MANAGING FORESTS AS COMPLEX ADAPTIVE SYSTEMS: AN ISSUE OF THEORY AND METHOD

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Classical forest management has worked out a series of forest regulation methods with the aim of obtaining the "fully regulated" forest. Considering the forest as a complex biological adaptive system means overcoming the reductionist and mechanist paradigm, and entails a shift towards a systemic approach in silviculture and forest management. The aim of this work is to discuss the objectives and theoretical assumptions of classical forest management methods in the light of the new systemic paradigm. I conclude that managing forests as complex adaptive systems and sustaining their ability to adapt to future changes is possible only if there is also a change in forest management methods so that they are consistent with the new theoretical approach.

Keywords: forest regulation methods, normal forest, complexity, systemic silviculture.
Parole chiave: metodi di assestamento, bosco normale, complessità, selvicoltura sistemica.

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1. Introduction

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

In analogy with this paradigm, silvicultural systems have aimed at guaranteeing stand regeneration according to a specific structural model and species composition, while forest management has strived to organize silvicultural operations in time and space in the attempt of obtaining a maximum and possibly constant yield (Ciancio and Nocentini, 1994; Puettmann *et al.*, 2009). This classical forest management paradigm treats population and ecosystem dynamics as if they acted in an invariable environment and according to predictable trajectories. In this approach, silviculture is based on the control of natural processes (Ciancio and Nocentini 1997; Puettmann *et al.*, 2009). The forest has been considered an instrumental entity, a sum of individual trees which can be organized spatially and temporally according to the desired, predictable outcomes (Nocentini, 2011).

Classical forest management has devised methods and procedures (*forest regulation methods*) to guide the forest towards the "fully regulated forest", an *ideal forest* capable of fulfilling sustained yield i.e. approximately equal annual harvest or equal annual growth from the managed forest (Davis *et al.*, 2001, p. 9). Under this view, the future has been considered as practically unchangeable, at least concerning the main factors influencing forest productivity and stand development, and forest ecosystems have been considered as systems which can be totally understood in their functioning and thus shaped so that future results meet management aims (Nocentini, 2011; Wagner *et al.*, 2014). This implies faith in the fact that ecosystems react to cultivation in a predictable and linear manner.

The acknowledgement that the forest is a complex, biological, adaptive system (Ciancio and Nocentini, 1997; Puettmann et al 2009; Messier *et al.*, 2013a; Filotas *et al.*, 2014) has changed this reference paradigm: from a logical, rational, analytic and reductionist way of thinking, based on the mechanistic view of nature, to a way of thinking which is intuitive, synthetic, holistic and based on the theory of complexity (Ciancio and Nocentini, 1997; Puettmann *et al.*, 2009; Messier *et al.*, 2013a).

With the awareness that the future conditions of forests and forestry might rapidly change following global change, the deterministic approach of classical forest management has lost one of its strong points: a certain and predictable future. If we accept the fact that the forest is a complex biological system, then we must accept the fact that forest ecosystem's organization and reactions follow processes which are neither totally predictable nor totally random (Anand *et al.*, 2010).

Shifting to the complexity paradigm thus requires a change in methods and approaches in forest management.

Here I analyze the theoretical background of the key methods which have been defined in the course of time. The aim is to define a possible methodological approach to managing forests which is consistent with viewing forests as complex adaptive systems and above all is capable of effectively maintaining the overall resilience of forest ecosystems.

2. Classical forest regulation methods

Over the years of forest history, a great many forest regulation methods have been developed in various parts of the world, especially in Europe; Recknagel in 1917 described 18 methods and more have been devised since then (Davis *et al.*, 2001).
Forest regulation methods address the question of determining the allowable cut in terms of area, volume or number of trees to be cut each year (or a combination of these) in relation to the fully regulated forest model (Patrone, 1944). Different criteria have inspired the "silvicultural method" described by Knuchel (1953), and of Gurnaud's Control method.

2.1. Area regulation methods: from forests to plantations

With *area regulation methods*, the working plan prescribes how many hectares should be cut annually or in each time period, without specifying the type or amount of volume to be cut. These are the simplest and oldest methods: according to Huffel (1926) the idea of fixing the area of the cut was so natural that it must have come immediately to mind to the first foresters who aimed at regulating forest felling.
The aim of these methods is to reach a forest with a "normal" age structure, i.e. a forest organized so that each age class occupies an equal area. According to Tahvonen (2004) the "normal forest" concept (or perfectly regulated or synchronized age class structure) has played an important explicit or implicit role in forestry. For example, Reed (1986, in Tahvonen, 2004) writes: "The ideal of normal forest is thus linked to that of sustained yield, and it has, it seems, occupied a central place in forestry thinking, for as long as a scientific discipline called 'Forestry' can be said to have existed."
With area regulation methods the "normal" forest can be reached only in the case of even-aged stands with prompt and reliable regeneration. For this reason they have been applied in Italy with some success to coppices (Ciancio and Nocentini, 2004). Applying this method to naturally regenerated high forests, where regeneration is less prompt and reliable, gives uncertain results. One of the consequences has been that to obtain the "normal" distribution of stands in age classes, many natural forests have been transformed into plantations. A classical example is that of Central Europe, where starting from the 19th century, large areas of the natural mixed forest were transformed into spruce plantations. This trend lasted well into the 20th century (Leopold, 1936a, 1936b; Wolfe e Berg, 1988). A good example in Italy is that of the Vallombrosa Forest where, following the application of forest regulation plans based on the area regulation method, silver fir plantations increased from 217 hectares in 1876 (Giacomelli, 1878) to 680 hectares in 1960 (Patrone, 1960; Bottalico *et al.*, 2014). It is interesting to note that even where the area regulation method has been consistently applied for long periods of time, the "normal forest" has almost never been reached, which proves the impossibility of exactly forecasting both forest response to management and changes in the general conditions. A clear example of this is the 1821 working plan drawn out by Cotta for the Colditz Forest, in Saxony, which was based on the normal age class series: in 1921, i.e. 100 years later, notwithstanding the same property, working plan principles, and the authority of Cotta, the forest was still far from "normality" (Heske, 1938, in Heilbron, 1990).

2.2 Volume regulation methods: the quintessence of predictability

Volume regulation methods prescribe the quantity of volume that must be felled each year. In the oldest and simplest form, each year the forester went through all the forest marking the biggest trees (in uneven-aged forests) or the oldest stands (in even-aged forests) until he reached the prescribed cut (Huffel, 1926). The first indications of a method for calculating the prescribed cut in terms of volume can be found in Germany around the middle of the eighteenth century, which later developed into Hartig's method (1795). In the same period the "Austrian Cameral method" was developed in Austria, a forest regulation method based on forest increment and on the "normal" standing volume. These methods were inspired by what Heilbron (1990) defines "the quantifying spirit" of the 18th century, when forest management turned to mathematics and geometry to organize production. According to Lowood (1990) the most striking example of this spirit can be found in Germany where forest management was one aspect of state administration which was scrutinized in order to fit "scattered pieces of knowledge ... into systems" and to transform "all sorts of activities previously left to habit ... into a science." (Bechstein, 1797, in Lowood, 1990). The result was quantification and rationalization applied both to the description of nature and to the regulation of economic practice.
According to Samuelson (1976), the 1788 Austrian Cameral method was the first example of the notion of sustained yield (Amacher *et al.*, 2009): with this method the best rotation age was described as the one that maximizes timber volume produced per unit of land over time. It is interesting to note that the Austrian Cameral method was the first method that referred directly to the concept of the standing volume of the normal forest. For this reason it has a great historical and conceptual importance. The Cameral method belongs to those methods that the Germans called *Formelmethoden* because it uses mathematical formulae to calculate the normal standing volume and the prescribed cut.
All these methods require a deep knowledge of the mechanisms that regulate forest growth. For this reason they stimulated the development of forest auxology and contributed to the birth and growth of forestry as a science. Yield tables have been one of the main products of this scientific activity. As standard tools for forest management, yield tables have been developed

mainly from 1795 until 1965 (Skovsgaard and Vanclay, 2008; Pretzsch *et al.*, 2013). Being based on survey data from long-term plots, they mirror growth under past environmental conditions (Pretzsch, 1996, 1999). An important component of this scientific approach is that forest growth can be modeled in a smooth and continuous manner and that spatial changes can be handled as gradual changes along one or more gradients (Skovgaard and Vanclay, 2007). Skovgaard and Vanclay (2007) point out that despite documented examples where site potential and forest site productivity are not constant but change over time (e.g. Spiecker *et al.*, 1996; Valentine, 1997), it is still widely held that site productivity should be constant and invariant within site types that are uniform with respect to climate, topography and soils. Skovgaard and Vanclay (2007) also point out that users should be aware that this does not always apply.
The importance of the "Cameral" approach in forest regulation in stimulating research in the field of forest growth and modeling must be acknowledged. But today we must also recognize that if these studies may be satisfactory when the main objective is to increase our understanding of current functioning and dynamics, it is less useful to study futures, where we need to emphasize what is not known (Bell, 2003).
If in 1926 Huffel already asked: "is knowledge in these fields sufficiently certain and complete to remove all risks from these methods?", today we can say that these methods are the quintessence of the deterministic approach: they are firmly and indissolubly tied to the possibility of forecasting with certainty the processes that determine forest growth.

2.3 Forest regulation methods based on the number and size of trees: nature entrapped in curves
According to Huffel (1926) the methods based on the number and size of trees to be cut were the first to be employed in forest regulation for uneven-aged stands because they were the simplest and most direct. The development of these methods brought to the definition of a "balanced" tree distribution in diameter classes in uneven-aged forests. The work of De Liocourt (1898) at the end of the 19th century started a line of research which has been developed throughout the 20th century (Peng, 2000). The balanced concept has been referred to as a sustainable, equilibrium, or steady state structure in uneven-aged modeling studies (Adams and Ek, 1974; Adams, 1976; Lorimer and Frelich, 1984; Hansen and Nyland, 1987; Chapman and Blatner, 1991; Gove and Fairweather, 1992; Peng, 2000).
The idea that it is possible to constrain a forest to adapt to the "normal distribution" is based on a solid faith in the possibility of predicting and directing with sufficient accuracy the auto-organizing processes of the forest. Or, in other words, nature entrapped in curves.

2.4 Gurnaud's control method: away from the normal forest
Gurnaud's control method (1886, 1890) is very different from all other forest regulation methods because the allowable cut is not calculated *a priori*, but is instead verified *a posteriori* (Ciancio and Nocentini, 1994). The method is based on the control of the reaction of the forest: at every inventory, growth is estimated by comparison with the preceding inventory. If the forest has reached the *étale* (Biolley, 1920), the allowable cut will be equal to the increment. Gurnaud never referred to the normal forest and Biolley (1920), cautioning against excessive dogmatism, wrote that the *étale* could and should be different according to the local situation, the callipering limit, the limits of the size classes (small, medium and big trees) and also following local market needs (Favre, 1980; Bettelini, 1986).
Gurnaud's method, by rejecting the normal forest concept, is not just a technical change, it is a real mutation in silviculture and forest regulation (Ciancio and Nocentini, 1994). The adaptive approach which characterizes it, i.e., adapting the cut to the reaction of the stands, can be considered an anticipation of concepts which are connected to managing forests as complex adaptive systems.

2.5 The silvicultural method
Pardé (1930) suggested prescribing the cut following exclusively silvicultural considerations for uneven-aged forests which could not be managed with "normal" methods i.e., mountain forests, old forests or forests where the main object was not wood production but conservation of the forest, such as in the case of the Fontainbleau forest. According to Knuchel (1953) the "silvicultural" method is different from all other forest regulation methods because these first calculate the allowable cut, which is then distributed among the different compartments according to the felling plan. With the silvicultural method, the cut is first determined for each compartment in accordance with silvicultural considerations, from which the prescribed cut for the whole forest is then derived. This method was customary in western Switzerland. The advantage of the method depended on the fact that the allowable cut was determined on the basis of local conditions and of the foresters' expertise. Thus all parts of the forest were treated according to the effective silvicultural needs of the stands; gross errors were avoided and errors of estimation could be soon spotted with inventories carried out at 10 year intervals (Knuchel, 1953). The guiding criteria was that after the felling, the forest should always be in a better state than before: the "possible yield ought not, therefore, be determined on the basis of a formula or of an exploitation plan alone, but attention should always be paid in the first instance to the silviculturist point of view" (Knuchel, 1953).
In Italy this method was first described by Cantiani (1963) as a method for guiding forest stands without a "normal" structure (which he called "irregular"), towards "normality", while at the same time increasing the productive capacity of each compartment. Thus the silvicultural method became a tool for bringing "irregular" forest stands back into the domain of classical forest regulation methods based on the "normal forest" model (Ciancio *et al.*, 1995).

Following Cantiani's approach, the silvicultural method has been used in Italy for stands where, for various causes, structure cannot be classified as clearly even-aged or uneven-aged. This is often the case of stands resulting from the incomplete application of silvicultural treatments such as the uniform shelterwood felling in beech forests. Here the prescribed cut is determined for each compartment following silvicultural considerations with the aim of bringing stand structure back to the "normal" situation, then the total prescribed cut is compared to the prescribed cut derived from classical volume regulation methods.

3. Managing forests as complex adaptive systems: a change in theory and method

From this quick outline of the development of forest regulation methods and their relationship to the underlying theories, it is clear that the area regulation method, the volume regulation method and those methods based on a balanced diameter distribution, are firmly anchored to the mechanist view of nature and to a paradigm based on the deterministic and reductionist approach.

Managing forests as complex adaptive systems changes the underlying paradigm and therefore a change in methods is also needed. As Rist and Moen (2013) have pointed out, forest management has long been oriented toward maximizing returns of a restricted set of outputs and still today the tendency to focus on a narrow set of management goals and methods fails to give adequate attention to the provisioning of a wide array of ecosystem services, including biodiversity. Furthermore, successfully managing a forest to maximise production of a service (or set of services) may lead to a less resilient and more vulnerable system, from both ecological and institutional perspectives (Rist and Moen, 2013). High adaptability and flexibility of forests are needed to cope with increasing uncertainty due to climate change in the future (Wagner *et al.*, 2014). Thus, management of complex forest systems cannot work on a deterministic basis (Ciancio and Nocentini, 1997; Puettmann *et al.*, 2009).

Changing management methods means adopting an approach which increases adaptability of forests by favoring diversification, self-organization and complexity. Management based on systemic silviculture, which considers the forest a complex and adaptive biological system, integrates analyses, methods and operational procedures that are coherent with many attributes of complex systems (Ciancio and Nocentini, 1997, 2011; Ciancio *et al.*, 2003; Nocentini and Coll, 2013).

With the systemic approach, monitoring is an essential element for adapting cultivation and management to the responses of the system. Management aims towards conserving and increasing complexity and implies decentralized control (Nocentini and Coll, 2013). Forest ecosystems are viewed as moving targets and, accordingly, management will need to be flexible, adaptive and experimental (Messier *et al.*, 2013).

Focus is not on the prediction of the effect of each intervention but rather on the reaction to it as tracked by relevant indicators. This means moving from a strictly ruled forest planning towards adaptive management where, generally, indicators are not used to define the desired future condition, but as parameters to measure changes over time (Ciancio and Nocentini 2004; Corona and Scotti, 2011).

The concept of a "minimum" growing stock, which should always be present on a management unit (Ciancio and Nocentini, 2011; Nocentini and Coll, 2013; Wagner *et al.*, 2014), addresses the question of keeping forest ecosystems above the "critical" zone, where the ecosystem may transfer to another stability domain (Ekins *et al.*, 2003), while at the same time keeping more options open for the future (i.e., increase flexibility).

Systemic forest management integrates the basic criteria of two forest regulation methods which have been considered marginal or even outside classical forest management: the silvicultural method, freed from any reference to the "normal forest" concept, and the adaptive approach typical of the control method.

In conclusion, managing forests as complex adaptive systems and sustaining their ability to adapt to future changes is possible only if there is also a change in forest management methods so that they are consistent with the new theoretical approach.

RIASSUNTO

La gestione del bosco come sistema biologico complesso e adattativo: una questione di teoria e di metodo

L'acquisizione in campo scientifico della nozione di bosco come *sistema biologico complesso e adattativo* ha comportato il superamento della visione deterministica e meccanicistica del bosco e il passaggio a una gestione basata sulla selvicoltura sistemica.

Lo scopo del lavoro è di verificare se l'assestamento classico può essere coerente con questa nuova visione. A tal fine vengono esaminati obiettivi e presupposti teorici dei principali metodi di assestamento.

Si conclude che solo rendendo di nuovo coerenti il metodo con la teoria, l'elaborazione di un piano di gestione forestale può diventare un supporto fondamentale per garantire l'aumento dell'efficienza complessiva dell'ecosistema forestale e soprattutto la sua capacità di adattamento ai cambiamenti che caratteriz-zano l'attuale realtà non solo ambientale ma anche sociale ed economica.

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