



From conservation to management: lessons from old-growth forests

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Abstract: Interest in old-growth and virgin forests dates to the second half of the nineteenth century, when they became subjects of scientific investigation in search of inspiration for the development of close to nature silviculture as an alternative to financial and production-oriented forestry. Research conducted across diverse environmental contexts revealed a remarkable diversity of forest structures and composition, showing that no single model of the “natural forest” exists. Today, there is growing recognition that attempting to manage complex, dynamic, and unpredictable ecosystems through deterministic models is a paradox. This perspective paper explores whether and how old-growth forests can inform closer-to-nature and silvosystemic forest management. Acknowledging their role in advancing ecological understanding, old-growth forests have much to teach us. Their value invites us to move beyond the traditional utilitarian paradigm of silviculture by embracing a deeper ecological comprehension and accepting complexity as an inherent feature of forest management.

Key words: old-growth forests ecological complexity, Silvosystemics; adaptive management; biodiversity conservation.

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1. INTRODUCTION

In recent years, silviculture and forest management have faced a growing demand for practices that better reflect the natural functioning of forest ecosystems. The European Biodiversity Strategy for 2030, under the motto “Bringing back nature into our lives,” calls on Member States to promote biodiversity-friendly forestry and approaches that are “closer to nature.” Similarly, the European Forestry Strategy for 2030 outlines a vision of

forest management aimed at enhancing both conservation value and climate resilience. Within this framework, the concept of “closer-to-nature forest management” has been defined by the European Forest Institute (Larsen et al., 2022), followed by the publication of official guidelines by the European Commission in 2023.

Increasing the naturalness of ecosystems is also a central objective of the EU Nature Restoration Law, which establishes legally binding targets for the restoration of terrestrial, ma-

rine, freshwater, and urban ecosystems, contributing to the EU's climate mitigation and adaptation goals.

The search for forest management approaches closer to natural processes is certainly not new. Between the late nineteenth and early twentieth centuries, the shortcomings of so-called financial forestry stimulated a search for both theoretical and practical innovations in forest management. This shift is well illustrated by some well-known aphorisms of the time: “*imitez la nature, hâtez son œuvre*” by Adolphe Parade and “*Zurück der Natur*” by Karl Gayer.

Nevertheless, despite the long history of nature-inspired forest management approaches and the vast scientific literature on the subject, silvicultural models that depart from the classical paradigm primarily, if not exclusively oriented toward timber production, are still struggling to become widely established, both in Europe and globally (Puettmann et al., 2015).

At the same time, there has been increasing attention in recent decades to the ecological importance of old-growth forests for biodiversity conservation (Paillet, et al., 2010; Sabatini et al., 2021). Scientific literature on this topic has grown rapidly since the first seminal contributions published in the last decades of the twentieth century (e.g., Franklin et al., 1981; Franklin & Spies, 1991; Hansen et al., 1991; Keddy & Drummond, 1996).

Research has turned towards identifying indicators of old-growth connected to biodiversity conservation (habitats and species) to be used to assess sustainable forest management practices (Lindenmayer et al., 2000; Bauhus et al., 2009). Furthermore, the role of virgin and old-growth forests as carbon sinks is today gaining increasing attention (Schulze et al., 1999; Luyssaert et al., 2008; Motta, 2008; Piovesan et al., 2010; Marchetti et al., 2012; Burrascano et al., 2016; Chiti & Piovesan, 2023; Keith et al., 2024). Beyond their ecolog-

ical and environmental dimensions, the cultural and spiritual significance of old-growth forests is increasingly recognized: they are seen as emblematic sites of the historical and symbolic relationship between humans and nature, guardians of landscapes and collective memories that extend far beyond purely productive functions (Moore, 2007; Owen et al., 2008; Kanowski & Williams, 2009; Connell et al., 2015; Gilhen-Baker et al., 2022).

The question of whether old-growth forests can serve as a reference model for closer-to-nature forest management is gaining renewed attention, particularly in light of increasing awareness of the complex relationship between human influence and forest evolution, an interplay that makes it difficult to clearly distinguish what is “natural” from what is anthropogenic.

The object of this perspective paper is to examine whether old-growth forests can inform forest management in line with closer to nature and silvosystemic approaches under current European frameworks. Starting from a historical overview, I then explore the role of old-growth forests in fostering a deeper ecological understanding and in integrating complexity as an intrinsic component of forest management. A specific focus on Mediterranean old-growth forests and a case study integrating forest planning and old-growth conservation are used as examples of the lessons that can be learned from research on these unique ecosystems.

2. SEARCHING FOR A MODEL OF FOREST NATURALNESS

Starting in the second half of the nineteenth century and continuing through the first half of the twentieth century, virgin forests increasingly attracted attention as a source of knowledge for developing a more “natural”

approach to silviculture (Brang, 2005). During this period, numerous studies on virgin forests were published (see Jones, 1945, for a detailed review). Foresters primarily sought to understand whether natural stands were monospecific or mixed, whether their structure was uniform or heterogeneous, and how natural regeneration processes operated (Rubner, 1920, cited in Brang, 2005).

Following the Second World War, the scarcity of virgin forests in Western Europe fostered collaborations with Eastern European researchers, particularly in the Carpathians and the Balkans, with the aim of strengthening the scientific basis of close-to-nature silviculture (Susmel, 1956, 1980; Leibundgut, 1959, 1960; Pintarič, 1959; Mlinsek, 1967). Although these studies often lacked clear management applications (Brang, 2005), an important exception was Lucio Susmel's "equilibrium state" model for uneven-aged forests, developed through comparisons between virgin forests and managed forest systems (Susmel, 1956, 1980).

Overall, these early comparative studies highlighted the considerable diversity in forest composition and structure, challenging the notion of a single and universal model of the "natural forest."

Between the late 20th and early 21st centuries, the forestry community experienced renewed interest in the study of virgin forests, accompanied by a gradual shift toward the use of the term *old-growth forest*. Originally introduced in North America, the concept referred to forests that had not undergone extensive logging and was distinguished from second-growth forests that developed after colonization and land-use changes.

Defining old-growth has proven to be a "wicked problem," involving ecological, historical, scientific, and management dimensions (Peskevits et al., 2011; Gray et al., 2023). The

debate has generated extensive discussion, especially in North America (e.g. Hunter, 1989; Hunter and White, 1997; Lund, 2001; Frelich et al., 2003; Helms, 2004; Wirth et al., 2009), and it has been argued that a universally accepted definition may neither be achievable nor desirable, given the diversity of forest ecosystems and their histories (Spies, 2004).

Currently, the definition of primary and old-growth forests adopted by international initiatives share many commonalities (FOREST EUROPE 2015; FAO 2018; Sabatini et al. 2018; Sabatini et al. 2020): the notion of old-growth forest may include both primary and secondary forests as long as the stands have developed for a long period without important anthropogenic disturbance, and provided they are characterized by functional, structural and compositional characteristics normally associated with old primary forests of the same type.

3. OLD-GROWTH FORESTS: RESILIENCE AND ADAPTIVE CAPACITY OF FOREST ECOSYSTEMS

Old-growth forests, however they might be defined, are a phase of a long development history which has often taken place in climatic and environmental conditions which might be very different from the ones that will be faced in a probably not so distant future. According to Noss (2001) a community of long-lived organisms is seldom, if ever, in equilibrium with the prevailing climate (Perry et al., 1991). Vegetational change lags behind climate change, such that the vegetation at any point in time is a legacy of climatic conditions decades or centuries in the past (Sprugel, 1991; Millar & Woolfenden, 1999).

A fundamental feature of old-growth forests, characterized by the presence of long-lived organisms, is their *ecological inertia*,

that is, their tendency to exhibit slow rates of structural and compositional change and to maintain key ecosystem functions despite environmental variability. This inertia reflects long-term ecological processes, biological legacies, and complex feedbacks rather than a static equilibrium (Millar & Woolfenden, 1999; Allen et al., 2002). In a rapidly changing world, it represents a unique heritage, providing valuable insights into the resilience, adaptive capacity, and temporal dynamics of forest ecosystems (Piovesan et al., 2019; Colangelo et al., 2021).

Alongside their apparent stability, old-growth forests also remind us that nature is governed by unpredictability. Sudden events, such as fires, windthrows, insect outbreaks, or diseases, can rapidly transform their structure. Far from being anomalies, these disturbances are an integral part of the forest life cycle, contributing to its diversity and complexity (e.g. Lingua et al., 2011; Martin et al., 2019).

Accepting unpredictability means recognizing that there is no fixed balance, but rather a dynamic interplay of processes that are constantly regenerating. Insights into the structure, composition and processes of old-growth forest ecosystems strengthen the thesis that forests are complex biological systems, which are subject to both internal and external influences (Filotas et al., 2014, Nocentini et al., 2017). This is particularly critical when dealing with previously managed forests, which have evolutionary dynamics that most likely will differ from the old-growth forests inherited from the past. Indeed, old-growth characteristics do not develop instantaneously at some magical age, but rather they increase over time along complex pathways.

Thus, if we are looking for a “natural” model of old-growth forests we are in fact looking at a moving target.

4. LESSONS FOR FOREST MANAGEMENT

The multiple dimensions involved when trying to define old-growth forests, both terminologically and ecologically, point out to the fact that it is impossible to identify “natural forest models” to serve as blueprints for management (Nocentini, 2024).

But, while old-growth forests should not be regarded as direct templates for managed forests, nevertheless there are some important lessons to be learned when available scientific knowledge is placed into the right reference frame, understanding the complexity of processes and interactions that take place in forest ecosystems.

4.1 Natural longevity should reshape thinking about tree age

In old-growth forests tree ages vary widely, but there is a significant presence of trees that live close to the biological life span of the species. These ages are very different from normal rotation ages used in conventional forest management, which are based on financial considerations and have often been applied uncritically. Thus, conventionally accepted rotation age should not be the only benchmark, the natural life span of the different species should be used as an ecological reference for increasing the variety of ages and favouring the presence of old and very old trees in managed stands.

4.2 Natural regeneration is more diverse than classical silvicultural models assume

Regeneration in old-growth forests follows different patterns according to species composition and natural disturbance regimes typical of the different geographical areas. Closer analysis of these patterns has shown that conventional forest management has often oversimplified the approach e.g. assuming that shade intolerant species require large openings,

i.e. clear cutting, while shade tolerant species thrive in closed uneven-aged stands.

As a consequence of these simplified assumptions, for example, most forests in Europe are managed outside their historical disturbance range (Aszalós et al., 2022) and show simplified structure and composition. Knowledge from old-growth forests challenges the simplistic assumptions underlying classical management systems and promotes a silvicultural approach which draws on the observation of natural regeneration processes abandoning the conventional lens of classic silvicultural systems.

4.3 *Forests are not only lists of species*

There is growing evidence drawn from the study of old-growth forests, that biodiversity is intimately dependent on complex structures and processes, acting at multiple space and time scales (see Oettel & Lapin, 2021 for a comprehensive review). In other words, forests cannot be seen only as lists of species but must be considered instead as complex adaptive systems.

In this context, research on biodiversity associated with old-growth forests and old-growth attributes should adopt a network perspective that explicitly considers interactions among species, structures, and ecological processes across multiple spatial scales. Interdisciplinary studies are essential for identifying and integrating diverse habitat requirements within the forest ecosystem as a whole.

To translate this knowledge into forestry practice it is necessary to move beyond the inherently reductionist assumption that, once the requirements of individual species have been identified, management can address them deterministically and thereby ensure the conservation of biodiversity. Unless they have been simplified far beyond their natural conditions, forest ecosystems are too complex and dynamic to allow for the deterministic man-

agement of all their components with any degree of precision.

In this sense it is necessary to revise the silvicultural and forest management paradigm that, in seeking to maximize one or a few forest functions, tends to reduce structural and process-related variability in favor of uniformity and regularity.

4.4 *The forest landscape as a connected network*

At the forest landscape scale, the importance of areas of old-growth is being increasingly recognized. In most of Europe, forest zoning is still overwhelmingly oriented toward timber production, while the extent of strictly protected forest reserves is insufficient to provide an effective balance between production and biodiversity conservation; furthermore many existing strict reserves are too small to encompass the natural disturbance dynamics required to sustain both old-growth specialists and disturbance-dependent species (Nagel et al., 2025).

The optimal size of old-growth areas for biodiversity conservation is being debated (Manton et al, 2025) but there is increasing evidence of the necessity of creating landscape networks of old-growth forests and old-growth attributes, from strictly preserved old-growth forests to the presence of old-growth elements in managed forests (Nagel et al, 2017; Oettel & Lapin, 2021; Barredo et al, 2021). It is also important to delimitate buffer zones where management should promote the development of old-growth attributes in younger stands, so as to accelerate the long-term biotic refugial potential of forest ecosystems (Hähn et al., 2026).

Forest planning should therefore promote differentiation across multiple spatial and temporal scales while fostering the persistence of those elements that provide ecological linkages among scales such as ecological corridors (space dimension) and biological legacies (time dimension).

4.5 *From managing complexity to interacting with complexity*

Old-growth forests exemplify the complexity and inherent unpredictability of forest ecosystems. Yet can complexity itself truly be managed? By its very nature, complexity defies simple definition, emerging from interactions among ecosystem components and processes that cannot be understood merely as the sum of their parts. Recognizing this complexity calls for a departure from the deterministic management paradigm that has long dominated forestry. Rather than seeking to control ecosystems to achieve predetermined outcomes, management should aim to interact with the ecological processes that shape natural systems. In this context, management should be conceived as an adaptive learning process in which the effects of interventions are continuously monitored using appropriately selected indicators, not as fixed thresholds but as measures of relative change over time. Such an approach fosters an ongoing process of mutual adjustment among silvicultural practices, ecosystem functioning, and the conservation of biological diversity, thereby enhancing the capacity of forests to respond to changing environmental conditions.

5. THE CASE OF MEDITERRANEAN OLD-GROWTH FORESTS

Millennia of human activity have profoundly shaped the forests and landscapes of the Mediterranean region, creating a natural heritage that is inextricably linked to its cultural legacy (Thirgood, 1981; Blondel, 2006; Blondel et al., 2010). Here any classification of old-growth forests must consider a wide range of landscape, biological, historical and social aspects (Marchetti et al., 2010; Robin et al., 2021).

Overall, Mediterranean old-growth forests have received far less scientific attention than those in other regions and are consequently likely underrepresented in current old-growth inventories (Badalamenti et al., 2025; Selvi et al., 2026).

Woodlands that have remained untouched by direct human intervention for long periods occur only in limited areas and under specific conditions, for example, in remote locations; where forests were maintained to protect settlements from avalanches and landslides (Piovosan et al., 2005); where steep terrain made logging economically unfeasible; or even as a consequence of long-standing disputes over property boundaries between neighboring communities.

Moreover, these remnants are often restricted to mountain environments, which limits the representation of different forest types. The known old-growth remnants are dominated by beech, mixed beech-silver fir, Calabrian black pine (*Pinus nigra* Arn. ssp. *laricio* Poir. var. *calabrica* Delamare), and Corsican pine (*Pinus nigra* Arn. ssp. *laricio* Poir. var. *corsicana*). Even rarer are thermo-Mediterranean and meso-Mediterranean examples, such as the old-growth holm oak forests of Corsica (Panaiotis et al., 1997) and the holm oak and farnetto oak stands of the Aspromonte National Park. Recently, Selvi et al. (2026) have identified old-growth forests dominated by broadleaves or evergreen sclerophylls in lowland areas under the influence of the Mediterranean climate in Tuscany.

These fragments of old-growth forests are frequently embedded within landscapes that have been profoundly altered by human activities, a condition that complicates their use as references, particularly for studying natural disturbance dynamics (Nocentini, 2010).

Human impact has been so pervasive and inextricably linked to the evolution of forests

in the Mediterranean area that defining old-growth here poses additional challenges. The presence of coppice stools or other traces of past human activity (such as charcoal kilns) is sometimes considered compatible with the definition of old-growth forest, provided that the stands retain the structural and ecological characteristics typical of old-growth forests (Panaïotis et al., 1997; Rozas, 2003; Di Filippo et al., 2005).

Although these forests cannot be regarded as pristine baselines and are often embedded in human-modified landscapes, they nonetheless provide unique opportunities to investigate natural structural development and regeneration processes that can inform contemporary silviculture.

In Apennine old-growth beech forests (*Fagus sylvatica* L.), for instance, regeneration has been shown to occur predominantly in small to medium-sized canopy gaps (Piovesan et al., 2005), with mean gap areas ranging from approximately 150 to 200 m² (Iovino et al., 2010; Iovino, 2024). Comparable patterns have been documented in old-growth Calabrian pine stands (*Pinus laricio* ssp. *laricio*) in southern Italy (Ciancio et al., 2010; Iovino, 2024).

Iovino (2024) demonstrated that the stand structures observed in old-growth beech and Calabrian pine forests of the southern Apennines closely resemble those produced by the small-group selection system, a silvicultural approach rooted in centuries-old local traditions. Historically, however, this approach was often discouraged in favor of official prescriptions based on even-aged management models. While forests managed under the small-group selection system differ markedly from old-growth stands, particularly in terms of maximum tree age and deadwood abundance, their structural organization and regeneration dynamics exhibit notable similarities to those observed in forests

that have experienced prolonged periods without direct human intervention.

These studies on the structure and regeneration dynamics of old-growth forests in Calabria, have provided empirical support for silvicultural approaches based on the creation of small canopy gaps and the maintenance of small group uneven-aged structures in both Calabrian pine and beech forests; these principles have recently been incorporated into the Calabria Regional Forest Regulations (Regione Calabria, 2024).

6. FROM CONSERVATION TO MANAGEMENT: AN EXAMPLE

In a “natural” forest landscape, subject only to natural disturbances, the different patches display a wide variability in age and successional stages, but the overall age distribution typically includes a long tail extending into the oldest age classes (Spies & Turner, 1999). Forest landscapes with a long history of human impact deviate considerably from this theoretical model of naturalness.

Planning should therefore aim to create a network of elements with old-growth forest characteristics at different spatial scales. A modern planning approach that integrates biodiversity conservation, sustainable forest management, and the preservation of historical and cultural values is exemplified by the management plan for the Vallombrosa Forest (Ciancio, 2009).

The Vallombrosa Forest is a 1,273-hectare State Nature Reserve, renowned for its silver fir stands and the Vallombrosan Abbey. When St. Giovanni Gualberto founded the Vallombrosan order in 1037, the forest was largely composed of broadleaves with scattered silver firs. From the 14th century onward, however, to meet the increasing demand for timber

from Florence and other Tuscan cities, the monks began cultivating silver fir, establishing pure, even-aged stands.

When the forest was transferred to the Italian State in 1866 and the Royal Forestry Institute¹ was founded, Vallombrosa became an important center for teaching and scientific experimentation. The silver fir stands were managed according to the classical even-aged model, with forest regulation plans prepared by the University's Chair of Forest management. The area of silver fir plantations was gradually expanded, reaching more than 600 hectares by 1960, nearly half of the entire forest.

In recent decades, forest management has undergone profound changes driven by social, economic and environmental factors. The last management plan, drafted in 1970, was never implemented, which allowed the forest to evolve spontaneously. In 2006, a new forest management plan was introduced, adopting a systemic approach aimed at enhancing the forest's biodiversity and resilience, while conserving its cultural and historical value (Ciancio, 2009; Ciancio and Nocentini, 2011). The Forest was divided into three sections with different management aims and prescriptions:

1. Management aimed at favoring, through silvicultural interventions, the natural evolution of the forest towards more diverse and complex structures (renaturalization);
2. Conservation of the traditional landscape and the management techniques which have historically maintained the pure, even-aged fir stands (in the *Silvomuseum*);
3. Natural evolution.

In this last section the aim is to monitor natural evolution of the different forest types that are present in the Vallombrosa forest, by creating an area that progressively develops old-growth characteristics where biodiversity

trends can be studied and compared to the managed sections. An area of approx. 60 ha was chosen in the less accessible part of the forest, including beech stands originating from ancient coppices in conversion to high forest and silver fir stands originating from plantation. Small planted patches of Calabrian pine occur on the steepest and most rugged terrain. All the stands have been strongly influenced by human activity in the past, even though in this area active management had been suspended from the early sixties. Today the most recent interventions in this area date from over 60 years ago and stand ages vary among compartments, ranging from approximately 100 years in the silver fir stands to about 240 years in the beech stands.

A survey carried out in 2015 based on 35 plots showed that standing volume is increasing substantially in all forest types and, in particular, the volumes of standing and downed dead wood have reached high levels. The first revision of the 2006 management plan is underway, and preliminary surveys indicate that the trend in this section is continuing: large amounts of deadwood are accumulating, and numerous tree microhabitats are present, including standing dead or broken trees (snags), downed logs, stumps, branches, cavities in living or dead trees. In addition, natural regeneration is occurring in small gaps created by the fall of large trees (G. Galipò, personal communication).

According to the adaptive management approach adopted in the Vallombrosa forest management plan, the ongoing survey will assess natural regeneration patterns in both section 1 (renaturalization) and section 3 (natural evolution). The results will be used to refine management prescriptions in section 1, where silvicultural interventions are designed to pro-

¹ The Forestry Institute was moved to Florence in 1914 where it became part of the University.

mote spontaneous regeneration by creating or enlarging canopy gaps. At the same time, in this section old trees, groups of large trees, and habitat trees will be retained, contributing to the progressive development of a network of old-growth attributes throughout the forest.

7. CONCLUSIONS: OLD-GROWTH FORESTS, ANCIENT WISDOM FOR A CHANGING REALITY

Old-growth forests are living records of ecological processes that have developed over long periods without significant human intervention. They embody a profound connection between a past in which society held different needs and values, and a present characterized by rapid social and climatic changes as well as emerging conservation challenges.

Using old-growth forests as models for silviculture assumes that managers can predict ecosystem responses with sufficient certainty to steer forests toward predetermined compositions, structures and functions. Yet this approach contains a paradox: attempting to manage complex, dynamic, and unpredictable ecosystems using deterministic tools and models.

Scientific knowledge gained from studies of old-growth forests must be integrated into a dynamic concept of forest management, where monitoring and feedback form a co-evolutionary continuum between cultivation and ecosystem response. Indicators of old-growth conditions should not be treated as fixed benchmarks but as dynamic reference points that guide monitoring and adaptive management. This approach aligns with the adaptive framework of silvosystemics, which considers environmental, economic, social, and cultural dimensions as inherently and continuously changing (Ciancio & Nocentini, 2011, Nocentini et al., 2021).

By acknowledging the intrinsic complexity of forest ecosystems and adapting interventions in response to ecosystem feedback, silvosystemics provides an operational framework for applying lessons from old-growth forests to forest management and, more broadly, for implementing the principles of “closer to nature forestry” as defined by the EU (Larsen et al., 2022).

At the same time, an integrative approach based solely on embedding biodiversity objectives within managed forests is insufficient to ensure the conservation of old-growth-dependent biodiversity (Nagel et al., 2017). Effective planning should therefore combine the strict protection of existing old-growth stands with the expansion of areas of naturally evolving forests and the promotion of old-growth attributes within managed landscapes.

In this sense the recent EU Nature Restoration Law, by placing renewed emphasis on forest naturalness and ecological integrity, can represent a turning point in environmental and forest policies. The implementation of the NRL provides opportunities to identify forest areas that can be designated for strict protection and allowed to develop through natural processes. On the other hand, it encourages interventions in structurally simplified forest ecosystems aimed at enhancing their diversity and complexity.

Ultimately, although they do not offer ready-made recipes, old-growth forests still have much to teach us. Their value, now recognized globally, calls on us to move beyond the traditional utilitarian paradigm of forestry, to integrate a deeper ecological understanding, and to embrace complexity as an intrinsic element of forest management.

Old-growth forests remind us that nature carries within it both memory and resilience. By inspiring wonder and respect, old-growth forests can help us rediscover a relationship of

care and responsibility toward all forests, recognizing them as living systems deeply intertwined with human history and culture.

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