally considered an entity with instrumental value which can be shaped by silviculture and management to respond to human aims and expectations. Instead, in the systemic approach, the forest is considered an entity with *intrinsic* value. We believe that this new ethical outlook, which is unique, as far as we know, to systemic forestry, can provide it with the cohesion and consistency of a general philosophy of forest management and conservation (*sensu* Batavia & Nelson, 2016).

Many more points in common can be found between systemic forestry and "resilience thinking" which has been proposed by Rist & Moen (2013) as a possible approach to dealing with sustainability challenges in forestry (Table 1). In both cases the reference paradigm is to complex social-ecological adaptive systems, uncertainty and unpredictability are acknowledged and strong emphasis is on adaptive co-management, as well as adaptive governance. But we believe that systemic forestry goes further on the operational level by defining silvicultural and management criteria and procedures (cfr. par 3.3, but see also Ciancio & Nocentini, 2011; Nocentini & Coll, 2013). And, finally, resilience thinking does not explicitly refer to the human-nature relationship.

Conclusions

In the last decades there has been a growing attention towards the need for a change in the way forests are viewed and managed. Systemic silviculture, first theorized in the 1990s', is based on the assumption that forests are complex biological systems and as a consequence, silviculture and management must change both the reference paradigm and operational approaches. Systemic silviculture anticipated the increasing attention that complexity theory is having at present in the forestry agenda. In addition, systemic silviculture urged for a change in the human-forest relationship, recognizing that forest ecosystems have *intrinsic* value. This latter aspect, concerning the ethical foundations of forestry, has only very recently come to the fore. Based on the concept that forest ecosystems are complex social-ecological systems, "systemic forestry" expands the scope of the systemic approach to include the planning and policy levels.

Our analysis shows that compared to other "alternative" forest management and silvicultural approaches which have been recently suggested, systemic forestry can embody a conceptual and operational framework which is coherent with complex adaptive systems theory, allows for uncertainty, is based on a co-evolutionary view of ecosystems and society, and includes ethical considerations.

Summing up, a series of actions will be needed to implement the systemic approach, depending on the changes that are expected, specifically:

1. Forestry is considered within a broader landscape approach: multi-sectoral coordination is achieved through developing connections between forestry action and other systems, at the broader level of a landscape. Action required: *Develop forestry strategy and forest management programmes as part of a landscape approach.*
2. The logic of forestry action changes from norms to process: this results in a move from juridical/technical norms into a process of analyzing links between ecology and social aspects, changing the way management plans are elaborated and applied, and considering the type of policy to be implemented (link policy-governance). Actions required: *New methodology for integrated forest management plans; new approach for forest policy formulation and assessment (depending upon demands for change expressed by stakeholders).*
3. Conservation is viewed as a search for resilience: while forestry faces internal/external changes, the forester's role is to look for optimal technical solutions for adapting without losing identity. Actions required: *New approach for conservation confronting experts in resilience (social, ecological) to stakeholders' expectations and demands; definition of local dynamic criteria and indicators to be used to assess the capacity of the system to absorb perturbations whilst maintaining its integrity*.
4. Multifuctionality is re-defined through a multi-entry approach: instead of counting on the supposed wake effect of either timber production (single entry through economy) or biodiversity (single entry through ecology), promote a multi-entry integration (ecology, economy, society) using a combination of optimization (experts' modelling) and negotiation (stakeholders' involvement) based on interrelated impact analysis. Action required: *New methodology for cross-checked impact studies integrating ecological, economic and social aspects.*
5. A re-framing of forestry institutions focusing on changing interactions: change from juxtaposed services with segmented tasks and expertise, to a new type of technical action linking people, sectors, and levels of decision making. Actions required: *Re-organize the public body support to stakeholders by type of*

interactions; promote inter-connections between sectors (e.g. agroforestry development, or land use and land use changes coordination).

6. A shift from the conventional anthropocentric world view to a more respectful relationship between humankind and forests. Actions required: *An open discussion on the ethical dimension of forestry and forest management.*

We are aware that our proposal, being a conceptual framework, must not be considered a one-size-fits-all solution: it will surely need to be adapted to the very different situations which characterize forestry, both from an ecological and institutional point of view. Developing a systemic forestry approach especially requires changing the role and work of the forest department in charge of accompanying the adaptation of the system, thus directly impacts the institutional and organizational structure, as well as the curriculum, training and education of foresters. Such a change is needed in order to link together sustainability and change, which are two basic components of the forestry issue.

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