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Classification of Forest Management Approaches: A New Conceptual Framework and Its Applicability to European Forestry

Philipp S. Duncker [1], *Susana M. Barreiro* [2], *Geerten M. Hengeveld* [3], *Torgny Lind* [4], *William L. Mason* [5], *Slawomir Ambrozy* [6] *and Heinrich Spiecker* [1]

ABSTRACT. The choice between different forest management practices is a crucial step in short, medium, and long-term decision making in forestry and when setting up measures to support a regional or national forest policy. Some conditions such as biogeographically determined site factors, exposure to major disturbances, and societal demands are predetermined, whereas operational processes such as species selection, site preparation, planting, tending, or thinning can be altered by management. In principle, the concept of a forest management approach provides a framework for decision making, including a range of silvicultural operations that influence the development of a stand or group of trees over time. These operations vary among silvicultural systems and can be formulated as a set of basic principles. Consequently, forest management approaches are essentially defined by coherent sets of forest operation processes at a stand level.

Five ideal forest management approaches (FMAs) representing a gradient of management intensity are described using specific sets of basic principles that enable comparison across European forests. Each approach is illustrated by a regional European case study. The observed regional variations resulting from changing species composition, stand density, age structure, stand edges, and site conditions can be interpreted using the FMA framework.
Despite being arranged along an intensity gradient, the forest management approaches are not considered to be mutually exclusive, as the range of options allows for greater freedom in selecting potential silvicultural operations. As derived goods and services are clearly affected, the five forest management approaches have implications for sustainability. Thus, management objectives can influence the balance between the economic, ecological, and social dimensions of sustainability. The utility of this framework is further demonstrated through the different contributions to this special issue.

Key Words: *basic principles; forest management approaches; management intensity; operational processes; silvicultural systems*

INTRODUCTION

Sustainable forest management (SFM) is a key concept that underpins modern forestry practice by recognizing the need to balance the social, ecological, and economic outputs from forests, as outlined in Europe in the principles agreed upon through the Ministerial Conference on the Protection of Forests in Europe (MCPFE 2003a). However, assessing the overall sustainability of different types of forestry practice is complicated because of variation both in the nature of the forest resource and in the impacts of different management measures in space and over time (Kimmins 1992). For example, European forests cover a wide range of climatic zones and forest types, ranging from the spruce–pine forests of boreal Scandinavia to the mixed oak and pine forests of Mediterranean Europe (European Environment Agency (EEA) 2006). In addition, there are extensive plantation forests of conifers in Atlantic Europe and broadleaved plantations in Hungary and other Central European countries. In each of these forest types, a range of silvicultural operations can be applied, from intensive systems based on clear felling and artificial regeneration to the fostering of irregular stand structures based on natural regeneration. Each coherent set of silvicultural operations applied to a given forest forms a silvicultural system that may be defined as “the process by which the crops constituting a forest are tended, removed, and replaced by new crops, resulting in the production of stands of distinctive form” (Matthews 1989).

Therefore, the informed choice of a silvicultural system is a crucial step in forest planning that can have major consequences for sustainability. The selection has to be made in a wider context, which can only be partially influenced by a forest manager. Some conditions are predetermined or are beyond the control of forest management, e.g., biogeographically determined site conditions, current tree species composition, climate, but also economic and market circumstances and the formal and informal demands made by society at large. Other conditions are under direct control of forest management through the application of silvicultural operations at the stand level, such as site preparation, tree species selection, planting, tending, thinning, and final harvest regime. The wide range of forest types, coupled with a variety of silvicultural systems, can make it difficult to carry out a

[1]Institute for Forest Growth, Albert-Ludwigs-Universität Freiburg, [2]Centro de Estudos Florestais, Instituto Superior de Agronomia, [3]ALTERRA - Wageningen UR, Team Forest Ecosystems, [4]Department of Forest Resource Management, SLU, [5]Forest Research, Northern Research Station, [6]Forest Research Institute

comparative sustainability analysis of different methods of forest management at either a regional or a continental scale.

Various studies have tried to classify silvicultural systems, usually along one of two main axes: an economic axis, where systems are categorized according to production factor utilization and economic return (Speidel et al. 1969, Dummel 1970, Arano and Munn 2006), or an ecological axis, where the categories depend on the degree of modification of natural conditions (Pro Silva 1999, Seymour and Hunter 1999, Gamborg and Larsen 2003, MCPFE 2003c). Most classifications of this type have tended to adopt a three-category system, which contrasts non-intervention reserves with intensively managed plantations and with a more extensive form of management that may seek to emulate natural disturbances or to practice close-to-nature forestry (Montigny and MacLean 2006, Gamborg and Larsen 2003). One problem with this structure is that it ignores the variety of silvicultural systems that can be used in the management of plantations; this can have consequential impact on biodiversity and other criteria of sustainability (Carnus et al. 2006). Current attempts to assess the sustainability of forest management practices in Europe, whether as part of a set of land uses (Helming et al. 2008) or as the first part of a forestry wood chain (Paivinen et al. 2010), require a standard classification that can be linked to criteria and indicators of sustainability at a local or national level, yet that is sufficiently flexible to be capable of application across a wide range of forest types.

In this paper, we present a new framework for classifying silvicultural systems and practices in relation to management intensity. Unlike existing classifications, which are generally centered on two dimensions of sustainability, this framework is designed to be used with criteria and indicators reflecting the full range of economic, ecological, and social components of sustainability. Irrespective of the particular aims of forest management, the actions taken (including a decision to take no action) will have consequences for forest ecosystem status and processes. Such actions will affect, to some degree, the goods and services derived from forests. Thus, the provision of goods and ecosystem services can be considered to be both a consequence as well as a driver of forest management. As such, our framework can serve as the foundation of any analysis wishing to explore the effect of changing policies and silvicultural operations upon criteria and indicators of sustainability, and upon the provision of ecosystem services.

A suite of forest management approaches (FMAs) is proposed, defined by the silvicultural operations practiced and the intensity of human manipulation of the processes of natural forest development. The FMAs are characterized by a coherent set of objectives and supporting practices, which results in a framework that should enable transnational, cross-regional, and within-region comparisons of different silvicultural systems. This framework includes the detail of local technological, economic, and ecological situations, while still being insightful for policy at the regional and cross-regional levels. We illustrate the potential utility of this framework of FMAs by applying it to five European regions with different tree species and varying silvicultural regimes.

BASIC DECISIONS AND PRINCIPLES IN FOREST MANAGEMENT

The implementation of a silvicultural system involves a number of decisions on the type of operations to employ at the various phases of the development of a stand or group of trees. These operations can affect one or more key stand variables, such as tree species composition, stand density and age structure, stand edges, or site conditions, which in turn influence the provision of a range of ecosystem services. Furthermore, within any given FMA, a particular criterion of sustainability (e.g., aspects of biodiversity, public preference for forest landscapes) may vary with different stages of tree growth. Therefore, we have classified the development of a stand or group of trees into four “phases of development” according to their height and diameter: Regeneration (I), Young (II), Medium (III), and Adult (IV). The phases are not mutually exclusive in space or over time because, under certain conditions, they may occur together in the same stand, e.g., in the complex stand structures characteristic of “close-to-nature” forestry. However, defining these phases is a means of arranging silvicultural operations and decisions along management cycles (Table 1). The value of being able to combine FMAs with their constituent phases is shown by Edwards et al. (2012) and Jactel et al. (2012).

The first phase refers to the period from the start of establishing young trees naturally or artificially until the stand has reached 2 to 3 m in height (Helms 1998). The second phase lasts until trees have reached pole size, i.e., 7 cm diameter at breast height (DBH). The third phase covers the period from trees having a DBH equal to 7 cm until the age/size when they have attained most of their potential height growth. The fourth phase is reached when height growth has largely ceased although diameter growth may continue; this phase includes the onset of senescence and eventual tree death. Although the phases are defined by tree size/health, they differ slightly from development stages sensu Oliver and Larson (1996). Whereas “Regeneration” corresponds to the “stand initiation” stage, their “stem exclusion” stage is split here into “Young” and “Medium” phases, which are typically characterized by precommercial or thinning operations, respectively. Although the beginning of the “adult” phase and their “understorey re-initiation” stage are quite similar, no separate “old-growth” stage is distinguished in our classification.

Table 1 summarizes the 12 critical decisions chosen for defining FMAs, the phases of stand or tree group development to which they predominantly refer, and the key variables they

Table 1. Major decisions involved in forest management, the associated silvicultural operations, and the link to sustainability indicators.

Decision and subsidiary elements (and phase of development†)	Silvicultural operation	Affected stand variable and sustainability criteria
1. Naturalness of tree species composition (I–IV‡)		
Species composition in relation to the potential natural vegetation Share of site-adapted tree species Share of introduced tree species	Selection of tree species	Biological diversity; Tree species composition
2. Tree improvement (I)		
Use of genetically improved material Use of genetically modified organisms	Selection of tree genotypes	Biological diversity; Stand genetic diversity
3. Type of regeneration (I)		
Planting, seeding, natural regeneration, or coppice	Stand establishment	Stand density (Growing stock); Age structure/ diameter distribution; Tree species composition
4. Successional elements (I-IV)		
Tolerance of successional elements, i.e., pioneer and nurse species or accompanying secondary tree species	Stand establishment Tending Thinning	Tree species composition Density pattern
5. Machine operation (I–IV)		
Machine movement/driving on forest soils Extent of forest opening for machine access	Fertilizing Liming Soil preparation Thinning Final harvest	Forest ecosystem health and vitality; Site condition
6. Soil cultivation (I)		
Mechanical, physical, and chemical site preparation Drainage	Soil preparation Drainage	Site condition
7. Fertilization / Liming (I–IV)		
Fertilization to increase yield (amelioration) Compensate for nutrient extraction and re-establishment of natural biogeochemical cycles	Fertilization Liming	Site condition
8. Application of chemical agents (I–IV)		
Extent of application of pesticides, herbicides	Pest control	Tree species composition
9. Integration of nature protection (I–IV)		
Tolerance of biotope/habitat trees Tolerance of deadwood Biotope protection within stands	Thinning Final harvest	Biological diversity; Tree species composition Density pattern Age structure
10. Tree removals (III–IV)		
Extent of tree components extracted in thinning or harvesting operations	Thinning Final harvest	Site condition; Carbon stock
11. Final harvest system (III–IV)		
Extent of area cleared by final harvest operation	Final harvest	Density pattern Age structure/ diameter distribution
12. Maturity (III–IV)		
Felling age in relation to the potential life span of a given tree species	Final harvest	Biological diversity; Age structure

† Phase of stand development the critical decision predominantly refers to.
‡ I "regeneration", II "young", III "medium" and IV "adult".

affect, as well as some associated silvicultural operations. This summary partly reflects criteria previously developed and discussed by Winkel et al. (2005). Having identified these essential decisions to be considered in the framework, clear differences have to be defined for each decision, which will allow one to distinguish among FMAs. We call these limits the "basic principles" of a FMA, which reflect the objective of the particular FMA and which identify the set of silvicultural operations appropriate for each decision.

FOREST MANAGEMENT APPROACHES

Using these 12 decisions and their associated basic principles, we are able to describe five FMAs arranged along a gradient of intensity of resource manipulation (from "passive" to "intensive"). The intensity of manipulation associated with a particular FMA results from the deliberate alteration of key stand variables through the use of production factors. Therefore, the degree of naturalness of forest ecosystems is indicative of the intensity of human intervention. Different levels of intensity can be characterized not only by changing stand structures but also by different species communities and, thus, influence the biological diversity of an area (MCPFE 2003b). Table 2 shows how the decisions and their basic principles relate to the five FMAs proposed, arranged along a scale of intensity of intervention. We also show how the different FMAs relate to traditional silvicultural systems used in European forests (e.g., Matthews 1989). In the following sections, the management objectives and basic principles of the five FMAs listed in Table 2 are described.

Passive—Unmanaged Forest Nature Reserve

Management objective
: An unmanaged forest nature reserve is an area where natural processes and natural disturbance regimes can develop without management intervention and where ecological and societal goals are given primacy. The aim is to maintain ecologically valuable habitats and their dependent biodiversity, while also providing a reference for the development of close-to-nature silviculture (see below). Depending on the dominating stand or tree group development phase within this FMA, the area may be more or less valuable for these objectives. Furthermore, as an important landscape feature, the reserve may serve as a backdrop to forest recreation, and may be used for basic and applied research (Parviainen et al. 2000). These areas may be protected by an ordinance or forest act (International Union of Forest Research Organizations (IUFRO) 2007).

Basic principles
: No operations are allowed in a forest reserve that might change the nature of the area. Stands have a history of development without direct management or exploitation, resulting in various qualities of naturalness (Sprugel 1991, Peterken 1996). Permissible operations (with limitations) can be the building of a trail so that people can visit these places of high ecological value. Other treatments may be allowed if the future of the area is compromised by external factors such as heavy browsing by deer or other animals. Such control measures must be limited, and their only purpose is to protect the reserve from destruction because, in Europe, these habitats are often very limited in size and, therefore, do not have the resilience against major disturbances that a larger area would have. A further reason for taking control measures would be to prevent major threats to adjacent stands managed under one of the four other approaches (Michalski et al. 2004, Popiel and Karczewski 2006).

Low—Close-to-Nature Forestry

Management objective
: Close to nature is a “classification of stands or forest according to how closely they resemble nature. This classification is based on the impact of man, for which naturalness is defined as the extent to which man’s impact is absent or hidden” (IUFRO 2007). The objective of close-to-nature forestry 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. Any management intervention in the forest has to enhance or conserve the ecological functions of the forest. Timber can be harvested and extracted during these activities, but some standing and fallen dead wood has to remain in the forest, which may reduce productivity (Food and Agriculture Organization (FAO) 2007).

Basic principles
: Only native or site-adapted tree species are chosen. The preferred method of regeneration is natural regeneration. Planting can be used to re-introduce native species into a devastated forest, but genetically improved planting material cannot be used. Species mixtures follow the typical composition for the stand type. Guidance on natural processes to be emulated and the patterns produced by various disturbance mechanisms is often based on findings from areas treated as “unmanaged forest nature reserves” (e.g., Brang 2005). Soil cultivation or fertilization can only be done to restore the “naturalness” of the forest, if for example the sites have been so intensively managed in the past that these treatments are necessary to initiate any potential natural vegetation. Chemical pest control can only be applied during major events that spread from the surrounding stands. Small outbreaks should not be treated so that natural control processes are promoted. Concepts such as rotation length are of limited value, and the decision regarding which tree(s) to harvest is often based on target diameters and stem quality rather than age. Biological legacies and natural biotopes should be promoted inside the stands. The final harvesting system should simulate the natural disturbance mechanisms, and therefore, clearcuts are not allowed unless stand-replacing natural disturbances are characteristic of this forest type. Extraction of biomass is limited to removal of the stems. Machine operations should be limited to a minimum, with an emphasis on the protection of the natural structures during the activities. The use of appropriate machines, which suit the structure and features of the forest (ProSilva 1999), is restricted to a strip road system (with an extensive rack system).

Medium—Combined Objective Forestry

Management objective
: This FMA is an approach that assumes that various management objectives can be combined in a manner that satisfies diverse needs better than through zoning, where individual objectives are maximized in separate areas. Generally, economic and ecological concerns play a major role in this FMA. Aside from timber production, additional objectives can include: habitat, water, and soil protection; mushroom production; game management and nature

Table 2. A list of the 12 major decisions and the basic principles used to distinguish among five forest management approaches (FMAs) as well as the main silvicultural systems associated with each FMA.

Decision	Basic principle by FMA Intensity scale				
	Passive “Unmanaged forest nature reserve”	Low “Close-to-nature forestry”	Medium “Combined objective forestry”	High “Intensive even-aged forestry”	Intensive “Short rotation forestry”
1. Naturalness of tree species composition	Only species characteristic of the potential natural vegetation (PNV)	Native or site-adapted species	Tree species suitable for the site	Tree species suitable for the site	Any species (not invasive)
2. Tree improvement†	No	Not genetically modified or derived from tree breeding programs	Planting material can be derived from tree breeding but not genetically modified	Planting material can be derived from tree breeding but not genetically modified	Planting material can be derived from tree breeding or produced via genetic modification.
3. Type of regeneration	Natural regeneration / natural succession	Natural regeneration (planting for enrichment or change in tree species composition)	Natural regeneration, planting, and seeding	Natural regeneration, planting, and seeding	Planting, seeding, and coppice.
4. Successional elements	Yes	Yes	Temporarily	No	No
5. Machine operation	No	Extensive	Medium	Intensive	Most intensive
6. Soil cultivation	No	No (only to introduce natural regeneration)	Possible (mainly to promote natural regeneration)	Possible	Yes
7. Fertilization / Liming	No	No (only if devastated soil‡)	No (only if devastated soil‡)	Possible	Yes
8. Application of chemical agents	No	No	Possible as a last resort	Possible	Possible
9. Integration of nature protection	High	High	High	Medium	Low
10. Tree removals	No	Stem (solid volume)	Stem and crown (solid volume)	Up to whole tree	Whole tree and residues
11. Final harvest (and main silvicultural) system	No	Mimics natural disturbances Single Stem Selection Group Selection Irregular shelterwood	All possible Seed tree Strip shelterwood Group shelterwood Uniform shelterwood Coppice with standards	All possible, clearcut (long rotation) preferably used	All possible, Coppice Clearcut (shorter rotation)
12. Maturity	No intervention	Long rotation length ≥ age of max. MAI or target diameter according to tree species and stem quality	Medium rotation length ≈ age of max. MAI or target diameter according to tree species and stem quality	Short rotation length ≈ age of max. financial return (low interest rate)	Shortest rotation length ≤ age of max. MAI or ≈ age of max. financial return (high interest rate)

† In this decision element, the definitions might need to be adjusted in future if the principle of genetic modification became more widely accepted in forestry. For example, planting stock produced through genetic modification might be accepted in “Intensive even-aged forestry.”
‡ Devastated soil = soil that needs measures to get it into an acceptable condition.

protection; avalanche and fire prevention; and recreation. Due to the great variability within combined objective forestry, it is often easier to define the limits of a combined objective forestry approach than the strategy itself. This allows for optimal adaptation to the local situation.

Basic principles
: Native or introduced tree species suitable for the site can be chosen. The preferred method of regeneration is natural regeneration, but planting or seeding is acceptable to introduce native or desired species that would not otherwise occur. Products of tree breeding can be planted, but genetically modified planting material cannot be used. Tree species

mixtures are typical for the forest type. Site cultivation and/or fertilization can be carried out to enhance the development of the forest, provided that these treatments are necessary to restore vegetation cover. Chemical pest control can be used in major outbreaks, which are either introduced from the surrounding stands or place the latter at risk. Minor outbreaks should not be treated with pesticides, and natural measures are preferred for pest control as well as to increase resilience (for example, greater use of mixed species stands). The rotation length is often longer than the age of maximum mean annual volume increment (MMAI) provided that financial criteria do not dictate otherwise. Biological legacies and natural habitats should be promoted inside the stands. The final harvesting system should be compatible with the chosen regeneration method. The intensity of harvesting is generally limited to solid wood volume, i.e., stems and branches with a diameter larger than 7 cm. Vehicle movement is restricted to a strip road system (with an intensive rack system), so that machine operations protect the residual stand and soil.

High—Intensive Even-Aged Forestry

Management objective
: The intensive even-aged classification is characterized by stand or forest types in which no or relatively small age differences occur among individual trees (IUFRO 2007). The age differences are usually less than 20% of rotation length. Typical stands consist of even-aged monocultures (sometimes with a small percentage of admixed species). The main objective of intensive even-aged forestry is to produce timber. If ecological aims can be achieved without much loss of revenue, they are normally incorporated. In many European countries, national guidelines outline the best practices for ensuring that operations in this approach are compatible with sustainability and environmental protection.

Basic principles
: Any non-invasive tree species suitable for the site can be chosen. Planting, coppice, seeding, and natural regeneration are all possible regeneration methods. Economic factors are used to decide among the alternative methods. Planting/seeding material can be genetically improved, but not genetically modified. Typically, monocultures with small percentages of mixed-species stands (admixed species preferably also produce merchantable timber) are used to implement this strategy. Admixed species are generally only used if some parts of the stand fail, and/or if no economic loss is associated with their use. Site preparation is often used to enhance establishment success, and remedial fertilization is used to increase growth rates. Chemical control of pests and weeds is kept to the minimum necessary. The rotation length depends mainly on the economic return and is normally similar to or shorter than the age of MMAI. Biological legacies can be incorporated to improve the ecological values of the stand, as long as the economic return is not substantially reduced. Biomass extraction is commonly limited to solid wood volume but might include whole-tree extraction, e.g., for bioenergy. Machine operations are not limited, as long as they do not harm the environment. The final harvest system is preferably clearcut or a combination of shelterwood and clearcut if natural regeneration is preferred to reduce the costs of establishment.

Intensive—Short-Rotation Forestry

Management objective
: The main objective of short-rotation forestry is to produce the highest amount of merchantable timber or wood biomass. Economic objectives are given priority, and ecological concerns play a minor role in this approach.

Basic principles
: The tree species selection depends mainly on the economic return. The planting material can be genetically improved and/or genetically modified. No natural colonization by other tree species is permitted if it reduces the growth of the chosen tree species. Sites are mechanically cultivated and can also be drained or irrigated if needed. Fertilization and liming are applied to the stands to enhance growth. Chemicals are used to treat pests and diseases and also for weed control. The rotation length only depends on the economic return, is often 20 years or less, and no biological legacies are included. No other habitats are maintained within the stand. The intensity of machine operations is at a maximum compared with the other approaches and is only limited by national environmental laws. The final harvesting system is a clearcut combined with removal of all woody residues if there is a suitable market for them.

USING FOREST MANAGEMENT APPROACHES TO CLASSIFY FOREST MANAGEMENT IN DIFFERENT EUROPEAN REGIONS

To illustrate the potential utility of the framework proposed in Table 2, current forest management practices from five forest types in different European case studies (see Appendix 1) were described and classified. These practices were taken from the best-practice guidelines for the relevant country or region. The classification process was based on evaluating each decision in the forest management cycle for each forest type according to the basic principles for the FMA. This provided a rating for the 12 basic decisions, and gave a quick overview of the intensity of the silvicultural practices described in each case study (Fig. 1).

The Białowieża National Park reserve in Poland exemplifies the Unmanaged Forest Nature Reserve FMA for which the main objective is to allow natural processes and natural disturbance regimes to develop without human intervention (Appendix 1.a). The next FMA along the intensity scale, Close to Nature, is represented by the European beech (*Fagus* sp.) management practiced in Baden-Württemberg, Germany (Appendix 1.b), where the emphasis is on use of native species,

Fig. 1. Evaluation of current forest management in different regions of Europe using 12 decisions on silvicultural operations and an intensity grade from passive (1) to intensive (5). Case studies are (a) Białowieża National Park, Poland; (b) European beech in Baden-Wuerttemberg, Germany; (c) mixed forests dominated by Norway spruce in northern Sweden; (d) Sitka spruce forests in Scotland, and (e) Eucalyptus in Portugal.

	a					b					c					d					e				
Basic decision	passive				intensive	passive				intensive	passive				intensive	passive				intensive	passive				intensive
	I	II	III	IV	V	I	II	III	IV	V	I	II	III	IV	V	I	II	III	IV	V	I	II	III	IV	V
Objective	■						■	■					■	■				■	■					■	■
1. Species composition	■						■						■						■						■
2. Tree improvement	■						■						■						■					■	
3. Regeneration	■						■						■						■						■
4. Succession	■						■						■					■	■						■
5. Machine operation	■						■							■					■						■
6. Soil cultivation	■						■							■					■	■					■
7. Fertilization	■						■					■							■					■	
8. Chemical protection	■						■						■						■						■
9. Nature protection	■						■	■					■					■	■					■	
10. Removals	■							■					■						■						■
11. Final Harvest	■						■							■			■	■	■						■
12. Maturity	■						■						■						■						■

natural regeneration, limited site disturbance, and no chemical inputs, all characteristic of this FMA. However, the intensity of timber removal in this approach is more characteristic of "combined objective forestry," which is here exemplified by the management of mixtures dominated by Norway spruce (*Picea abies* (L.) Karst.) forests in Sweden (Appendix 1.c) . In the latter case, site preparation, machine operation, and final harvest are more intensive than would be expected, whereas fertilization is less intensive. In Scotland, the management of Sitka spruce (*Picea sitchensis* (Bong.) Carr.) forests is generally representative of intensive even-aged forestry, but there are components, such as the acceptance of successional elements and the provision for nature protection, that are indicative of less intensive FMAs (Appendix 1.d). Finally, eucalyptus (*Eucalyptus* sp.) stands in Portugal grown in short rotations under coppice regimes represent one of the most intensive levels of management found in European forests (Appendix 1.e).

DISCUSSION

In this paper, a framework is presented that classifies forest management according to the degree of interference with natural processes resulting from the silvicultural systems employed. Based on this framework, five forest management approaches (FMAs) have been defined along a gradient of management intensity. Our framework defines forest management intensity as the manipulation of natural processes (i.e., along an ecological axis) but at the same time includes cost and yield objectives in the classification scheme (i.e., along an economic axis). This allows grading and comparison of various types of forest management with different objectives both between and within regions. The gradient of management intensity covered by our framework is illustrated through the application to five case studies (Fig. 1).

The intensity of forest management is often described using either economic or ecological considerations. In managerial economics, intensity addresses the extent to which the production factors, such as soil, labor, energy, and capital, are used (Martin 1991). The intensity is set in relation to the management objectives to define the optimal input of production factors. On this basis, classes in forest management intensity were defined in relation to net-return criteria (Speidel et al. 1969), and production costs have been used as a measure to evaluate management intensity (Arano and Munn 2006). These proposals imply that management intensity primarily reflects the productive function of forests, whereas other non-market goods and services only justify maintenance of management costs not covered by wood sales (Kroth et al. 1969). This has provoked discussion whether the approach is acceptable for long-term forest planning (Möhring 1969, Speidel 1969, Dummel 1970). Furthermore, because production costs are the product of a production factor price and the utilized factor quantity, they are of limited use if intensity is to be defined in a wider operational dimension (Sagl 1990). Forest management implies purposeful manipulation of stand and site, which can result in a changed ecosystem. The more natural conditions are controlled and modified through operational processes, the more intensive a management approach might be considered. Various factors, such as controllability, the amount of usage (i.e., extracted volume of biomass), and the degree of modification of natural conditions required to achieve management objectives,

Table 3. Comparison of MCPFE classes of protected and protective forest and other wooded land in Europe, forest management approaches (FMAs), and separated forest areas according to the Triad zonation approach.

MCPFE Classes[†]		FMA	Triad zonation approach[‡]
1: Main Management Objective "Biodiversity"	1.1: "No Active Intervention"	FMA 1: Passive - Unmanaged forest nature reserve	Protected areas
	1.2: "Minimum Intervention"		
	1.3: "Conservation Through Active Management"	FMA 2: Low - Close-to-nature forestry	Multifunctional areas under ecosystem management
2: Main Management Objective "Protection of Landscapes and Specific Natural Elements"			
3: Main Management Objective "Protective Functions"		FMA 3: Medium - Combined objective forestry	
No equivalent MCPFE classes are defined		FMA 4: High - Intensive even-aged forestry	Intensive plantations
		FMA 5: Intensive - Short-rotation forestry	

[†] MCPFE 2003c
[‡] Seymour and Hunter 1999

differentiate approaches in forestry (Seymour and Hunter 1999, Pro Silva 1999, Gamborg and Larsen 2003) or serve to group forested areas (MCPFE 2003c). Where the classifications along the economic axis focus on the productive function, the classifications along the ecological axis tend to focus on the protective functions of forests and are usually policy driven. Our framework combines both considerations through the formulation of critical decisions (Table 1) and basic principles (Table 2) and thus allows grading and comparison of various types of forest management with different objectives, as illustrated with five case studies.

The selected case studies (Fig. 1) describe management based on the manipulation intensity associated with each basic principle. As a result, a silvicultural system is classified under a particular FMA depending on how the basic principles are distributed across the gradient of management intensity. Moreover, the distribution of basic principles across the intensity gradient shows the separation between FMAs and also indicates the possibility of conversion between FMAs. If management objectives for a forest change, then the balance of the various decisions and elements (Table 1) used to determine which FMA is prevalent in a given forest may also be affected. Therefore, over time, the classification of a forest may change from one FMA to another, for example, if Norway spruce forests managed under FMA 4 are converted to close-to-nature forestry due to ecological considerations (e.g., Kulhavý et al. 2004). In such cases, a transition period should be defined, and the length of time required for this transition will vary with forest type and region. The duration of this period is likely to be longer when moving between FMAs that are far apart on the intensity scale (Table 2) than for those that are close together. For example, even under favorable conditions, conversion of an existing forest to close-to-nature forestry requires decades (Spiecker et al. 2004). Less flexible situations (e.g., forests in areas with a high risk of fire or wind damage) often limit the conversion of older stands, and more natural stand structures cannot be developed before the regeneration phase of the next generation of stands. It is generally quicker to implement a move to a more intensive FMA than the reverse because aspects such as the establishment of young trees are faster when achieved through cultivation and planting than through natural regeneration.

The identification of five different FMAs offers greater flexibility in evaluating the impacts of forest management on sustainability indicators than is the case when using the Triad zonation approach (Seymour and Hunter 1999) whereby forests are separated into protected areas (equivalent to our FMA 1), multifunctional areas under ecosystem management (FMAs 2 and 3), and intensive plantations (FMAs 4 and 5) (see Table 3). The value of this framework is underlined by comparing the forestry principles proposed by the European federation of foresters (Pro Silva), which advocates forest management on natural processes (Pro Silva 1999) against our decision criteria. Their preference for "responsible forest management following natural processes" would be graded as a "low" intervention forest management approach according to our framework, although some operations of "medium" intensity occur.

It is also possible to relate our FMAs to other forest classification systems developed by European conservation and environment agencies. For instance, the FMAs can be compared to the five classes of protected and protective forest and other wooded land in Europe (MCPFE 2003c) (see Table 3). MCPFE Class 1 covers areas with "Biodiversity" being the main management objective and has three subclasses according to the restrictions on intervention. The first two subclasses 1.1 and 1.2 with no active and minimum intervention match our passive “unmanaged forest nature reserve” FMA. MCPFE subclass 1.3 with active interventions to achieve specific conservation goals only excluding silvicultural measures detrimental to the management objective might be assigned to our low intensity “close-to-nature” approach. For a proper assignment of MCPFE-Class 2 “Protection of Landscapes and Specific Natural Elements” and Class 3 “Protective Functions” to FMAs, the specific conservation goal of the protected area needs to be known. However, judging by the definitions, MCPFE Class 2 still relates to our “close-to-nature” approach and the “combined objective” FMA might well maintain the protective functions characteristic of MCPFE Class 3 through a combination of protection and timber production in a holistic, integrative concept (Parviainen and Frank 2003). Although not coping with the detail of subclasses in the MCPFE system, our FMAs are compatible with the major MCPFE Classes and have the advantage of going beyond that classification system to include production forestry.

Because FMAs are defined by their objective and basic principles, there is some flexibility to allow adaptation to local situations within one FMA. As FMAs are arranged along an ordinal scale, they allow reasonable categorization of forest management intensity but do not provide a measure for absolutely quantifying the magnitude of interference with natural processes nor the effects on ecological services. Inevitably, there is some overlap between FMAs, as an examination of the framework used to evaluate the case studies in Fig. 1 has shown. If, in a hypothetical example, the allocation of decision criteria appears to be evenly split between one FMA and another, then we suggest that a more detailed examination of the subsidiary elements listed in Table 1 will allow allocation to the most appropriate FMA. Nevertheless, with the current state of forest resource and ecology modeling, this flexible framework can enable comparison of different forest management approaches at a single stand or landscape level or of the same FMA in different forest types or regions, and with evaluation of potential effects over time. Not only can this comparison involve economic production, but can also consider ecological criteria such as biodiversity, water quality, and carbon stocks (Duncker et al. 2012), the recreational use of the forest (Edwards et al. 2012), or the risks from hazards such as biological pests, fire, or windthrow (Jactel et al. 2012). Furthermore, this methodology can provide a uniform framework for quantifying forest management in Europe-wide forest resource models (Hengeveld et al. 2012). By combining the use of one management objective and one set of basic principles within one FMA with the flexibility of applying silvicultural operations that are specific to local circumstances and traditions, the framework of FMAs proposed in this paper is expected to provide a useful tool for facilitating communication between forestry policy and practice. For instance, Mason et al. (2009) have used this methodology to explore the implications of current forest policy in the United Kingdom upon future carbon sequestration and carbon stocks in British forests. Pizzirani et al. (2010) employed the framework to explore the effect of four different scenarios upon the management of Scots pine (*Pinus sylvestris* L.) forests in northern Scotland and the consequent effects upon a range of sustainability indicators.

CONCLUSION

Forest management approaches can be characterized based on an objective and a set of basic principles reflecting decisions on operations that occur at various stages during the development of a stand. The FMAs form a gradient that reflects the intensity of manipulation of natural processes and structures, so that the methodology can be applied flexibly to classify a range of regional examples, as shown here for diverse European forest management approaches. The five FMAs defined in this paper provide an extension of the MCPFE forest classes by including more intensive forest management strategies. They can be applied for evaluating existing forest management strategies, for comparing the effects of different silvicultural options on stand or landscape levels, or facilitating communication between forestry policy and practice.

The case studies selected illustrate the value of the FMA framework when it comes to discriminating between contrasting silvicultural systems. Nevertheless, to demonstrate the wider applicability of this method, further tests of the FMA classification should be carried out. The wider relevance of this classification will only be confirmed after being traced in a wider range of European countries and silvicultural systems, as well as being used for within-region comparisons.

Responses to this article can be read online at:
http://www.ecologyandsociety.org/issues/responses.php/5262

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APPENDIX

A. Forest nature reserve in Białowieża National Park, Poland

This description corresponds to the best preserved fragment of forest in Białowieża National Park in North-Eastern Poland, which is under strict protection. The beginning of Białowieża National Park can be traced back to 1921, when the "Reserve" forest was created at the place currently occupied by the Park. In 1932, this „Reserve" was transformed into „National Park in Białowieża" and in 1947 this unit was reinstated as Białowieża National Park by an ordinance of the Cabinet [1].

The Białowieża National Park covers the last natural forest in the European lowlands which retains a primeval character, with stands characterized by large amounts of deadwood at various stages of disintegration and very high biodiversity of plants and animals.

According to the "Ordinance of the Cabinet about Establishment of Białowieża National Park, 1947", the main objective of an unmanaged forest nature reserve is to allow natural processes and natural disturbance regimes to develop without management intervention to create natural ecological valuable habitats and biodiversity, in the last primeval forest in lowland Europe. Furthermore it serves as a field laboratory for basic and applied research.

Tree species selection, genetic engineering, regeneration type, and succession elements
According to the "Ordinance of the Cabinet about Establishment of Białowieża National Park, 1947" in an unmanaged forest nature reserve under strict protection no management to favour particular tree species takes place. The forest is naturally regenerated.

Machine operation, soil preparation, fertilisation and liming
There is no machine operation, soil preparation, fertilisation and liming.

Application of chemicals or protective agents, integration of nature protection
There is no application of chemicals or protective agents. Maintenance of undisturbed nature has the highest priority.

Tree removals, final harvesting system, and maturity
There are also no tree removals.

According to the strict protection by the ordinance of the Cabinet Białowieża National Park is to be classified as an unmanaged forest nature reserve (see Figure 1.a).

B. European beech management in Baden-Württemberg, Germany

The following description of current management of European beech refers to the forest type "European beech forest with coniferous admixture" of the corresponding regional directive (Landesforstverwaltung Baden-Württemberg 1999) in Germany. This forest type is widely distributed in the sub-mountainous temperate zone of Baden-Württemberg. European beech (*Fagus sylvatica*) grows naturally on most sites in the region, except on organic or heavy clayish soils, sites with highly fluctuating water availability, wet sites, floodplains and steep sites with moving rocks. Current beech forests are said to represent the natural forest

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[1] Rozporządzenie Rady Ministrów z dnia 21 listopada 1947 r. o utworzeniu Białowieskiego Parku Narodowego (Dziennik Ustaw Nr 74, pozycja 469) - (Ordinance of the Cabinet of 21. November 1947 establishing the Białowieża National Park (Official Gazette No. 74, item 469))

vegetation and can be assigned to the climax forest communities of Galio- and Lonicera-Fagetum (Ellenberg 1996). Here, beech is highly competitive, thus admixed tree species only compete outside the natural range of beech.

The long term forest development objective is semi-natural, well structured European beech stands with significant admixtures of conifers (20-50 %) and limited amounts of other broadleaved species (0-20 %). The admixed tree species are distributed either as single trees or in small groups. On small areas the stand structure is multi-storied during the regeneration phase. Apart from this, where not dominant itself, beech can form an understory under the conifer admixture. Beech trees and the partly pruned conifers produce valuable stem wood. The target diameter for European beech is 60cm or more depending on stem quality and the risk of economic losses through red heartwood formation.

Tree species selection, genetic engineering, regeneration type, and succession elements
European beech is only favoured on adequate sites where it generally is part of the potential natural vegetation. Most European beech stands are naturally regenerated with planting on spots where no sufficient regeneration is available. If there is insufficient natural regeneration, beech is planted at a spacing of approximately 2 x 1 m (~5000 seedlings/ha) with additional planting of site adapted mixed species in patches (~20%). The planted material may originate from seed stands. Currently no genetically improved material is being used. Admixed tree species and especially light demanding ones are to be maintained in the stand.

Machine operation, soil preparation, fertilisation and liming
The directive does not discuss site cultivation, fertilization or liming. However, it is mentioned that soil fertility is well preserved under mixed beech stands. Again, machine operation is not directly addressed in the directive. Vehicle movement is restricted to racks with a minimum distance apart of 20 or 40 m depending on soil vulnerability.

Application of chemicals or protective agents, integration of nature protection
Forest protection is regulated by the forest law and plant protection act and not by the directive itself. Within the rationale of integrated plant protection approach the application of protective chemical agents is seen as a last resort. The directive requires maintenance of the forest community with site adopted flora and fauna.

Tree removals, final harvesting system, and maturity
After selection of 60 – 80 future crop trees per hectare, when natural pruning reaches 25-35% of expected final tree height, the main competitors (1-3) for these trees are removed in 5-10 year intervals with no more than 80 $m^3 ha^{-1}$ removed per thinning. Even though this is not stated in the directive, generally only solid wood is removed. The rotation length is chosen according to target diameter and is not defined by age. According to the growth dynamics and the risk of red heartwood formation, production time might be in the range of 80 to 150 years. The final felling system is mostly harvesting trees that have reached the target diameter, or uses group cuttings in order to promote natural regeneration.

Given the statements made in the directive the management recommendation for European beech can be classified as “low intensity category” with some “medium intensity” measures (see Figure 1.b).

C. Norway spruce management in the county of Västerbotten in Sweden

The following description of Norway spruce management refers to the forest type "Mixed forests dominated by Norway spruce," i.e. where more than 70% of growing stock consists of Norway spruce (*Picea abies* [L.] Karst.). Other common tree species in the mixed forest are birch (*Betula pubescens* or *B. pendula*) and Scots pine (*Pinus sylvestris*). About 22% of the forest area corresponds to this type. Norway spruce grows naturally on most sites except on dry soils dominated by lichens and on mires.

The main objective is to produce wood to obtain a good profit. Additional objectives are typically water protection, habitat protection, nature protection, and recreation. The magnitude and importance of additional objectives depends on the local situation.

Tree species selection, genetic engineering, regeneration type, and succession elements
The preferred methods of regeneration are planting of Norway spruce after clear-cut or natural regeneration with a shelterwood system. Normally, the planting material is genetically improved but not genetically modified. The number of plants depends on site index but on average about 2000- 2500 per ha. Birch and/or pine seedlings almost always occur on the regeneration sites. Biological legacies and natural biotopes should be promoted inside the stands. If necessary, pre-commercial thinning is carried out to reduce the number of trees at 1.5 – 4 m medium height.

Machine operation, soil preparation, fertilisation and liming
Machine operations are not limited, as long as they do not harm the environment. Site cultivation is applied to sites when necessary. Fertilization can be an option, but is not widespread.

Tree removals, final harvesting system, and maturity
The rotation period of a stand is chosen by the potential natural vegetation as well as economic interests. Additional to this, the Swedish Forestry Act (Skogsstyrelsen 2010) has a lowest allowable clear-cut age depending on site index and geographical location. The final harvest system is preferably clear-cut or a combination of shelterwood and clear-cut if natural regeneration is preferred to reduce the costs of reforestation.

Summarizing the management recommendations result in "medium intensity" measures (see Figure 1.c).

D. Sitka spruce management in Scotland

The forest area of Scotland comprises about 1.4 M ha of which some 530,000 ha is composed of forests of Sitka spruce (*Picea sitchensis* (Bong.) Carr.). These plantation forests are fast growing in European terms with an average productivity of 14 m^3 ha^{-1} $yr^{-1}$and better sites yielding more than 20 m^3 ha^{-1} yr^{-1}. All forests are managed to conform to principles of sustainable forest management with a commitment to meeting multi-purpose objectives (McIntosh 1995). In practice, the balance between timber production, conservation, recreation and amenity will depend upon local conditions. Stands are generally managed so that pulpwood and small roundwood is produced in early thinnings while sawtimber is provided by later thinnings and final fellings.

Tree species selection, genetic engineering, regeneration type, and succession elements
The commonest method of regeneration is by planting at density of 2500-2700 trees ha^{-1}. About 20 per cent of other species are planted along with Sitka spruce to increase diversity (Mason 2007). Genetically improved material derived either from seed orchards or from propagation of controlled cross mixtures, is widely planted and is expected to give increased timber yields over first generation stands (Moore et al. 2009). No genetically modified material is planted. Natural regeneration of spruce, pine, larch and various broadleaves is accepted when it occurs but the other species rarely survive beyond canopy closure because of the fast growth of the spruce stands. Respacing (precommercial thinning) is carried out in dense natural regeneration when trees are 2-3 m tall.

Machine operation, soil preparation, fertilisation and liming
Machine operation is not limited provided the guidance on soil conservation and maintaining water quality is observed. Site cultivation is standard practice when replanting occurs while fertilisation is much reduced compared to the earlier afforestation phase (Mason 2007). No liming is carried out.

Application of chemicals or protective agents, integration of nature protection.
Under the certification process, there is an aim to reduce levels of chemical input to the forest system but the use of chemical herbicides and pesticides is permitted where no practical cost-effective alternatives exist (Willoughby et al. 2004). Conservation considerations are incorporated through the forest design process (McIntosh 1995).

Tree removals, final harvesting system, and maturity
The customary rotation period is between 35 and 50 years depending upon site productivity and the risk of windthrow. A non-thin regime is used on more exposed sites: elsewhere 3-4 intermediate thinnings are carried out on a 5 year cycle followed by clear felling. In some locations of high amenity or recreational value, attempts are being made to introduce continuous cover forestry into the management of Sitka spruce forests.
Summarizing the management measures (see Figure 1.d) suggests that most are of high-moderate intensity although there are current tends to reduce the intensity.

E. Eucalyptus management in Portugal

Eucalyptus (*Eucalyptus globulus)* is an exotic species that grows exceptionally well in Portugal. Eucalyptus is a fast growing species for which the maximum net increment occurs before the age of 5, although high productivities do not persist for a long time (Soares et al. 2007). Most of the stands are planted and plantations are mainly managed as short rotation coppice systems, with an average cutting cycle of 10-12 years to benefit from its productivity. The main objective is to produce high quality wood for pulp and paper production.

Tree species selection, genetic engineering, regeneration type, and succession elements
Eucalyptus first rotation stands are usually planted with a density of 1250 seedlings per ha. A beating up operation is performed 6 months after planting to replace dead trees (15%). Its fast growth rate makes this species quite competitive and intolerant to succession elements, which reduces the regeneration of natural vegetation resulting in pure even-aged stands. Due to this species high coppicing ability, a first cycle of planted seedlings is usually followed by 2 to 3 cycles of coppiced stands. To increase productivity, improved genotypes resulting from tree breeding can be used and genetically modified material may be used in the future.

Machine operation, soil preparation, fertilisation and liming

There is a set of mechanised silvicultural operations that are performed. Whenever replanting is considered, stump removal and harrowing for woody debris incorporation are performed. Site preparation can be carried out through harrowing, ploughing or ripping operations. It is common to fertilize at planting with a NPK slow release fertilizer plus a phosphorus fertilizer. Additional mechanical fertilizations with NPK fertilizer can take place when the soil proves to be deficient in some specific nutrient(s). One or more mechanical weed control operations can be done in order to eliminate competition and decrease the risk of fire. Usually, weed control and mechanical fertilizations are done at the same time in a single operation reducing costs and compaction problems caused by machine movement on forest soil. In high fire risk areas weed control can be more frequent and/or more intense forest and building of forest roads' conducted to improve access.

Tree removals, final harvesting system, and maturity

In coppice stands, the number of sprouts per stool is reduced down to 1.2 to 1.6 by motor-manual cutting of shoots selected according to the intensity of mortality occurred in the transition from planted to coppice stands. Management is conducted in order to minimize the effects of natural hazards: stands showing any sign of being infected with any pest or disease may be submitted to chemical/biological control, pruning (after intense night frosts and/or *Botrytis cinerea* attacks) or even pre-commercial thinning (after insects or fungi attacks), Normally, only cut stems are removed from the stand although the extent of components extracted in thinning and final harvest operations can go up to the whole tree. A clear-cut is carried out at the age of 12 years producing 400-600 m^3 ha^{-1}. The size of the clear felling area depends upon the landscape.

The basic principles behind the current forest management of planted and coppice Eucalypt stands are very similar, differing only in the type of regeneration, and in specific silvicultural operations associated with it such as soil preparation and tree removals (see Figure 1.e).