Forestry An International Journal of Forest Research
Institute of Chartered Foresters

Forestry, Vol. 85, No. 2, 2012. doi:10.1093/forestry/cps004
Advance Access publication date: 29 February 2012

Forest naturalness assessment as a component of biodiversity monitoring and conservation management

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Summary

A primary prerequisite for the preservation of global diversity is often assumed to be a high level of naturalness. This paper reports a synthesis of naturalness definitions, distinctions between the concepts of naturalness and of hemeroby and an analysis of different naturalness assessment approaches. Naturalness may be commonly defined as 'the similarity of a current ecosystem state to its natural state'. Hemeroby, a concept related to human impacts, is often associated with naturalness but, in principle, the two concepts are not inversely related. The hemeroby concept defines narrow assessment classes for greater hemeroby, whereas the naturalness concept defines narrow assessment classes for great naturalness. The rapidly increasing number of forest naturalness papers relies on the following main indicators in decreasing order of use: tree species, forest structure, fauna, ground vegetation and deadwood. A review of the literature on forest naturalness suggests four main reasons for the lack of a widely accepted approach for assessing naturalness: (1) the lack of a commonly accepted reference concept, (2) an incomplete list of essential naturalness traits, (3) unknown linkages between some naturalness traits and biodiversity and (4) the lack of an assessment approach that can be adapted for use at both regional and large scales. Following review of the literature on forest naturalness, a seven-level framework is presented to guide development of naturalness assessment approaches as a component of forest biodiversity monitoring and conservation management.

Introduction

The main reason for the decrease in forest biodiversity worldwide in 'all its forms and all its levels of organization' (Hunter, 1990) is degradation and loss of forest ecosystems (Foley *et al.*, 2005). Decrease in biodiversity correlates with a decreasing number of habitat niches (e.g. Winter and Möller, 2008; Heino *et al.*, 2009; Michel and Winter, 2009). The concept of naturalness relates to the degree to which a natural state has been degraded. The underlying idea of comparing the current state of an ecosystem with its natural state was developed in central Europe during the last century. In this context, forest naturalness correlates with forest structural diversity (Christensen *et al.*, 2005; Winter and Möller, 2008; Michel and Winter, 2009; Ranius *et al.*, 2009) and with biodiversity characterized by the presence of saproxylic beetles (Müller *et al.*, 2007a) and wood-inhabiting fungi (Müller *et al.*, 2007b). Greater naturalness is characterized by a large number of adapted, specialized and often endangered plant and animal species. Thus, in order to halt the loss of forest biodiversity, more emphasis must be directed at maintaining and restoring greater naturalness as has already been stated by Angermeier and Karr (1994), Majer and Beeston (1996), Trombulak *et al.* (2004) and Cardoso *et al.* (2007). Consequently, greater naturalness is one of the main prerequisites for maintaining global forest biodiversity and should be a main focus of forest and conservation management at all scales. Nowadays, because sustainable forest management includes ecological sustainability, naturalness assessments must guide management efforts to restore and maintain forests. Without a consensus on naturalness assessment, forest monitoring is of limited value because observations of naturalness traits cannot be combined to produce a single value that summarizes the ecological status of the forest. Consequently, naturalness assessments are increasingly being required to determine and to monitor both the ecological status and the development of forests (Bartha, 2004).

As a component of forest monitoring, naturalness assessments should lead to management practices that increase the functionality of ecosystem by maintaining habitat and thus ensuring continuous ecosystem use by endangered and specialized species. Identification of naturalness by the Ministerial Conference on the Protection of Forests in Europe (MCPFE, 2003) as one of the seven sustainable forest management indicators clearly underpins the importance of a sound forest naturalness concept. Additionally, the COST Action E43 project on the harmonization of national forest inventories (Winter *et al.*, 2008; McRoberts *et al.*, 2009; Chirici *et al.*, 2011) conducted under the auspices of the European programme 'Cooperation in Science and Technology' (COST, 2009) proposed naturalness as one of the main indicators for international reporting on forest biodiversity. The main purposes for assessing naturalness are threefold: (1) to properly estimate and report the ecological state of forests for purposes of evaluating nature conservation and forest management, (2) 'to develop objective standards for forest conservation and (3) to identify natural, old-growth forests that can be designated as protected areas' (McRoberts *et al.*, in press).

Although the naturalness concept has great relevance for forest biodiversity maintenance and restoration and is known and accepted by the European public in general (Fischer and van der Wal, 2007), a common naturalness definition and an approach for naturalness assessments are lacking. Further, naturalness traits vary widely, both in kind and number. Without a commonly accepted naturalness definition and a naturalness assessment approach, there can be no effective means of monitoring forest biodiversity trends. Further, until a common and scientifically based approach to assessing the state of forests is developed and applied, objective and thorough reporting on the ecological quality of our forests is impossible. The danger is that forest degradation will neither be apparent nor adequately recognized, and the loss of biodiversity will increasingly be accepted by forest managers and other decision makers.

Further, differences between the concept of naturalness and the associated concept of hemeroby, which emphasizes human impacts, are not clearly differentiated in the literature, a result that further hinders clarity and development of a common naturalness assessment approach.

The literature review that follows aims at clarifying the naturalness concept by contrasting it with the hemeroby concept and by describing previous use of and gaps in assessment approaches. The review has five specific objectives:

1. To synthesize definitions of forest naturalness and hemeroby for the purpose of proposing a common definition,
2. To elucidate differences between the concepts of naturalness and hemeroby so that the two concepts can be appropriately used in scientific studies and for forest biodiversity monitoring,
3. To analyse different naturalness perceptions, traits, indicators, assessment frameworks and approaches,
4. To conduct a gap analysis and
5. To construct a framework for naturalness assessments based on the conclusions from the literature review and the gap analyses.

Materials and methods

Numerous papers (about 80) on forest naturalness and hemeroby (see reference list) were analysed for their contribution to the five main objectives presented above. Papers mentioning the concept of naturalness range from those marginally using the term to those reporting thorough naturalness studies. All available papers from the Web of Science (Web of Science, 2012) on forest naturalness (keywords: naturalness and forest) and on hemeroby (keyword: hemeroby without further selection) and several publications from other sources were analysed relative to four factors:

1. Definitions of naturalness and hemeroby,
2. Differences between the naturalness and hemeroby concepts,
3. Traits considered for naturalness and/or hemeroby assessment and
4. Assessment approach.

Literature considered other than from the Web of Science was published in German and included the early publications on naturalness and the source publication on hemeroby as well as publications with modifications of the hemeroby concept.

Literature review to assess the current status of the naturalness concept

Variety and inconsistency of naturalness definitions and distinction from the concept of hemeroby

Wherever definitions of naturalness are provided in the literature, they seem to vary. However, two main naturalness definitions and additionally one related hemeroby concept can be discerned:

First, the definition of naturalness is often understood as a 'comparison of the current ecosystem state with its natural state' (Table 1). Naturalness, or sometimes redundantly called the degree of naturalness, is proposed to be estimated either as a continuum from lesser to greater naturalness (e.g. Hunter, 1996; Angermeier, 2000) or as distinct classes that cover the range of the continuum (overview see Colak *et al.*, 2003). Naturalness, whether assessed as a continuum or in classes, may use a broad scale ranging from highly artificial states such as large cities to primeval forests (Sjörs, 1986; Haber, 1991). Alternatively, a narrower scale that relates only to forest ecosystems may be used that ranges from the naturalness of forests

Table 1: Naturalness definitions (literature examples; further literature on forest naturalness do not provide any additional definitions)

Reference	Naturalness definition (original texts of the papers)	Approach 1: naturalness defined as similarity to the natural state	Approach 2: naturalness regarded as maximum natural state	Is a reference forest needed?	Is the hemeroby concept mentioned?
McRoberts *et al.* (in press)	A continuum with entirely natural and entirely artificial at the extremes.	X		–	X
Winter *et al.* (2010)	Naturalness is the opposite theoretical focus to the prevalence of man's activity (hemeroby). Naturalness depicts the distance between the current and the potential natural status. Man is part of nature but simultaneously divides nature from culture.	X		X	X
Liira *et al.* (2007), Liira and Sepp (2009)	None	X		X	–
Paillet *et al.* (2008)	No comprehensive definition but naturalness is mentioned as being the distance to the natural state of a habitat.	X		X	–
Roberge *et al.* (2008)	Naturalness is best described as a continuous variable, where forest stands and landscapes span a gradient from mainly artificial forests through semi-natural to naturally dynamic forests.	X		X	–
Derous *et al.* (2007)	The 'naturalness' criterion is defined as the degree to which an area is pristine and characterized by native species.	X		X	–
von Oheimb *et al.* (2005)	A high degree of naturalness is reflected in a high continuity of woodland existence, a long period of anthropogenically undisturbed development, a tree species composition corresponding to the natural vegetation and an extensive forest area.	X		–	–
Petriccione (2006)	The level of naturalness, defined like the degree of self-functioning of the natural processes and the intensity of human interventions on the function and structure of ecosystems.	X		–	–
Westphal *et al.* (2004)	Naturalness in forests is a process-related measure that develops in relation to time span as well as to intensity of anthropogenically undisturbed woodland dynamics. Its material expression is found in a continuously changing set of species and structures resulting from these dynamics.	X		X	–
Colak *et al.* (2003)	Natural likeness: the difference from the original natural conditions.	X		X	X
Mrosek (2001)	The existing state of a forest in comparison to the natural forest.	X		X	–
Anderson (1991)	(1) The degree to which the system would change if humans were removed; (2) the amount of cultural energy required to maintain the functioning of the system as it currently exists and (3) the complement of native species currently in an area compared with the suite of species in the area prior to settlement.	X		–	–
Wehenkel *et al.* (2009)	None	–	X	–	–
Papers (out of 13)		11	1	8	3

established as plantations which are characteristic of intense anthropogenic forest disturbances to primeval forests (Liira and Sepp, 2009; Tierney *et al.*, 2009). Naturalness assessments that aim to evaluate management activities should be on as small a scale as possible to obtain specific results. Other objectives such as reporting on large-scale biodiversity may require a broader range.

The second use of the term naturalness (Table 1) in the literature refers to the 'state of a forest without human impact' (e.g. Wehenkel *et al.*, 2009). This definition considers naturalness to be synonymous with the term 'primeval forest'. This use is misleading and represents a misapplication, because the naturalness concept covers the entire range between the artificial and the natural state of an ecosystem.

Scientific investigations on forest naturalness were probably initiated in the German-speaking countries of Central Europe using two German words: 'Naturnähe', which connotes a comparison between the current state and a natural reference state, and 'Natürlichkeit', which connotes the current state of the forest. Both terms are widely acknowledged and are still accepted in the German-speaking scientific community (Kowarik, 1987, 1999; Leuschner, 1997; Zerbe, 1999), although the first definition, meaning 'closeness to its natural state', is more commonly used. In the peer-reviewed English language scientific literature where naturalness is first mentioned by Anderson (1991), the concept is discussed, but not conclusively defined (Table 1). As a consequence, various definitions appear in the current English language scientific literature. Furthermore, numerous papers that mention naturalness still do not define the underlying concept (e.g. Smelko and Fabrika, 2007; Winter and Möller, 2008; Hancock *et al.*, 2009; Heino *et al.*, 2009).

The hemeroby concept (Table 2) was introduced and defined by Jalas (1955) and promoted by Sukopp (1976) as a degree or measurement of human influence on ecosystems. Thus, hemeroby is an integrated measure of anthropogenic influence on landscapes or habitats (Jalas, 1955; Table 2). Other publications on hemeroby either refer to or cite the hemeroby definition given by Jalas and Sukopp or use a similar definition. Altogether, the definitions used for hemeroby are more homogenous than those for the naturalness concept, because the source definition of hemeroby was available from the beginning.

Scientific papers from the Web of Science that mention the concept of hemeroby almost all apply it to vegetation and flora, clearly indicating that the hemeroby concept was developed by vegetation ecologists (Jalas, 1955, modified by Sukopp, 1972). The term is still used by vegetation ecologists when referring to non-forested areas. Naturalness is currently considered much more frequently in forest research studies than is hemeroby. Furthermore, most authors who mention hemeroby also mention naturalness (Table 2).

Perception of the two concepts in the literature

The relationship between hemeroby and naturalness varies in the literature. First, the terms are regarded as synonyms (mentioned in Colak *et al.*, 2003); second, hemeroby is defined as being included within the naturalness concept (Jalas, 1955; Sukopp, 1976; Kowarik, 1988; Colak *et al.*, 2003); third, naturalness and hemeroby are expressed in a reciprocal way (Klotz and Kühn, 2002; Fu *et al.*, 2006) and fourth, the two concepts are interpreted as being independent and with different reference points. For example, naturalness is referred to as being the historical, original state of the past, whereas hemeroby is considered to be the potential state of unmanaged forests in the future (Hornschuch and Riek, 2009).

Naturalness and hemeroby as opposite extremes of a gradient

Most authors mentioning naturalness agree that greater hemeroby and greater naturalness tend towards opposite extremes of a continuous gradient. Further, the gradient is mostly subdivided into naturalness or hemeroby classes (for an overview, see Schirmer, 1998) with the classes at the extremes characterized using many different details and differently focused indicators (see next section). The conclusion from the literature is that naturalness assessments place greater emphasis on the natural end of the scale, whereas hemeroby emphasizes human influence at the opposite end of the scale. For both naturalness and hemeroby, the class widths decrease as the respective extreme classes are approached. Some authors conclude that naturalness and hemeroby classes coincide when the number of classes and the gradient scale are the same (e.g. Colak *et al.*, 2003) without recognizing that the class widths tend to be substantially different because the concepts have distinct frameworks (see below).

Thus, results of a hemeroby assessment are not fully adequate to assess forest naturalness. Furthermore, hemeroby should be regarded as a tool for differentiating among forests with serious human impacts, whereas naturalness assessments differentiate among more naturally managed and abandoned forests. Because the naturalness and hemeroby concepts are complementary, neither the concepts nor their gradient classes are compatible.

All things considered, the concepts of naturalness and hemeroby and their assessments cannot be regarded as interchangeable.

Variety of naturalness assessment traits, indicators and approaches

The naturalness concept is increasingly being incorporated into scientific studies (Figure 1). Whereas in early studies, the concept was mainly just described and discussed (Anderson, 1991, 1992; Gotmark, 1992), the trend in forestry is now to search, test and define naturalness traits and indicators of naturalness in detail and to quantify them (Azeria, 2007; Barbati, 2007; Cardoso *et al.*, 2007; Corona, 2007; Liira *et al.*, 2007; Midgley, 2007; Müller *et al.*, 2007b; Smelko and Fabrika, 2007; Tyrvainen *et al.* 2007; Gibbons *et al.*, 2008; Gil-Tena *et al.*, 2008; Magura *et al.*, 2008; Paillet *et al.*, 2008; Raunikar *et al.*, 2008; Roberge *et al.*, 2008; Skornik *et al.*, 2008; Winter and

Table 2: Hemeroby definitions (literature examples; further literature on hemeroby do not provide any additional definitions)

Reference	Hemeroby definition (original texts of the papers)	Naturalness is mentioned in the paper	Paper includes a definition of naturalness
McRoberts *et al.* (in press)	The degree of human influence.	X	X
Testi *et al.* (2009)	An indicator of human impact on vegetation, ranging from 0 (no impact) to 9 (totally artificial).	–	–
Atici *et al.* (2008)	No definition, the text refers to the hemeroby classes oligohemerobe and mesohemerobe.	X	–
Tasser *et al.* (2008)	Measures the degree of human impact on ecosystems (after Steinhardt *et al.*, 1999).	X	X
Fu *et al.* (2006)	Hemeroby or hemerobic state is an integrated measure for the anthropogenic influence on landscapes or habitats.	X	–
Colak *et al.* (2003)	Conscious or unconscious manner of total impacts by human on natural ecosystems (after Blume and Sukopp, 1976).	X	X
Papers in German (translated)			
Klotz and Kühn (2002)	The system of hemerobic levels describes how close to nature or how far away from nature a vegetation unit is.	X	–
Kowarik (1988)	A measure for the human impact on ecosystems.	X	–
Sukopp (1976)	An integrative measure for the impacts of all human intervention on ecosystems, whether they are intended or not. The degree of hemeroby is the result of the impact on a particular area and the organisms which inhabit it.	X	–
Jalas (1955)	An integrated measure for the anthropogenic influence on landscapes or habitats.	X	–
Papers (out of 11)		10	3

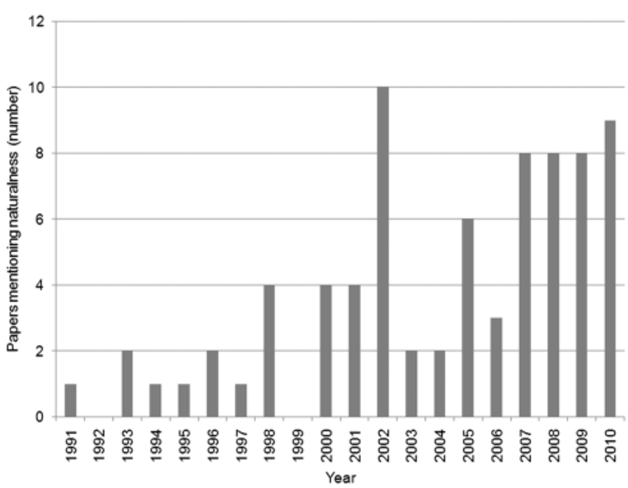

Figure 1. Papers mentioning naturalness (number) within the Web of Science, 1991–2010.

Möller, 2008; Halme *et al.*, 2009a; Hancock *et al.*, 2009; Heino *et al.*, 2009; Liira and Sepp, 2009; Napierala *et al.*, 2009; Wehenkel *et al.*, 2009).

The objectives of currently published papers can be classified into three general categories:

1 To investigate or test available traits and indicators in case studies (e.g. Heino *et al.*, 2009; Liira and Sepp, 2009);

2 To emphasize improvement of programmes for monitoring habitats or landscapes; however, these studies mostly mention the concept of naturalness only briefly or regard it as one indicator among others without describing the assessment approach in detail (e.g. Paillet *et al.*, 2008; Halme *et al.*, 2009a, b);

3 To refine existing or develop new approaches to naturalness assessments (e.g., Gibbons *et al.*, 2008; Winter *et al.*, 2010).

The three most comprehensive naturalness studies published in recent years focus on these clearly distinct categories. First, Liira and Sepp (2009) presented a comparative study of 171 boreo-nemoral forest stands along a management gradient and studied 50 stand characteristics in order to compile a critical and statistically confirmed list of naturalness indicators. This extensive study is similar to other investigations that seek to identify indicators for naturalness assessment but differs in that it considers a large number of qualitative features and quantitative variables. Second, Paillet *et al.* (2008) conducted a study on forest fragmentation in France, referring to this approach as a 'multi-criterion method based on the difference between a natural value and a conservation value'. The method was developed by Du Bus de Warnaffe and Devillez (2002). Paillet *et al.* (2008) used this method to compare the naturalness of sycamore maple forests with surrounding deciduous forests. It is an applied study that was initiated to demonstrate the suitability of the specific naturalness characteristics and combined the concepts of naturalness and hemeroby. Third, Gibbons *et al.* (2008) present an objective approach for predicting reference conditions and reference benchmarks for some biodiversity indicators in different forest communities in Australia.

In conclusion, the forest naturalness concept has been less widely discussed in the last few years, whereas studies on naturalness traits and the definition for reference benchmarks have gained in importance.

The main naturalness traits considered in reported research studies are the diversity of tree species, forest structure, fauna, ground vegetation and deadwood (Figure 2). Most frequently, the naturalness of tree species composition is analyzed. Forest structure, fauna and ground vegetation are considered in more than half of naturalness papers and deadwood in about one-third. In most papers, only one or two naturalness traits are considered, mainly 'tree species' and 'forest structure'. The three thorough papers on naturalness assessments by Gibbons *et al.* (2008), Paillet *et al.* (2008) and Liira and Sepp (2009) incorporate a large number of indicators in their naturalness approaches, suggesting that multiple traits are needed to portray naturalness more reliably.

The linkage between biodiversity and naturalness traits such as deadwood, structural heterogeneity and forest development phases has been confirmed in several studies (see Introduction section). But still, for most species groups, the relationship between the proposed assessment traits and the ecological status of these species groups has not yet been adequately studied. Heino *et al.* (2009) state that 'the extensive surveys in protected and managed areas have not been conducted for a majority of taxonomic groups and ecosystem types, which makes it difficult to assess how large a portion of biodiversity is at least potentially under protection' or sustainably managed.

The most thorough assessment approach and its application were reported by Grabherr *et al.* (1998). This approach was developed for assessing the human impact on the forests of Austria and uses several indicators, such as plant species composition and the vertical and horizontal forest structure including forest layering, developmental phases, stand density, diameter distribution and deadwood. This approach, by far, is the most comprehensive and complex. Grabherr *et al.* (1998) developed a scientifically relevant and appropriate assessment algorithm and used it to produce a distinctive classification of the Austrian forests. The 11 traits considered were given individual weights following the questionnaire results from a Delphi technique (Schöllhammer, 1970, modified) on the importance of the traits for hemeroby assessment. Questionnaire responses were obtained from academics working in the field of forest ecology. The algorithm for estimating total naturalness uses five assessment levels to incorporate the traits to a single naturalness value (Grabherr *et al.* 1998, p. 190). Taking into account the distinction between the naturalness and hemeroby concepts presented in Materials and methods section, Grabherr *et al.* (1998) mainly incorporate the hemeroby concept.

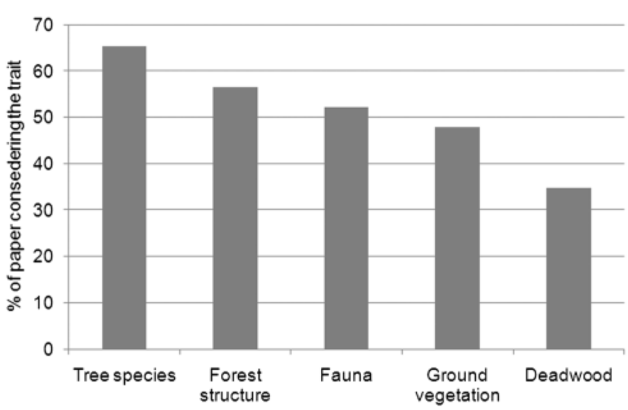

Figure 2. Traits of forest naturalness (% of about 80 papers) considered most often in naturalness studies.

None of the currently published naturalness studies focuses on an algorithm for naturalness assessment or on the question of how to apply the forest naturalness concept in science, nature conservation or in biodiversity monitoring. The latest approach was published in French by Du Bus de Warnaffe and Devillez (2002). Their assessment includes 14 naturalness indicators that refer to compositional, structural and functional naturalness levels. The approach culminates with an estimate of mean naturalness for each of these three levels and finally in an overall naturalness estimate calculated as the mean of the naturalness estimates for three levels. Uotila *et al.* (2002) focused on naturalness by comparing managed and unmanaged boreal forests in Fennoscandia. Neumann and Starlinger (2001) assessed forest naturalness by applying different indices for stand structure and diversity in Austrian forests using data for permanent monitoring plots. The former (Uotila *et al.*, 2002) conducted a complex comparative study considering common naturalness indicators such as coarse woody debris, living forest structure (number of trees, basal area, volume and range of diameter) and the proportion of deciduous tree species, but the indicator results were not combined with a general assessment approach of naturalness. However, Neumann and Starlinger (2001) applied 11 diversity indices such as the Clark–Evans index, the Shannon index, the Pielou index (Pretzsch, 1996, 1997) to develop assessment algorithms. Nevertheless, the authors found no correlation between the naturalness of tree species composition and the estimated diversity indices; thus, the study did not result in an assessment approach.

Winter *et al.* (2010) were the first to attempt development of a thorough forest naturalness assessment method based on multiple biodiversity levels although the approach focused mainly on structural indicators. However, in order to include direct indicators of flora and fauna, further efforts are desirable. For further naturalness assessments of forests, the hemeroby-based approach of Grabherr *et al.* (1998) may also be modified and further developed in the future.

For development of naturalness assessment approaches, the focus on indicators for assessing naturalness and hemeroby on the two gradient extremes must be considered. Naturalness assessments require indicators that are able to detect even small differences between habitats and their reference states, whereas hemeroby assessments require indicators that respond in a meaningful way to human impact. Two examples elucidate this general difference between naturalness and hemeroby indicators. First, in European lowland beech forests, the herb species *Anemone nemorosa* L. is significantly more abundant in forests that are not managed than in managed forests (Dzwonko, 2001). A decline in prevalence is correlated with a decreasing number of years since harvesting was abandoned. Thus, *A. nemorosa* is an indicator species for naturalness assessments (Rose, 1999) because it relates to the natural state of a forest. However, the herb species *Veronica officinalis* L., the grass species *Calamagrostis epigeios* (L.) Roth and the neophyte herb species *Impatiens parviflora* DC. become more abundant with increasing intensity of forest management and less abundant in more natural forests. Thus, these species are indicators for hemeroby because they relate to human impact on a forest (Liira *et al.*, 2007).

Second, generally, the number or frequency of native tree species increases with increasing naturalness, while in general, the number or frequency of non-native tree species increases with the management intensity (Gibbons *et al.*, 2008). Consequently, the number or frequency of native tree species is an indicator for naturalness, while the number or frequency of invasive or exotic tree species is an indicator for hemeroby by depicting the forest conversion intensity of native forest communities. However, a small number of native tree species does not necessarily indicate forests with large transformations due to anthropogenic impacts, and conversely, a small number of exotic tree species does not necessarily indicate or differentiate natural forests. Differentiation in the same sense just described is found in indices for forest connectivity that indicate naturalness and likewise in indices for forest fragmentation that indicate hemeroby (Winter *et al.*, 2010). Thus, conversions of hemeroby assessment results to naturalness assessment results and vice versa are not appropriate.

Gaps in the algorithms for assessing naturalness

The identification and description of gaps in our knowledge on naturalness assessments are the basis for improving future assessments. The preceding review of the literature on naturalness provides insights into how to develop and improve naturalness assessments in the future by revealing the gaps in the current knowledge on naturalness (assessments). Four main gaps were evident: (1) the lack of consensus regarding both the naturalness concept and the related concept of reference forest for which comprehensive knowledge is inadequate, (2) an incomplete list of the naturalness traits considered essential for the assessment and the lack of a comprehensive assessment algorithms, (3) unknown linkages between naturalness traits and forest biodiversity and (4) lack of assessment approaches that can be adapted from regional to large scales.

Gap 1: lack of a naturalness definition, a reference concept and benchmarks

Accepting that forest naturalness includes a comparison between the current and a comparable reference state of forests, estimates of naturalness require the inclusion of suitable references and reliable reference values. Wehenkel *et al.* (2009) summarize the problem as follows: ‘All measurements are confounded by the dilemma that maximal naturalness is unknown’. Gibbons *et al.* (2008) support both identifying references and estimating benchmarks for reference forests, an approach that is used in some Australian forests. However, this method requires data that are not currently acquired by existing monitoring programmes and therefore is not immediately useful for large-scale applications.

In many cases, authors recognize that a precise and proper knowledge of the forest reference is required (Table 1). Discussions are underway to determine the qualities a forest reference should provide for naturalness assessments. A common view is that the reference should represent the most natural forest relative to growth conditions (environmental drivers) such as climate, soil, aspect and elevation for the managed forests that are assessed (Westphal *et al.*, 2004; Derous *et al.*, 2007). A reference definition that also takes into account variable references in forest naturalness assessments in landscapes where virgin forests no longer exist was recently developed by Winter *et al.* (2010). For assessing hemeroby, knowledge about natural forests is required, but for naturalness assessments, knowledge of the traits of extreme anthropogenic impacts is not required. Thus, the naturalness concept relies less on other concepts and is more independent of them than the hemeroby concept. Furthermore, in order to compare the concepts, it is vital to consider that even the classes used in different approaches to naturalness assessments do not have the same width and meaning (Schirmer, 1998). However, this can be regarded as an adaptation of the naturalness assessments that depend on detailed assessment objectives.

Further research should provide general guidance for choosing appropriate reference forests and should generate benchmarks for different large-scale forest communities such as the 13 forest categories (EEA, 2006) used to classify European forests or at least for different large-scale climatic zones such as the boreal or temperate zone.

Gap 2: incomplete list of naturalness traits

A list of naturalness indicators along with appropriate inventory methods is still not conclusive. According to the literature, for the most commonly considered naturalness traits (Figure 2), three additional issues should be considered:

Impact of plot size: McRoberts *et al.* (in press) indicate that estimates of tree species diversity vary with small changes in plot sizes; this result prohibits regional comparisons that use national inventory data obtained from plot of different sizes. However, it is assumed that on a large scale, the plot size effect might be negligible (Winter *et al.*, 2012). Nevertheless, the need for comparable data entails the need for a harmonization approach. An initial holistic approach to incorporate national forest inventory data from European countries and the US is presented by Chirici *et al.* (2011). Studies on the effect of plot size on the estimates of natural traits and studies on the harmonization of existing data should be continued.

Forest structure: The second most frequently considered naturalness trait may include multiple characteristics such as tree density by diameter class (Gibbons *et al.*, 2008), vertical heterogeneity (Paillet *et al.*, 2008) or cover by canopy layer (Liira and Sepp, 2009). Structural components such as tree microhabitats that are essential for forest biodiversity (Winter and Möller, 2008; Michel and Winter, 2009) and ecologically integrative forest development phases (Winter and Brambach, 2011) are innovative naturalness traits that should be included in naturalness assessments. However, we are currently still searching for the methodology to record adequately some traits such as microhabitats.

Appropriate number of naturalness traits: There is a need for investigations into the number of naturalness traits sufficient to provide a comprehensive assessment of naturalness. The number of naturalness indicators that have been proposed for inclusion in assessments is increasing (e.g. Müller *et al.*, 2007a, b; Liira and Sepp, 2009; Winter *et al.*, 2010). Thus, more studies should be initiated on the use of integrative indicators such as developmental phases and microhabitats (Winter *et al.*, 2008; Chirici *et al.*, 2011) to better monitor naturalness. Prospective results will lead to a sensible implementation of innovative naturalness indicators in monitoring methodologies. Furthermore, analyses should be conducted to acquire insights into the minimum number of indicators that are needed for a reliable portrayal of naturalness.

Gap 3: unknown linkages between some naturalness traits, forest biodiversity and sustainable forest management

Large-scale forest management still lacks harmonized ecological overview data to monitor biodiversity reliably and to improve preservation of biodiversity in managed forests. Insights on forest naturalness values may contribute to forest biodiversity management. Mrosek (2001) developed a hierarchical five-level approach for forest management based on assessments of criteria and indicators but without adapting forest management in accordance with the results of indicator-based assessments of reference forests. Moreover, Mrosek (2001) regards the very existence of unmanaged forests as one criterion of the assessment. Without a clear focus on forest naturalness in forest monitoring, reliable sustainable forest management encompassing the maintenance of forest biodiversity will not be possible.

Gap 4: lack of assessment approaches that can be adapted from regional to large scales

Current assessment approaches are based on local to regional studies. The adaptation of these methods for large-scale application or for the development of an innovative large-scale assessment approach has not yet been fully demonstrated. The only example of a large-scale application is the hemeroby study by Grabherr *et al.* (1998) on Austrian forests. However, this study was conducted in a country that uses country-specific forest inventory methods. In an initial attempt, McRoberts *et al.* (in press) and Winter *et al.* (2012) suggest using an assessment approach that harmonizes data from different national forest inventories for tree species composition and some forest structural features such as the tree diameter. But harmonization of heterogeneous national forest inventory data or estimates (Ståhl *et al.* in press) still results in simple naturalness assessments. The proposed large-scale naturalness assessments are not feasible on a scale as large as the European Union. Thus, a more general and comprehensive approach is required.

Seven-level framework for forest naturalness assessments and its application for biodiversity and nature conservation surveys

For purposes of proposing a framework for assessing forest naturalness, a definition of naturalness for common use is first given: 'naturalness is the similarity of a current ecosystem state to its natural state'. The first afore-mentioned approach for defining the term naturalness (see Variety and inconsistency of naturalness definitions and distinction from the concept of hemeroby section) is meaningful and clear because naturalness is regarded as a concept which is different and distinguished from the concepts of hemeroby and of nature in the sense of a primeval forest state. This definition underlies the development of the seven-level framework described in the following sections.

Second, the framework is based on and addresses the conclusions from the literature review. From the literature on naturalness, a comprehensive naturalness assessment approach that supports forest biodiversity monitoring and conservation management entails seven successive steps (Figure 3):

1. Definition of the criteria for identifying reference forests (e.g. primeval forests or forest with the maximum time past since the management was abandoned).
2. Evaluation of the main traits for assessing naturalness on a large scale. Evaluation schemes from the literature (Figure 2) or Delphi techniques reveal the essential traits of biodiversity which are documented by Chirici *et al.* (2011) and are appropriate for evaluating the main naturalness traits.
3. Selection of a set of naturalness indicators such as deadwood volume, deadwood decay classes, sizes of the largest trees and native tree species composition. Following the concepts and definitions of biodiversity (Whittaker, 1972; Noss, 1990) which are widely acknowledged, the indicator set for naturalness assessments should include indicators of two different concepts of forest diversity to encompass the main biodiversity components. On the one hand, there is the concept developed by Noss (1990) where three basic ecosystem components are defined: (a) 'compositional' indicators relating to the diversity of elements such as taxons, e.g. tree species, (b) 'functional' indicators describing the ecological and evolutionary

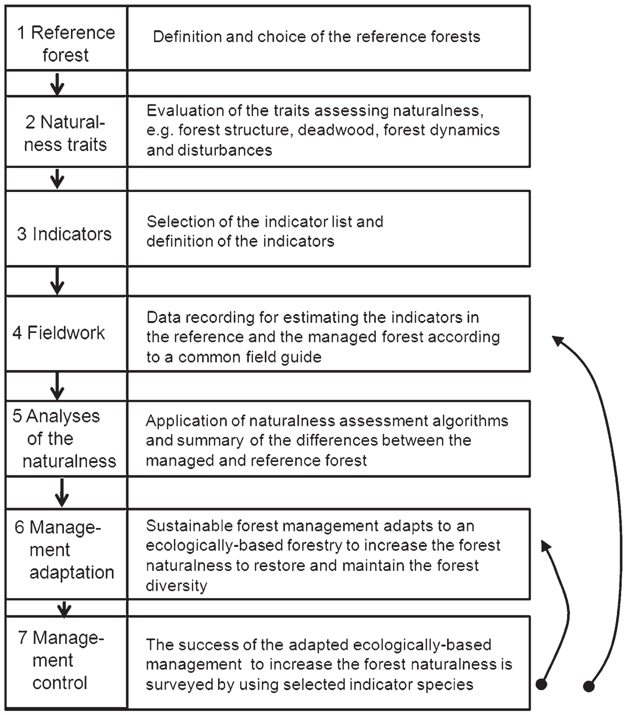

Figure 3. Seven-level framework for naturalness assessments and conservation management.

process of the forest ecosystem, e.g. forest connectivity representing processes within populations (Winter *et al*., 2010) and (c) 'structural' indicators encompassing the physical (and spatial) organization of the elements such as the amount of deadwood. On the other hand, within the other concept (Whittaker, 1972), different levels of diversity from the local to the large scale are defined and should thus be addressed by different assessment approaches.

4 Development of a consistent and common field guide to record data for the indicators in the reference and managed forests.
5 Development of algorithms to compare results for the reference and managed forests.
6 Adaptation of the forest management standard with respect to the results of the naturalness assessment to increase the naturalness and its associated forest biodiversity.
7 Evaluation of the success in maintaining and restoring biodiversity via monitoring indicator species (Halme *et al*., 2009b). The outcomes of the evaluation control may result in further management adaptation.

After developing the naturalness assessment, levels 4–7 form the continuous naturalness assessment as a component of the forest biodiversity survey which could be part of existing monitoring programmes such as national forest inventories.

Developments of naturalness assessments that follow the seven-level framework are feasible for detailed monitoring of the maintenance of forest biodiversity, for instance, of threatened saproxylic beetles (Winter and Möller, 2008; Brunet and Isacsson, 2009) as listed for Central Europe by Müller *et al*. (2005).

Discussion and conclusions

A general approach for assessing naturalness has not yet been developed. We still lack the capability to progress from naturalness case studies to an overall assessment approach. Therefore, it is difficult to conduct large-scale naturalness assessments and there is a high degree of uncertainty in the application of available regional assessment approaches at large scales.

Naturalness assessment of forests is common practice for multiple European countries (13 of 19 analysed European countries, Chirici *et al*., 2011) with forest management following the sustainability paradigm, at least for annual wood production (Roberge *et al*., 2008; Skornik *et al*., 2008). But considering the spatial distribution of countries and regions with studies on naturalness such as in Australia, several countries in Central, Northern and Southern Europe and in the US, it is obvious that naturalness assessments can be conducted in different forest zones with clearly different forest communities ranging from eucalyptus forests, deciduous forests, e.g. with *Fagus sylvatica*, to boreal forests with *Picea abies* and *Pinus sylvestris* to thermophilous forests with, e.g. *Quercus* spp. and *Carpinus* spp., and to Populus–birch forests, respectively. Naturalness studies in tropical forests are not available, but considering the main traits currently used, naturalness assessments might also be applied in tropical forests. In addition to spatial feasibility, temporal validity must be considered. Following the seven-level framework concept, the assessment includes changes of the forest reference, e.g. due to global climatic changes.

The concept of forest naturalness is similar to other concepts, such as 'ecosystem quality' of a forest community, 'habitat quality', forest 'ecosystem health' and assessment of 'habitat natural quality' (Liira and Sepp, 2009). Paillet *et al*. (2008) mention 'ecological assessment' of forest stands and combine indicators of the naturalness and hemeroby concept in their assessments. For example, indicators related to forest function include the intensity of tourist activity, silvicultural treatments and the export of ligneous biomass; these are clearly variables used to assess human impact following the hemeroby approach. Tierney *et al*. (2009) developed an approach to assess the 'ecological integrity' of forests which resembles a naturalness assessment. Angermeier (2000) suggests that the term ecological integrity should be an integral part of the naturalness concept. Cardoso *et al*. (2007) used the term 'biotic integrity' in their study of arthropod communities and used it synonymously with ecological integrity. 'Natural likeness' is mentioned by Colak *et al*. (2003). However, to distinguish naturalness precisely from the closely related terms mentioned above is beyond the scope of this paper. But obviously, the term naturalness and its links to several other related terms should be clarified in the future.

Recommendations drawn from the literature for future studies on naturalness are as follows: (1) hemeroby and naturalness approaches should be clearly distinguished, (2) more comparative studies are necessary to identify a select number of indicators and to enhance our biodiversity-related knowledge of the indicators for their inclusion in naturalness assessments, (3) studies should be conducted to investigate the explanatory proportion of different naturalness indicators to determine the minimum number of indicators needed for naturalness assessments and (4) naturalness assessment studies should follow the seven-level framework presented herein and could be conducted using national forest inventory data from different countries (using a small set of additional ecologically relevant indicators) in order to explore the opportunities to harmonize heterogeneous international databases.

Acknowledgements

Thanks to R.E. McRoberts who discussed with me the naturalness concept several times and for his substantial editing of the text for the final manuscript version. Thanks to Mark Laurence, Mike McManus and Elizabeth Hamzi-Schmidt for improving my English. Thanks to H. Pretzsch, M. Flade, M. Zaplata and A. Fischer for improving the paper in different ways. And thanks to Helen McKay, editor of the journal *Forestry: An International Journal of Forest Research*, and an anonymous reviewer for their very good comments on a former version of the manuscript.

Conflict of interest statement

None declared.

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Received 27 May 2011