Developing a forest naturalness indicator for Europe

Concept and methodology for a high nature value (HNV) forest indicator

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Acronyms

AISF	Italian Academy of Forest Sciences
AUC	Area under the (ROC) curve
BD	Biodiversity
BIF	Biologically important forest
BFW	Bundesforschungs- und Ausbildungszentrum für Wald
CAP	Common Agricultural Policy
CDDA	Common Database on Designated Areas
CLC	Corine Land Cover
CMEF	Common Monitoring and Evaluation Framework
Corine	Coordination of Information on the Environment
CSGRD	Community's Strategic Guidelines for Rural Development
CWD	Coarse woody debris
DEM	Digital elevation model
DG	Directorate-General
EAP	European A programme
EC	European Commission
EEA	European Environment Agency
EFDAC	European Forest Data Centre
EFT	European forest types
EMERALD	Network under the Bern Convention of areas of special conservation interest (ASCIs)
ENFIN	European National Forest Inventory Network
ENV	Environment
ETC	European Topic Centre
EU	European Union
EUFORGEN	European Forest Genetic Resources Programme
FAO	Food and Agriculture Organisation
FPR	False positive rate
FRA	Forest Resource Assessment
FT	Forest type
GIS	Geographical information systems
HCVF	High conservation value forest
HNV	high nature value
IBA	Important bird area
ICP Forests	International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests
IEEP	Institute for European Environmental Policy
INRA	French National Institute for Agricultural Research
IPA	Important plant area
IUCN	International Union for Conservation of Nature
IWD	Inverse weighted distance
JRC	Joint Research Centre

LiDAR	Light detection and ranging or Laser imaging detection and ranging
MCE	Multicriteria evaluation
MODIS	Moderate resolution imaging spectroradiometer
MS	Member State
NFI	National Forest Inventory
NIWT	National Inventory of Woodlands and Trees
PEBLDS	Pan-European Biodiversity and Landscape Strategy
PNV	Potential natural vegetation
RANA	Reference approach for naturalness assessments
RDR	Rural Development Regulation
RF	Random forest
RMSE	Root mean square error
ROC	Receiver operating characteristic
RPC	Root Probability of Connectivity
SEBI	Streamlining European Biodiversity Indicators
SIA	Spatial Information and Analysis
TPR	True positive rate
UNECE	United Nations Economic Community of Europe
VOLANTE	Visions of Land Use Transitions in Europe

Foreword

European forests are a complex mosaic of conditions, constantly influenced by internal dynamics and external pressures determined by natural and anthropogenic factors. The latest statistics reveal an overall trend of growing forest area in the pan-European region, 0.41 % yearly (excluding Russia (UNECE/FAO, Forest Europe, 2011)). The question is whether the quality of our forests is increasing accordingly.

The quality of an ecosystem can be expressed in various ways. One way is to show the degree of forest naturalness as reflecting the intensity of human interventions on forest ecosystems, i.e. specifying the extent of human influence (Cluzeau and Hamza, 2007). This means that the closer to the potential naturalness it is, the higher the quality of the forests. What is the naturalness level of European forests? And what is the trend over time?

The concept of forest naturalness has been defined several times and in very different ways, without consensus from the scientific community. Much confusion still exists concerning terminology and definitions, making it extremely challenging to objectively assess areas with a high value of nature. Whichever definition and monitoring method are adopted, assessing forest naturalness is essential to supporting European environmental protection policy implementation. This is mirrored in the policy agenda of the European Union (EU) (Europe 2020, Biodiversity Strategy 2020, 7EAP).

Over the past 15 years, much effort has been dedicated to developing a system for monitoring the level of naturalness in agricultural areas in Europe. The concept of 'high nature value (HNV) farmland' was adopted as specific indicator in the Streamlining European Biodiversity Indicators (SEBI) process (Area under management practices potentially supporting biodiversity, SEBI 019).

To date, no similar concept has been developed for assessing the area of HNV forests in Europe. A study by the Institute for European Environmental Policy (IEEP) (2007) proposed a first definition for HNV forest areas that was strongly influenced by the work carried out for HNV farmland. It was suggested that more scientifically oriented forest naturalness approaches be integrated in the HNV forest definition and assessment methods.

This European Environment Agency (EEA) technical report documents the first steps for the development of a forest naturalness indicator for Europe. Can we apply the concepts used when evaluating farmland to forest habitats? Do we have enough information in Europe to determine the level of naturalness of our forests, or do we need to acquire new information? And if so, should this be done using a sampling approach in the field, or a wall-to-wall methodology mainly based on maps and remote sensing tools?

An enhanced European HNV forest indicator and its corresponding map will enable us to gain better insight into the current status and extent of forest naturalness, and will allow for further analyses on spatial and time trends.

Executive summary

Background

In Europe, forests cover around 40 % of the land area (190 million ha), making Europe one of the most forest-rich regions in the world. Forests are important habitats for many species of wildlife. Yet, forestry can also have negative impacts on biodiversity as unsustainable forest operations can lead to forest degradation and loss of biodiversity. In more recent times increased land use, expanding urban areas, and climate change have all contributed to place more pressure on forests.

The European Union (EU) has long been committed to biodiversity conservation in the EU. EU nature legislation dates back to 1979 and its biodiversity strategies have been in place since 1998. Forests and biodiversity are strongly related. Forest biodiversity depends on the health and vitality of forested areas. A main threat to forest biodiversity is the loss of 'naturalness' of forest ecosystems as a consequence of intensive and inappropriate ecosystem management.

Measuring the level of naturalness can be defined as 'the similarity of a current ecosystem state to its natural state' (Winter, 2012). A virgin forest, for example, would be considered to have a high level of naturalness as it is as close to its original state as is possible. Meanwhile, a plantation could be considered to have a low level of naturalness as it often contains only one species of tree of a similar, if not exactly the same age, and planted in a uniform manner.

The high nature value (HNV) concept

A number of EU strategies and regulations are related to the protection of nature and environment as well as to halting the loss of biodiversity. Forest protection is viewed as an important tool to conserve and generally maintain and enrich biodiversity. As part of this broader discussion the HNV concept emerged in the early 1990s. It aimed to support farming and forestry practices in order to maintain and protect biodiversity in rural landscapes. Much effort was put into developing a system to monitor the level of naturalness in agricultural areas in Europe.

Several studies and initiatives have been launched to develop a HNV indicator for forest areas, some of them by the European Environment Agency (EEA). A first definition for HNV forest areas was proposed by the Institute for European Environmental Policy (IEEP) in 2007 as a parallel to the HNV farmland process: *all natural forests and those semi-natural forests in Europe where the management (historical or present) supports a high diversity of native species and habitats, and/or those forests which support the presence of species of European, and/or national, and/or regional conservation concern*.

As both naturalness and biodiversity are complex concepts they should be monitored through the use of several indicators. If only one or a limited number of indicators are used, erroneous conclusions may be drawn.

This EEA technical report aims to clarify the HNV concept for forests. It also proposes a feasible and replicable methodology to define and identify HNV forest areas in Europe. The proposed methodology, and by extension the ability to measure and monitor changes in HNV areas, is considered essential for supporting European environmental protection and policy implementation.

The report reflects on the work carried out since 2011. To simplify the work and for the sake of transparency, the methodology was applied to beech forests only. Beech forests are well documented and rather homogenous forest types and were considered appropriate for such a test.

The present work focuses on identifying areas of forests that approximate to a certain level of naturalness. Only countries where beech forests are found are represented. These countries are: Austria, Belgium, Bulgaria, Croatia, the Czech Republic, Denmark, France, Germany, Hungary, Italy, the Netherlands, Norway, Poland, Slovakia, Slovenia, Spain, Sweden, Switzerland, and the

United Kingdom. Work is ongoing to extend the concept to cover all forest areas in the EEA-39 countries ([1]).

In **Chapter 1**, an overview of the policy context is provided. The HNV concept is defined and discussed in comparison with other relevant concepts: naturalness, biodiversity, high conservation value forests (HCVFs), and biologically important forests (BIFs). Other international and country experiences are reviewed.

The chapter reflects on nine case studies carried out in 2011 as part of an EEA project to explore how a HNV forest indicator could be developed. These studies took into account existing national level assessments and underlined the need for a clearer definition of the HNV concept as applied to forests.

These case studies revealed several important issues:

- some confusion exists about the monitoring target — biodiversity, naturalness and conservation status are mixed up;
- in the absence of a clear definition of HNV forests, local monitoring systems tend to be based on multiple criteria with different sets of indicators; and
- the availability of data in the investigated area often determines the choice of indicators.

It is therefore clear that there is a need for pan-European agreement on the monitoring target, with clear definitions for the different concepts. Two strategies may be followed in setting up an operational monitoring framework: (i) aggregating national efforts and products, or (ii) developing a new system based on information commonly available across Europe.

As a result of the diversity of country approaches and the lack of available harmonised data, it was considered more feasible to develop the HNV forest area based on available data at the European level rather than at an individual Member State level. **Chapter 2** discusses such an approach, which was applied to beech forests only, and included a selection of existing and available spatial data sets.

The assessment of HNV forest area is based on five indicators:

- naturalness;
- hemeroby (the degree of human influence on the ecosystem);
- accessibility (expressed by the steepness of terrain and thus how accessible the forest is for management);
- growing stock (the volume of living trees);
- connectivity (forest availability and distance between patches of forests i.e. the extent to which the landscape facilitates or impedes the movement of species).

The chapter describes these indicators and the multi-criteria approach used to assess HNV.

Chapter 3 presents the results of this multi-criteria approach applied on beech forests in Europe. The report suggests that using such a multi-criteria approach means that defining a HNV forest area is now possible. Aggregate results from the five indicators led to a first HNV beech forest assessment. After validation against site data and various statistical tests, it was decided to simplify the approach to include the 'naturalness' of tree species' composition, accessibility and connectivity.

A map of HNV beech forests for Europe was produced covering 19 countries within the EEA region. A plausibility test was carried out by comparing the map to three independent information sources on potential natural vegetation. These were the European Forest Genetic Resources Programme (EUFORGEN); an analysis on habitat suitability carried out by the Joint Research Centre (JRC) for European forest types (JRC, 2012c); and the map of potential natural vegetation in Europe, the so-called 'Bohn map' (Bohn et al., 2004). A first comparative analysis with existing networks of protected areas (Important Bird Areas (IBAs), Natura 2000 and Common Database of Designated Areas (CDDA) sites) was also conducted.

([1]) The EEA-39 countries are the EU-28, Iceland, Norway, Liechtenstein, Switzerland, Turkey and the cooperating countries: Bosnia and Herzegovinia, Serbia, Albania, Montenegro, former Yugoslav Republic of Macedonia, and Kosovo (UNSCR 1244/99).

This comparison resulted in further refinement of the definition of HNV forest areas to an *area covered by forests or other wooded lands having a current ecosystem state similar to its natural state.*

Chapter 4 presents conclusions, challenges and the way forward for developments of HNV forest areas. The study carried out for beech forests demonstrated that some pan-European data sets already exist for developing analysis of HNV forest areas. The results for beech forests were contrasted against observations in mature forests with no significant signs of human activity (known as 'old-growth' forests), demonstrating that some of the tested indicators have promise. However, the test also highlighted the complexity of a multi-criteria approach based on several indicators.

One main outcome of the study was to further simplify the approach to assess naturalness by analysing each of the five indicators one at the time. A follow-up study considered the naturalness of tree species composition only, and enlarged the analysis, considering the overall forest area for specific forest types according to the EEA European Forest Type (EFT) classification. A first test and mapping were successfully carried out for forests within the 'boreal' region of Scandinavia, a region with a subarctic climate.

Both proposed outcomes are under further development to produce HNV forest area maps for the all forest areas in Europe. The approach and its results will be presented and compared with country level estimates of HNV forest areas based on more detailed forest data and information. The approach will be further refined as soon as more forest information is made available at the European level with the support of data and information from the European Forest Data Centre (EFDAC).

1 What is a HNV forest and why is it important?

1.1 Importance of forest ecosystems

Forests are the largest land type in Europe, covering about 40 % of land area in the EEA region (Forest Europe, UNECE and FAO, 2011). Forests provide a range of ecosystem services which are vital to society and human well-being: timber, fuel wood, fodder and other non-timber forest products, pollution control, soil protection and formation, nutrient cycling, habitat provision, biodiversity protection, water (quality and quantity), air quality regulation, cultural and recreational services and disturbance regulation.

Forests and biodiversity are strongly interlinked, since biodiversity depends to a large extent on the integrity, health and vitality of forested areas. Forest management has altered natural systems through the cultivation of simplified forests with a heavy human imprint on species composition. Even if the interdependencies between ecosystems, climate change and other anthropogenic impacts are extremely complex, altered forests may be more prone to disturbances (Milad et al., 2011).

The importance of close-to-natural, vital, healthy, resilient and multifunctional forests, is reflected in many EU policies, and especially those related to biodiversity and climate change. Because of their structural and functional complexity, forests are ideal habitats for many plants, birds and animals (EEA, 2010), and these species are often highly dependent on the environmental quality of forests. But this quality has been altered in the past due to human impacts such as silvicultural practices and the use of exotic species, resulting in a general simplification of these systems (European Commission, 2006). Today, only 25.5 % of the world's forest area is considered intact, and only 4 % of this is in Europe (Thies et al., 2011). Conservation projects should protect remnant areas with a high degree of naturalness; comprehending these is essential if we are to derive information to support management criteria that mimic natural dynamics (Schnitzler and Borlea, 1998).

One of the action points in the EU Biodiversity Action Plan (COM (2006) 216) is the identification of HNV forests. Their identification and monitoring can support halting the loss of biodiversity in forest ecosystems. Monitoring HNV forest areas through the development of a HNV forest indicator is essential for assessing the impact of current programmes on biodiversity in managed forests in Europe (European Commission, 2009).

1.2 Policy context

Conservation and management of natural resources are regarded as core objectives and key challenges at international and EU level. A main objective has been to improve the management, avoid overexploitation of natural resources, and recognise the value of ecosystem services. Forest biodiversity is mentioned in the Rio Convention, the Convention on Biological Diversity (CBD), the Convention on the Conservation of European Wildlife and Natural Habitats (the Bern Convention), the pan-European Biodiversity and Landscape Strategy (PEBLDS) and the European Landscape Convention (CETS No.: 176); likewise, it is mentioned in the Habitats (92/43/EEC) and Birds (2009/147/EC) Directives, and the Rural Development Policy (Paracchini et al., 2008). The main threat to forest biodiversity is the loss of naturalness of forest ecosystems. Maintaining and restoring forest biodiversity means monitoring forest naturalness, protecting remnant natural forests and supporting the implementation of close-to-nature forest management approaches.

The HNV concept emerged in 1993, mainly in relation to agricultural systems. It was recognised throughout Europe that biodiversity was declining (Baldock et al., 1993) as a consequence of intensive and inappropriate ecosystem management. The HNV indicator refers to the protection of certain farming and silvicultural practices to maintain biodiversity in rural landscapes. As such, HNV was selected as an indicator in the Rural Development Regulation (RDR) (EC 1698/2005) and Council

Regulation (EC) 1257/1999. The Common Monitoring and Evaluation Framework (CMEF) provided guidelines for Member States for rural development interventions in the period from 2007 to 2013.

For these reasons, the purpose of the Community Strategic Guidelines for Rural Development (CSGRD) (2007–2013) differs from that of possible development of a pan-European HNV forest area indicator. The CSGRD encourage Member States to put in place measures to preserve and develop HNV farming and forestry systems and traditional agricultural landscapes, with the aim of 'protecting and enhancing the EU's natural resources and landscapes in rural areas. The resources should contribute to three EU-level priority areas: biodiversity and the preservation and development of HNV farming and forestry systems and traditional agricultural landscapes; water; and climate change' (Council of the European Union, 2006).

The development of a European HNV indicator aims at estimating the likely distribution of HNV in Europe, according to a standardised methodology. The present work covers forest areas only, complementing the work carried out so far on HNV farmland by Paracchini et al. (2008) — see Box 1.1.

The objective of this work is **not** to develop rural development measures to preserve and develop HNV farming and forestry systems, as carried out at Member State level. The results are neither intended nor suitable for evaluating the impact of rural development measures at national or regional level.

The HNV concept has been designed to better safeguard natural and semi-natural areas supporting great diversity of species and habitats, both inside and outside the established protected areas.
The HNV concept brings an approach to nature conservation that differs from, and complements, the more established approach based on site protection. The HNV concept and the indicators developed for defining HNV areas will contribute to the first three targets of the EU 2020 headline target, of halting biodiversity loss by 2020. An enhanced European map offers better insight into the current distribution of HNV on farmland and forests, and also allows for further analyses on spatial and time trends. This will support analysis and targeting of relevant instruments for current EU policies on biodiversity, in view of the use of wood for bioenergy, and for the reform of the Common Agricultural Policy (CAP).

Box 1.1 What is HNV farmland?

The development of a HNV farmland indicator has been evolving since the mid-1990s. HNV farmland has been defined as *those areas in Europe where agriculture is a major (usually dominant) land use and where agriculture supports or is associated with either a high species and habitat diversity or the presence of species of European conservation concern or both* (Anderson et al., 2003).

The farmland indicator links the preservation of biodiversity and the wildlife value of the countryside to the need to safeguard the continuation of farming in certain areas. The rationale behind the farmland indicator is to help monitor and assess agri-environmental policies and programmes, and to provide contextual information for rural development in general — this is linked in with the reform of the CAP.

Another rationale is to identify environmental issues related to European agriculture, help target programmes and address agri-environmental issues, and understand the links between agricultural practices and the environment (COM (2001) 144, p. 3).

Typical examples of HNV farmland are extensively grazed uplands in the United Kingdom, alpine meadows and pastures, steppe areas in eastern and southern Europe and dehesas and montados in Spain and Portugal. Small-scale agricultural farming systems in Central and Eastern Europe are particularly important for biodiversity; they are responsible for creating and maintaining species-rich semi-natural grasslands.

1.3 What is HNV forest area?

A standardised approach for defining and identifying HNV forest areas does not yet exist. The Forest Task Force of BirdLife International aimed to identify and map Europe's forest areas which have HNV, and proposed the concept of biologically important forests (BIF) in this context. A BIF is defined as a forest retaining features of natural forests or having started to develop such features. It is considered a key area for the protection of forest-dependent species which require a certain quantity and quality of suitable habitat, in order to survive and maintain vital populations.

A study by IEEP (2007) proposed a first definition for HNV forest areas that was strongly influenced by HNV farmland-related work: *all natural forests and semi-natural forests in Europe where the management (historical or present) supports a high diversity of native species and habitats, and/or those forests which support the presence of species of European, and/or national, and/or regional conservation concern* (IEEP, 2007).

This definition overlaps partially with the concept of biodiversity and with the concept of high conservation value (HCVF, see Box 1.2), as with protected areas, or fragile and threatened habitats. Since areas considered to have a high potential nature value are located in proximity to existing natural sites, these have also a potential high natural value (e.g. buffer zones, ecotones, and areas with management systems that are drivers for HNV).

Several studies and initiatives have been launched to develop a HNV forest area indicator; some of them were coordinated by the EEA. The present report documents the development of the HNV indicator for forests and the preparation of a pan-European wall-to-wall and spatially explicit assessment, so as to acquire a first approximation of the extent and distribution of potential HNV forests in the EEA region. A first review in 2011 studied country case studies to define the HNV forest indicator (summarised in Section 1.4). In 2012, a pan-European methodology was explored and tested to assess the use of current pan-European information for mapping HNV forest area indicators for a test species (*Fagus sylvatica*).

First step is to propose a clear definition of HNV forest areas, and on this basis, to develop a method to gain an accurate and comprehensive European picture of the current situation and extent of forest naturalness.

1.4 Country-level experiences in development of a HNV forest area indicator

In Greece, Dimalexis et al. (2008) identified the following HNV forests: i) Corine Land Cover (CLC) forest categories (311, 312 and 313) when included in national forest parks, natural reserves and Natura 2000 sites; ii) a reselection of Corine forest categories and a weighted overlay analysis of the reselected

Box 1.2 High conservation value forests (HCVFs)

The concept of HCVFs was first developed by the Forest Stewardship Council (FSC) to describe those forests falling under Principle 9 as defined by the FSC Principles and Criteria of Forest Stewardship (FSC, 1996). The approach has proved useful for identifying and managing environmental and social values in production landscapes. HCV is now widely used in certification standards (forestry, agriculture and aquatic systems) and more generally for resource use and conservation planning. Following the FSC (2012) definition, HCVFs are forests of outstanding or critical importance. The significance of these forests is that they support extremely important environmental or social values (high conservation values).

In line with the FSC definition, HCVFs should meet at least one of the following criteria:

- contain globally, regionally or nationally significant concentrations of biodiversity values (this includes protected areas, rare or threatened species, endemic species, and seasonal concentrations of species);
- be globally, regionally or nationally significant large landscape-level forests;
- be in or contain rare, threatened or endangered ecosystems;
- provide basic services to nature in critical situations (including protection of watersheds, and protection against erosion and destructive fire);
- be fundamental to local communities meeting their basic needs;
- be critical to local communities' traditional cultural identity and recreation, and as religious and cultural sites.

map with forest biodiversity data and with a slope criterion; iii) plantations fulfilling the IEEP (2007) criteria.

In Italy, one geographical analysis of high conservation value forests was performed by Maesano et al. (2008), overlapping the different protected areas with the forest area from CLC.

Blasi et al. (2011) performed an analysis based on large pixels of 100 km^2, and ranking the cells in terms of plant richness. This took into account the total number of vascular species and habitats recorded on the basis of botanical relevés, and conservation value, and the number of vascular species and habitats rated by experts as being of high conservation value.

Finally, HNV forests were identified by Pignatti et al. (2011) on the basis of data from the National Forest Inventory (NFI). Each sampling unit of the NFIs was classified as HNV (adopting a Boolean yes/no approach) if the habitat in the plot was one of those listed in the Habitats Directive, if the unit was inside one protected area, or if the forest was uneven aged, or a complex high forest or an old coppice.

Mapping of BIFs was initiated for the Baltic countries, even though Kurlavicius et al. (2004) refer to their work as a search for potential HCVFs. The analysis was based on stand-level data available for all forests, inherited from the Soviet era, together with data available on grid cells. The identification of potential HCVFs was based on multiple criteria, including, but not limited to absence of human influence signs, stand age, amount of dead wood, non-fragmented forests, steep slopes (> 15°), forest structure, presence of large trees, tree species diversity, age variance, disturbances (fire, storm, flooding), presence of endangered vegetation types, presence of rare forest-dependent species and presence of very old trees.

The approach was later adopted by BirdLife International, who introduced the term BIFs and expanded the analysis to include Belarus, Bulgaria, Poland and Romania (Kostovska et al., 2008; BirdLife International, 2009; Yermokhin et al., 2007), i.e. all countries using the stand level inventory system.

In Russia, Yu et al. (2001) first developed an approach for mapping intact forests of at least 50 000 ha which are defined as contiguous forests. The approach was then implemented by Greenpeace at global level (Thies et al., 2011).

In the absence of a clear definition for HNV applied to forest areas, some countries implemented local definitions and methods in the framework of HNV farmland assessment. In Scotland, a set of indicators derived from the National Inventory of Woodlands and Trees (NIWT), available for squares of 1 ha, was used to calculate the extent of three types of HNV woodland (type A: seminatural features and low intensity management; type B: diversity of features and low intensity; and type C: species of conservation concern). For woodland type B, the following indicators (with thresholds) were used: percentage of native species of at least 20 %, presence of old-growth woodland, at least 3 habitat patches, volume of deadwood of at least 15 m^3/ha, shrub layer under canopy cover of at least 10 %, and at least 3 tree species (The Scottish Government, 2011).

The synoptic analysis of country experiences (see Table 1.1) reveals several important issues: (i) some confusion exists about the monitoring target; biodiversity, naturalness, and conservation status are mixed up; (ii) in the absence of a clear definition of HNV forests, local monitoring systems tend to be based on multiple criteria using different sets of indicators; (iii) the availability of data in the investigated area often determines the choice of indicators.

There is a need for pan-European agreement on the monitoring target, with clear definitions for the different concepts. Next step will be to set up an operational monitoring framework. Generally speaking, two strategies may be followed: either aggregating national efforts and products (bottom-up), or developing a new system based on information commonly available across Europe (top-down). The top-down approach appears more feasible at present; the great diversity of country approaches is hindering the bottom-up aggregation.

This short analysis of the experiences of defining HNV forests or similar concepts did not refer to the substantial scientific literature on assessing naturalness and the level of anthropogenic disturbances (hemeroby) of the different ecosystems, habitats or biomes. This will be covered in the following chapters.

Table 1.1 European case studies, their methodology and criteria used for identifying HNV forests

Case study	Main metod	Criteria used																Reference
		Tree species composition	Naturalness	Introduced tree species	Dead wood	Protected forests	Slope	Important habitat types (Habitat directive Annex 1)	Important Bird Areas	Important plant areas	Little or no signs of human influence	Stand age	Uneven age structure/old trees	Fragmentation	Large scale natural disturbance and natural regeneration	Water courses, surface spring, flooded areas	Limited access areas	
Greece	GIS analysis		x			x	x	x										Dimalexis et al. (2008)
Italy 1 (HCVF)	GIS analysis					x			x	x								Maesano et al. (2011)
Italy 2	GIS analysis									x								Blasi et al. (2011)
Italy 3	National Forest Inventory	x	x	x	x	x												Pignatti et al. (2011)
Bulgaria and Romania	GIS analysis and forest inventory				x		x		x	x	x	x	x	x	x	x	x	BirdLife International (2009)
Belarus and Poland	GIS analysis and forest inventory				x		x		x	x	x	x	x	x	x	x	x	Yermokhin et al. (2007)
Russia	GIS analysis										x			x				Yaroshenko et al. (2001)

1.5 Naturalness and HNV forests

Based on the presented country experiences and the scientific literature available in this study, we attempted to construct a definition and a methodology for HNV forest pan-European assessment. The only current definition for HNV forests so far is that of the Institute for European Environmental Policy (IEEP, 2007). The proposal for a definition of HNV forests should be developed on the basis of the general framework of biological integrity. This concept was originally developed for the assessment of water quality, and has been adopted by the United States Environmental Protection Agency, but can be easily applied to forest habitats, too (Ballentine and Guarraia, 1977). A literature survey by Wirth et al. (2011) based on 2 153 scientific papers on the biological integrity of forest ecosystems, reveals the complexity of the concept.

Biological integrity is associated with how close a given habitat is to a 'pristine' condition represented by the potential or original state before human alterations. Biological integrity is mostly expressed as the degree of human impacts on forest habitats. Forests that are untouched, or have had limited impact from human activity, or have recovered from alteration due to human activity are frequently described as ancient, antique, climax, frontier, heritage, indigenous, intact, late-serial, late-successional, natural, original, over-mature, pre-settlement, primary, primeval, pristine, relict, undisturbed, untouched, virgin and old-growth.

Evaluation of the biological integrity of a given habitat should be based on the assumption that a decline in ecosystem functions is primarily caused by human activity or alterations. In the context of conservation biology, the term natural is used to define anything that has not been made or influenced by humans, particularly by technology (Hunter, 1996; Angermeier, 2000). The present HNV forest area concept is focused on naturalness, while many EU initiatives are focused on biodiversity — see also Box 1.3. In future uses, both biodiversity and naturalness assessments should be assessed.

Box 1.3 Naturalness and biodiversity

The concepts of naturalness and biodiversity are sometimes misinterpreted. If naturalness can be defined as 'the similarity of a current ecosystem state to its natural state' (Winter, 2012), biodiversity can be defined as 'the diversity of life in all its forms and all its levels of organization' (Hunter, 1990). Confusion arises between the two concepts because some virgin forest ecosystems (with high naturalness) also harbour a large amount of biodiversity. But this is not always the case: a pristine forest habitat located in environments affected by strong limiting factors (extreme cold or drought, poor soils, etc.) may still have very high level of naturalness, even if it is usually characterised by a limited number of life forms, and thus has a lower level of biodiversity. So naturalness and biodiversity are not correlated in all forest ecosystems.

Both naturalness and biodiversity are complex concepts that should be monitored through the use of several indicators. If only one or a limited number of indicators are used, erroneous conclusions may be drawn. For example, one commonly used indicator of forest biodiversity is the number of tree species; it is based on information routinely acquired through NFIs.

Old-growth beech forests (with a very high level of naturalness) are frequently characterised by almost pure stands, while an artificial plantation (very limited naturalness), for example, can be created with a mixture of several tree species. If one measures biodiversity only in terms of number of tree species, the plantation appears to have more biodiversity than the old-growth forest!

Since biodiversity loss is mainly caused by a loss of naturalness of ecosystems (Hunter, 1990), it is essential to include naturalness in monitoring programmes, in order to support sustainable forest management and conservation planning.

Finally, a biodiversity indicator can be used as part of a multicriteria approach for monitoring naturalness.

'Naturalness' can thus be considered as a gradient, ranking from the extreme of absolutely natural to the opposite, absolutely artificial. For the purposes of this study, naturalness can be considered synonymous with biological integrity. Winter (2012), after reviewing approximately 80 scientific papers, stated that a commonly agreed definition of naturalness is 'the similarity of a current ecosystem state to its natural state'.

Following this approach, HNV forests are forest-dominated areas which, in the continuum gradient of naturalness, are located close to natural conditions. At this point, it is important to define the term 'forest area' and then the term 'natural conditions'.

The definition of forest has been a subject of great debate in recent years. The community of national forest inventories (NFIs) has reached a consensus concerning this definition: 'forest is a land spanning more than 0.5 ha with trees higher than 5 metres and a crown cover of more than 10 %, or trees able to reach these thresholds in situ. For tree rows or shelterbelts, a minimum width of 20 m is required. It does not include land that is predominantly under agricultural or urban land use' (Vidal et al., 2008). This definition is currently implemented at global level in the FAO Global Forest Resource Assessment and by Forest Europe, in the framework of reporting for the *State of Europe's Forests*.

Current global and European statistics of forest area on the accounting on different level of naturalness were based on a very simplified system of nomenclature. In the last Forest Resource Assessment (FRA) (FAO, 2010) three classes were also used: planted forests, other naturally regenerated forests, and primary forests. In the *State of Europe's Forests* (Forest Europe, UNECE and FAO, 2011) three categories were used: undisturbed, seminatural and plantation forests. About 87 % of European forests, excluding those of Russia, are classified as seminatural. We need more information on the different levels of naturalness of these forests.

Table 1.2 The 3 categories of forest naturalness as reported from different sources, and their relationship to forest naturalness and HNV forests

European Commission		Forest Europe, UNECE and FAO	FAO FRA	Naturalness	HNV forest
Plantations	Forest stands are established by planting and/or seeding in the process of afforestation or reforestation. They are intensively managed stands of introduced or indigenous species and meet the criteria of regular spacing, even age class and 1 to 2 species. Excluded are established plantations which have not been managed for a significant period of time which are considered to be semi-natural forests	Plantations	Planted forests		NO
Semi-natural	These are forests whose natural structure, composition and function have been modified through forest operations. Most forests with a long management history	Semi-natural	Other naturally regenerated forests		SOME OF THEM
Naturally dynamic	Forests whose structure, composition and function have been shaped by natural dynamics without substantial anthropogenic influence over a long time period.	Undisturbed by man	Primary forest		YES

Source: Modified from European Commission, 2009.

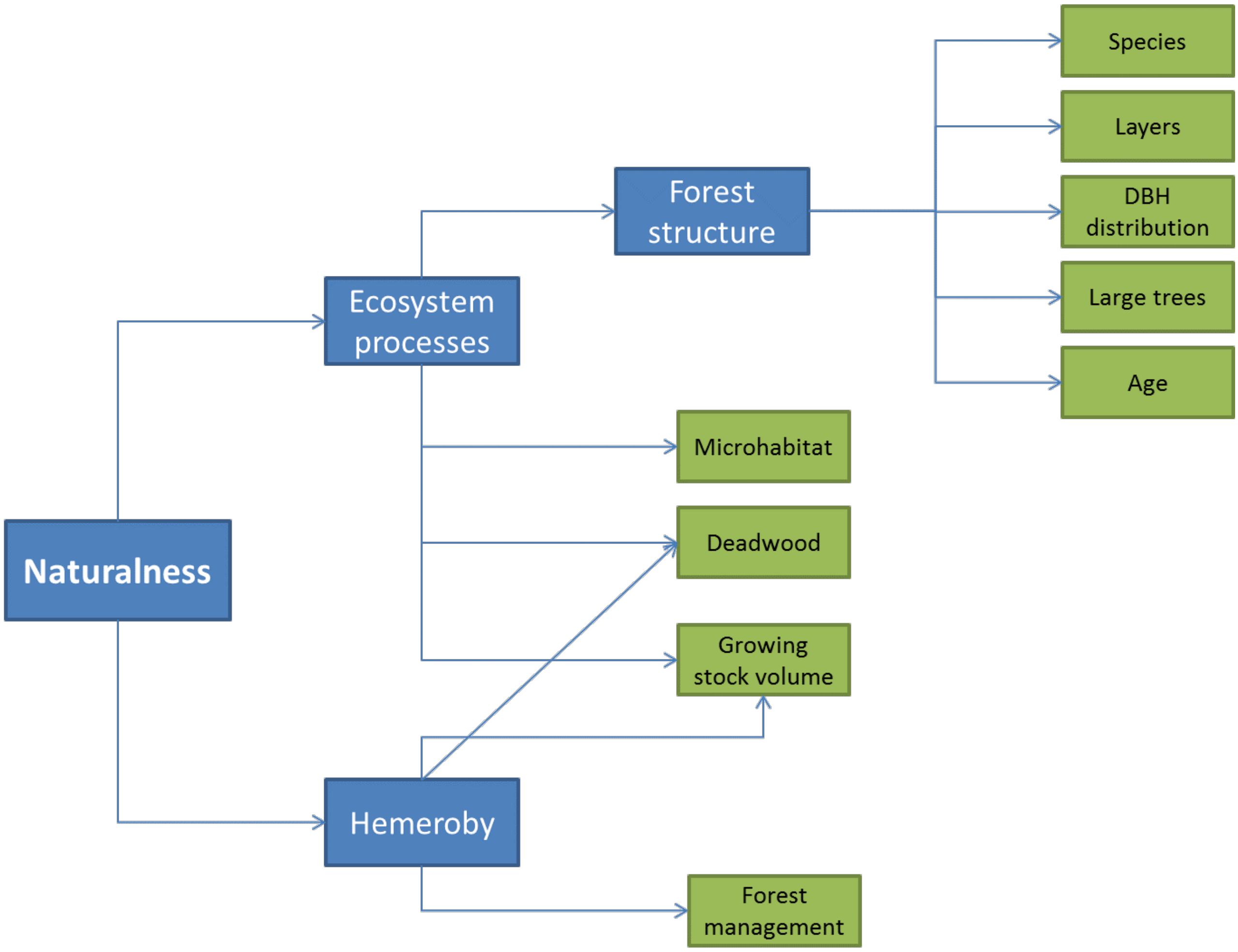
The more an environment and its original processes are altered, the less biological integrity it holds for the community as a whole. If these processes were to change over time naturally, without human influence, the integrity of the ecosystem would remain intact. Biological integrity relies heavily on the processes that occur within the ecosystem, because these determine what organisms can inhabit an area and the level of complexities of their interactions.

Many studies were devoted in the last decade to naturalness assessment methods (Hancock et al., 2009; Roberge et al., 2008; Winter and Möller, 2008; Winter, 2012) and developing forest indicators for assessing naturalness (Liira and Sepp, 2009; Uotila et al., 2002). McRoberts et al. (2012) and Gibbons et al. (2008) present methods for identifying forest plots or stands with the greatest naturalness without using pre-established naturalness classes. Only a few approaches assess naturalness using a gradient from low to high naturalness with discrete categories (Heino et al., 2009; Smelko and Fabrika, 2007) or in a continuous gradient (McRoberts et al., 2012; Smelko and Fabrika, 2007).

In reviewing approaches for forest naturalness assessment, McRoberts et al. (2012) identified two approximately complementary perspectives. The first approach is based on an assessment of ecosystem processes (Peterken, 1996). The advantage of this approach is that the assessment focuses on the ecosystem. The disadvantages are the difficulties in defining and measuring parameters that relate to ecosystem processes and that can be evaluated in a globally consistent manner at broad geographical scales. The second approach is based on the degree of human influence at play (Rolston, 1990; Anderson, 1991; Duncker et al., 2012), and focuses on human activity as the driver of ecosystem disturbance. Jalas (1955) introduced the term hemeroby, from the Greek *hemeros* meaning cultivated, tamed, or refined, as a measure of human impact on ecosystems. Both approaches may lead to a consistent quantification of forest naturalness through the use of indicators (see Figure 1.1).

Anderson (1991) noted that an assessment of the degree 'to which [an eco]system would change if humans were removed from the scene' is a strictly hypothetical model without quantitative

Figure 1.1 Naturalness assessments with indicators from ecosystem processes and hemeroby approaches



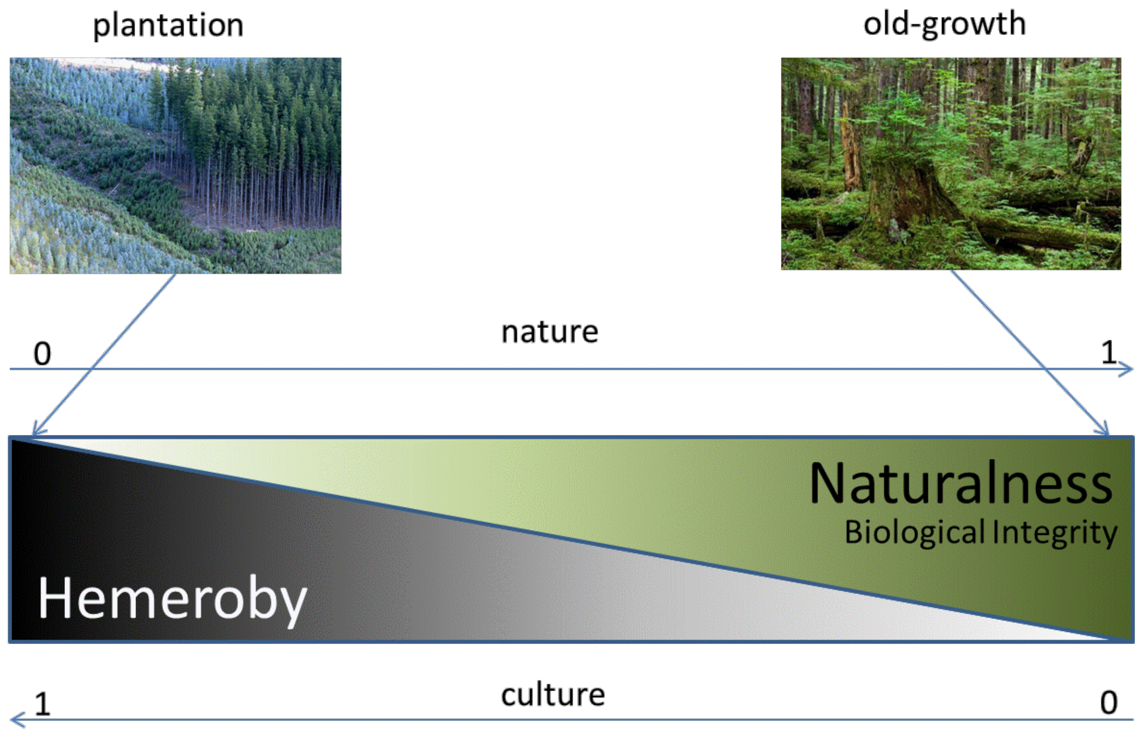
Source: Modified from McRoberts et al., 2012.

(measurable) variables. However, the Relative Quantitative Reference Approach for Naturalness Assessments (RANA) from Winter et al. (2010) presents an estimator of naturalness based on definitions of no naturalness (0) and full naturalness (1) with an intervening continuum. Based on preceding definitions, 0 % naturalness of a habitat is equivalent to 100 % hemeroby (see Figure 1.2). Even the greatest naturalness includes a certain direct or indirect impact from humans (for example, due to climate change).

In summary, most naturalness studies focused on detecting reliable naturalness indicators and on describing reference forests with a high naturalness. Both are basic steps, necessary to subsequently developing an applicable naturalness assessment approach.

This means that whatever indicators are used for depicting or estimating the naturalness of forest habitats, the local reference values for original landscapes and virgin forests for each indicator and for each forest type must be assessed. Such references are the conditions that nature would have potentially produced in the absence of human impacts (Winter et al., 2010). At least, in the absence of the impact of modern human society's technology, since the influence of pre-modern activities in the ecosystems is accepted as natural (Angermeier, 2000), Demangeot (1989) places artificial influence at the start of agriculture (since approximately 8 000 years ago).

Figure 1.2 Theory of the relative quantitative reference approach in naturalness assessments



Source: Modified from Winter et al., 2010.

1.6 HNV forest area: a possible pan-European assessment?

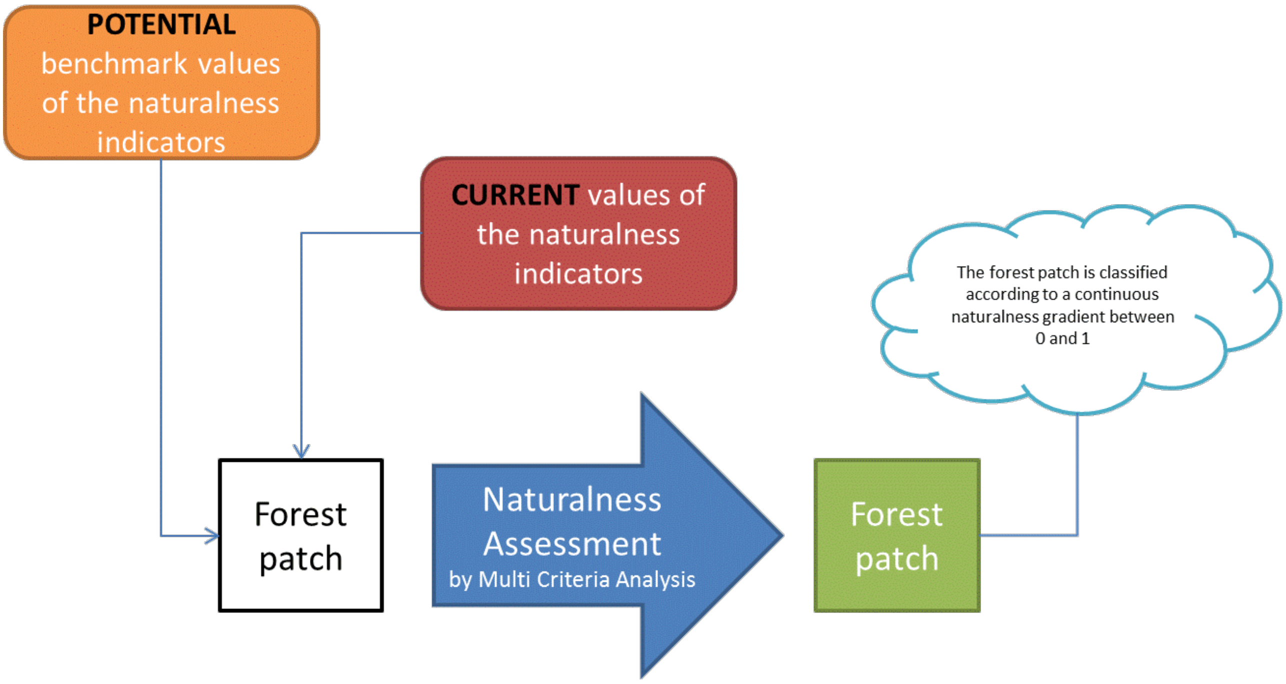
The identification of HNV forest areas should be based on multiple criteria through the use of several indicators. This was clearly expressed in IEEP (2007) and suggested by previous experiences. Once the indicators for assessing forest naturalness are selected, for each forest type and biogeographical area in Europe, the benchmarks values of the different indicators must be defined. This can be done by measuring the values of the indicators in old-growth forests or from theoretical ecology studies. By comparing the current value of the indicator with the benchmark potential value, it is possible to assess the relative naturalness for a given indicator. The indicators can be aggregated by multicriteria analysis to derive a final quantification of forest naturalness ranging between 0 and 1 (see Figure 1.3): 0 for 100 % hemeroby and 0 % naturalness, and 1 for 0 % hemeroby and 100 % naturalness.

The resulting HNV forests will be forests with naturalness values above the given thresholds, defined by forest types and local biogeographical conditions or other specific applications.

Two strategies are proposed for implementing this approach. The first strategy is based on a sampling approach similar to that used in many NFIs. For each sampling unit, the naturalness indicators are calculated, and given the forest type and biogeographical location of the unit, the potential benchmark values of the indicators are estimated. Naturalness is calculated for each sampling unit, and the HNV forest area is inferred using traditional statistical estimators.

The same method could be applied with a mapping approach. Instead of using sampling units from a field campaign, naturalness can be calculated for each forest patch or pixel if current and potential benchmark values of the indicators are locally available.

Figure 1.3 Proposed method for calculation of forest naturalness, based on comparison between current and potential values of different indicators



Despite the fact that a large number of local and regional tests for assessing forest naturalness exist, a pan-European assessment of forest naturalness has still not been carried out. Several indicators have been proposed for monitoring naturalness/hemeroby. For example, IEEP (2007) proposed identifying HNV in semi-natural forests based on the proportion of native species, the volume of standing and lying deadwood in the forest; the density of large trees, and the proportion of the area of a forest which is made up of stands older than the age of economic maturity.

Many of these indicators can be calculated through the use of NFI data. However, despite their common primary objective, NFIs do not assess common sets of variables, nor do they use common definitions of variables. Furthermore, inventory sampling designs, plot configurations, measurement protocols, and analytical methods vary considerably among countries (Tomppo et al., 2011). These disparities contribute to the lack of comparability among data and estimates available for national and large area assessments of sustainability and biodiversity and for international forest resource reporting (McRoberts et al., 2009). Furthermore, presently at pan-European level, no harmonised plot level data from NFI are available as input data.

There is thus a need to investigate the feasibility of developing a quantitative and pan-European homogeneous methodology for the assessment of HNV forests, based on existing data at European level. This is discussed in Chapter 2.

2 Developing a top-down, wall-to-wall assessment of HNV forest areas in Europe

This study aims to explore existing and relevant data sets and maps at European level that could support the development of a spatial identification of high nature forest areas in Europe. The approach defines HNV forests as those forest habitats with the highest naturalness (i.e. the high similarity of the current ecosystem state to its natural state). A multicriteria assessment of forest naturalness is based on different criteria through the use of indicators. The approach is carried out in a consistent way for all Europe on the basis of existing and available spatial data sets, in order to derive a map of HNV forests. This means that selection of the indicators is strongly limited by the available data sets.

The optimal source of input information needed for this analysis should be provided by the NFIs, which are responsible for extensive and comprehensive data provision on the status of European forests at country level. A large project is currently under way at the JRC for populating the European Data Forest Centre with data provided by the NFIs. Unfortunately, these data are not available at the time of writing. The methodology developed and presented in this report is intended to be reproduced on the basis of NFI data when these data are made available and harmonised. This study is expected to stimulate future derivation or acquisition of forest information that could facilitate the future assessment of HNV forests in Europe and support forest policy decisions at European level.

The test was restricted to forest areas dominated by beech forests (*Fagus sylvatica* L.). This species was selected because most parts of old-growth forests in Europe with a relict high level of naturalness are dominated by beech. As will be presented in Section 3.1, hotspots of naturalness in Europe (old-growth forests) were used to validate the naturalness assessment.

2.1 Input data sets

All input map layers are projected in the ETRS89/ ETRS-LAEA89 system with a common grid cell of 1 km x 1 km. This is the resolution of many of the input layers, which are all available at pan-European level (despite having different spatial coverage). Details of these layers are set out in Annex 1, as are references to scientific literature and web resources on the methodologies used for their derivation and their accuracies or the results of specific validation procedures.

The present input layers include:

- tree species distribution map of Europe produced by the JRC (2012a);
- tree species distribution map of Europe produced by EFI-Alterra (Brus et al., 2012);
- tree species habitat suitability maps of Europe produced by the JRC (2012b);
- growing stock volume map from Gallaun et al. (2010);
- Digital Elevation Model (DEM) from the GTOPO30;
- Corine Land Cover for the year 2006 (EEA, 2006);
- EUFORGEN potential distribution map of beech (EUFORGEN, 2012);
- Natura 2000 sites, IBAs and CDDA sites;
- European forest types habitat suitability maps for beech categories (JRC, 2012c);
- connectivity index (Estreguil et al., 2012);
- potential vegetation map of Europe (Bohn et al., 2004).

2.2 Geographical coverage

The number of countries in this EEA study was restricted, as mentioned above, to the coverage of beech forests. The input layers used are provided with different geographical coverage, and have been integrated with a logical operator AND to define the overall study area coverage. The resulting terrestrial area covers 4 908 378 km^2 including the following main 31 countries: Albania, Austria, Bosnia and Herzegovina, Belgium, Bulgaria, Croatia, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Montenegro, the Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland and the United Kingdom.

The missing countries, Cyprus, Iceland, the former Yugoslav Republic of Macedonia, Kosovo under UNSCR 1244/99, Liechtenstein, Luxembourg, Malta and Turkey, were not included due to missing coverage of beech forests or non-availability of data. This constitutes a first step in methodology development. All countries are planned to be included in future, and the HNV forest area will not include only beech forests. The studies of HNV farmland and HNV forest area will cover the same geographical area.

Natura 2000 sites are not available in Albania, Bosnia and Herzegovina, Croatia, Montenegro, Norway, Serbia and Switzerland. Similarly, the present study did not include the EMERALD sites; these will be included in future assessments of HNV forest area in the EEA region and in cooperating countries.

2.3 Applied methodology

As a first step, the beech-dominated forest area was identified. This information is not available in the input layers, since both tree species distribution maps (JRC, 2012a; Brus et al., 2012) report the percentage of each tree species for each 1 km x 1 km pixel. The extraction of the beech forest information (pixels) was based on data from NFIs published in Annex 1 of the last *State of Europe's Forests* report (Barbati et al., 2011). An iterative process was used with different thresholds to derive a Boolean beech forest map in the study area, using the continuous values in the JRC (2012a) and EFI-Alterra (Brus et al., 2012) maps. A value of 1 or of 0 was associated to each pixel of the input maps, depending on whether the original value was respectively above or below a given threshold, and resulting in a Boolean mask of beech forests.

The total beech forest areas were aggregated at country level and compared with the data from Barbati et al. (2011) on the basis of a regression analysis, calculating the correlation root mean square error (RMSE). Several thresholds were tested with a reiterative approach in order to identify the thresholds able to minimise RMSE. The following thresholds were identified: 0.28 (28 %) for the JRC (2012a) map, and 0.20 (20 %) for the EFI-Alterra map (Brus et al., 2012).

The total aggregated beech area for the 23 countries was 87 746 km^2 for the JRC map (2012a) and 84 127 km^2 for the EFI-Alterra map (Brus et al., 2012), compared with the area of 84 400 km^2 reported from NFIs (Barbati et al., 2011). Even if the difference between the aggregated maps in terms of total beech area was limited, the spatial distribution of beech forests was clearly very different. The JRC map (2012a) appeared less realistic, with large clustered beech areas interrupted by blank areas. This is probably due to the irregular distribution of the International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests) monitoring sites (forest points on a 16 km x 16 km grid) mirrored in the spatial extrapolation method conducted by the JRC (Map 2.1). For this reason, in the following steps of the analysis, the Brus et al. (2012) map was preferred.

In order to achieve a better match with the NFI beech forest area reported in Barbati et al. (2011), a threshold of 0.2 was applied to the original map of Brus et al. (2012), for all countries except France, Bulgaria, Austria, Germania, Czech Republic and Poland, for which the thresholds were 0.13, 0.32, 0.14, 0.27, 0.11, 0.10 respectively. The beech-dominated forest area in the study area resulted in 168 403 km^2, which is around 3 % of the total study area (4 908 378 km^2); see Map 2.2.

Comparing this result at country level with the total beech area for the 19 countries available in Barbati et al. (2011) and included in the study area, generated an RMSE of 0.54 % (Figure 2.1).

Although the per country beech-forest area comparison between the maps resulting from Brus et al. (2012) and the NFI statistics for the 19 countries available in Barbati et al. (2011) was very satisfying (Figure 2.1), the spatial commission and omission errors of the beech forest mask in Map 2.2 are unknown, for the time being.

Map 2.1 Beech forest area distribution

The beech forest area distribution based on data from JRC (2012a).

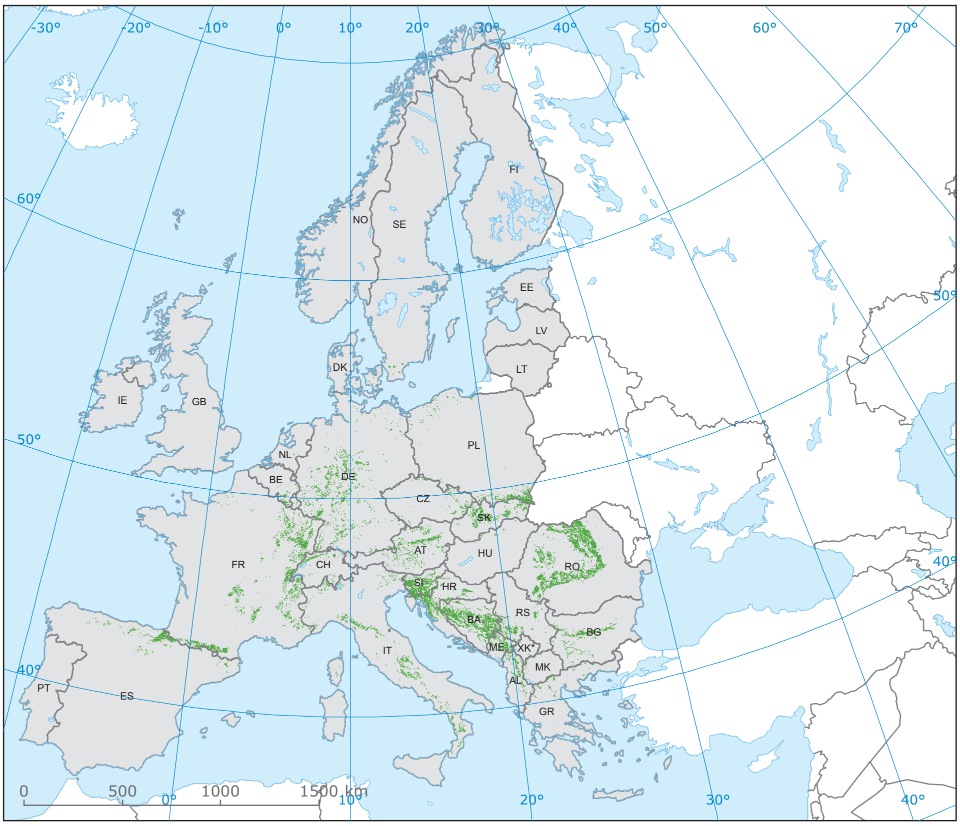
Beech forest

The beech forest area distribution based on data from Brus et al. (2012).

Beech forest

Sources: Green (left) distribution based on data from the JRC (2012a) and red (right) distribution based on Brus et al. (2012).

Map 2.2 Beech-dominated forest area (168 403 km²) in the 19 countries included in the study



Beech dominated forest area

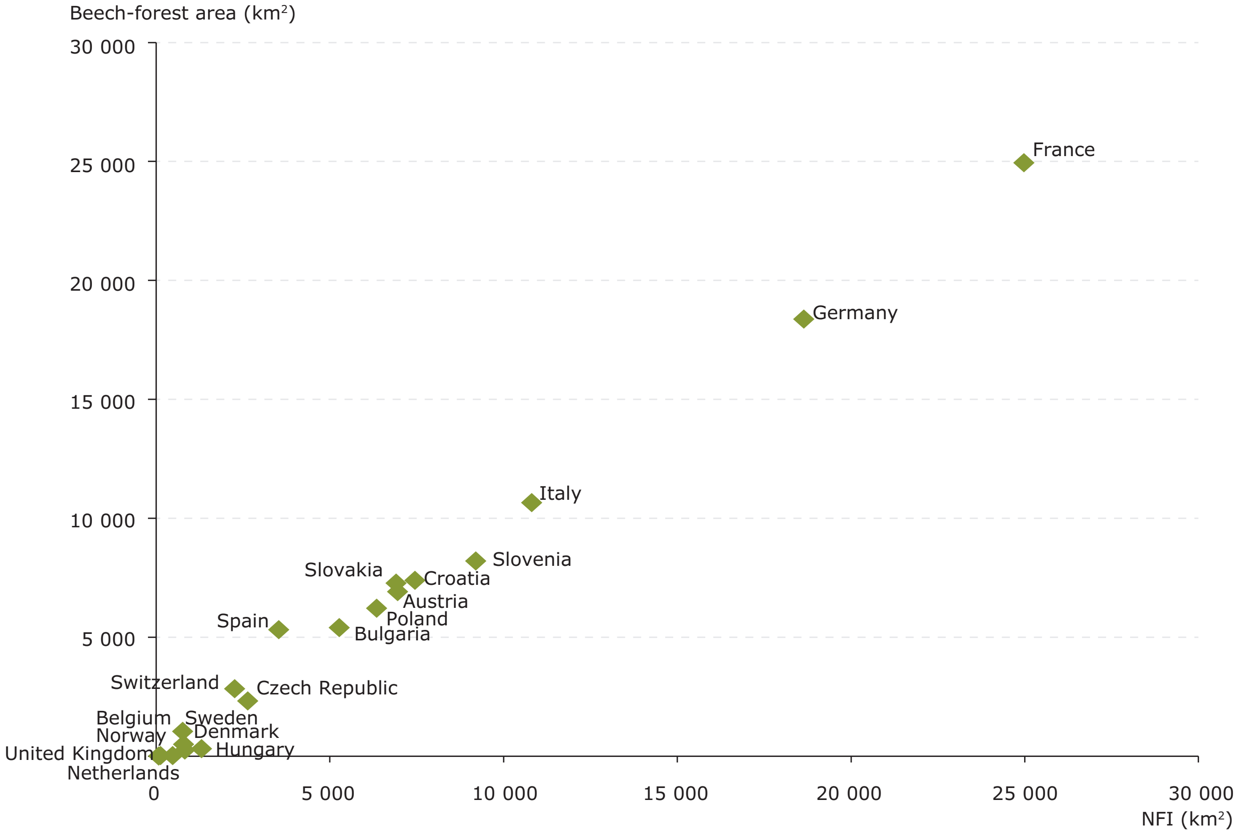
Beech

Outside coverage

XK: Kosovo under UNSCR 1244/99*

Source: Based on the threshold of the Brus et al. (2012) map.

Figure 2.1 Beech-dominated forest area in 19 countries compared with area reported in NFIs



Note: Values in km².

Source: Barbati et al., 2011.

2.3.1 *Potential variables for delineation of high nature forest (beech) area mapping*

The naturalness of the 168 403 1 km x 1 km pixels dominated by beech forests delineated in the previous step was assessed by multiple variables selected according to the availability of the data sets and allowing a wall-to-wall analysis across Europe.

Five indicators were selected:

- naturalness of tree species composition
- hemeroby
- growing stock volume
- accessibility
- connectivity.

The rationale in the selection of the indicators in this step was to test, as far as possible, all the information available in Europe. In order to clarify their potential usefulness in forest naturalness assessments and enable a comparison, the five variables were standardised using fuzzy membership functions — see Box 2.1.

Box 2.1 Fuzzy sets theory

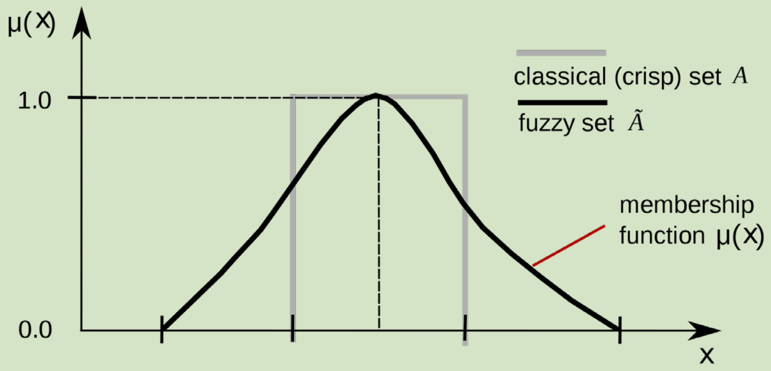
In mathematics, fuzzy sets are sets whose elements have degrees of membership.

Fuzzy sets generalise classical sets, also called crisp sets. While in a classical set an element may belong or does not belong to the set, in a fuzzy set elements may gradually belong to the set. The membership function which describes the inclusion of the element in a fuzzy set may vary in the real interval [0, 1] while in crisp sets it may only take values 0 (if not included in the set) or 1 (if included in the set).

A fuzzy set is characterised by a fuzzy membership grade (also called a **possibility**) that ranges from 0 to 1, indicating a continuous increase from non-membership to complete membership. A **fuzzy membership function** assigns the possibility *μ(x)* for each value of a given variable x.

Fuzzy sets were introduced by Zadeh (1965) as an extension of the classical notion of sets. Eastman (1996) strongly influenced and facilitated their operational use in geographical information systems (GIS), especially in multicriteria evaluation.

Figure 2.2 Comparison between membership functions for a crisp and fuzzy set



Source: 'Membership function (mathematics)', Wikipedia: The Free Encyclopedia, Wikipedia Foundation, Inc. (http://en.wikipedia.org/wiki/Membership_function_(mathematics)) accessed 17 March 2014.

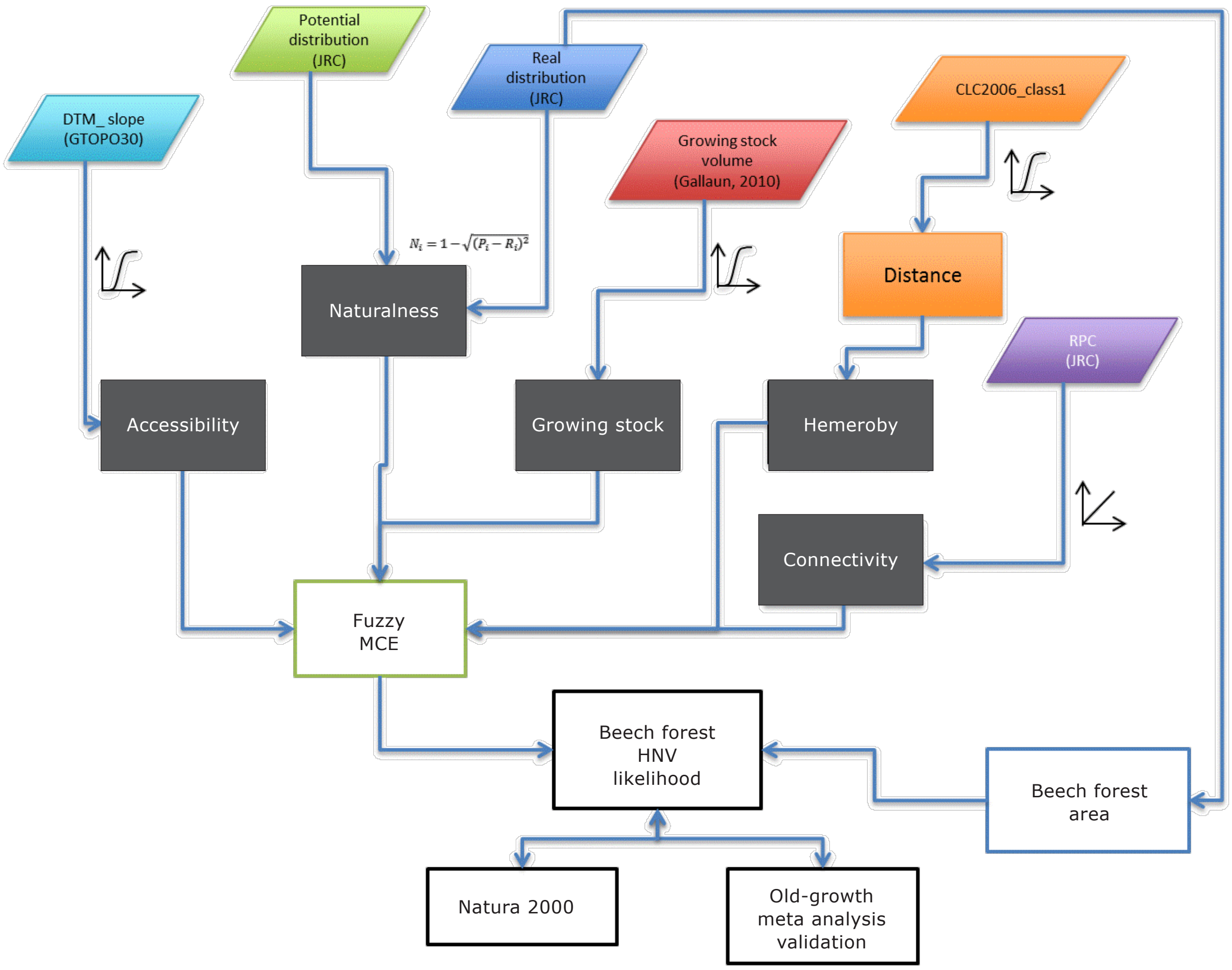
Following the recommendations of McRoberts et al. (2012) and Winter et al. (2010), each indicator was expressed as the ecological distance between real values and potential values typical for virgin forests.

As a result of the application of fuzzy membership functions, each variable was expressed in the same range between 0 and 1: 0 expresses the lower naturalness, 1 expresses the maximum naturalness. The five standardised variables were finally aggregated by linear weighted combination to express a final HNV likelihood value (see Figure 2.3).

Here the term HNV **likelihood** is used, since the analysis is based on the mere hypothesis that forest naturalness is really related to the selected indicators — this is not based on specific evidence, but is mainly because of the geographic scale adopted. For this reason, the aggregation of the indicators lead more to a likelihood value than to a real direct assessment of forest naturalness.

In the first part of the study, each indicator was expected to contribute to the quantification of the overall HNV likelihood with the same weight.

Figure 2.3 Flowchart of the methodology followed in the study



Note: RPC: root probability of connectivity.

Indicator 1: Naturalness of tree species composition

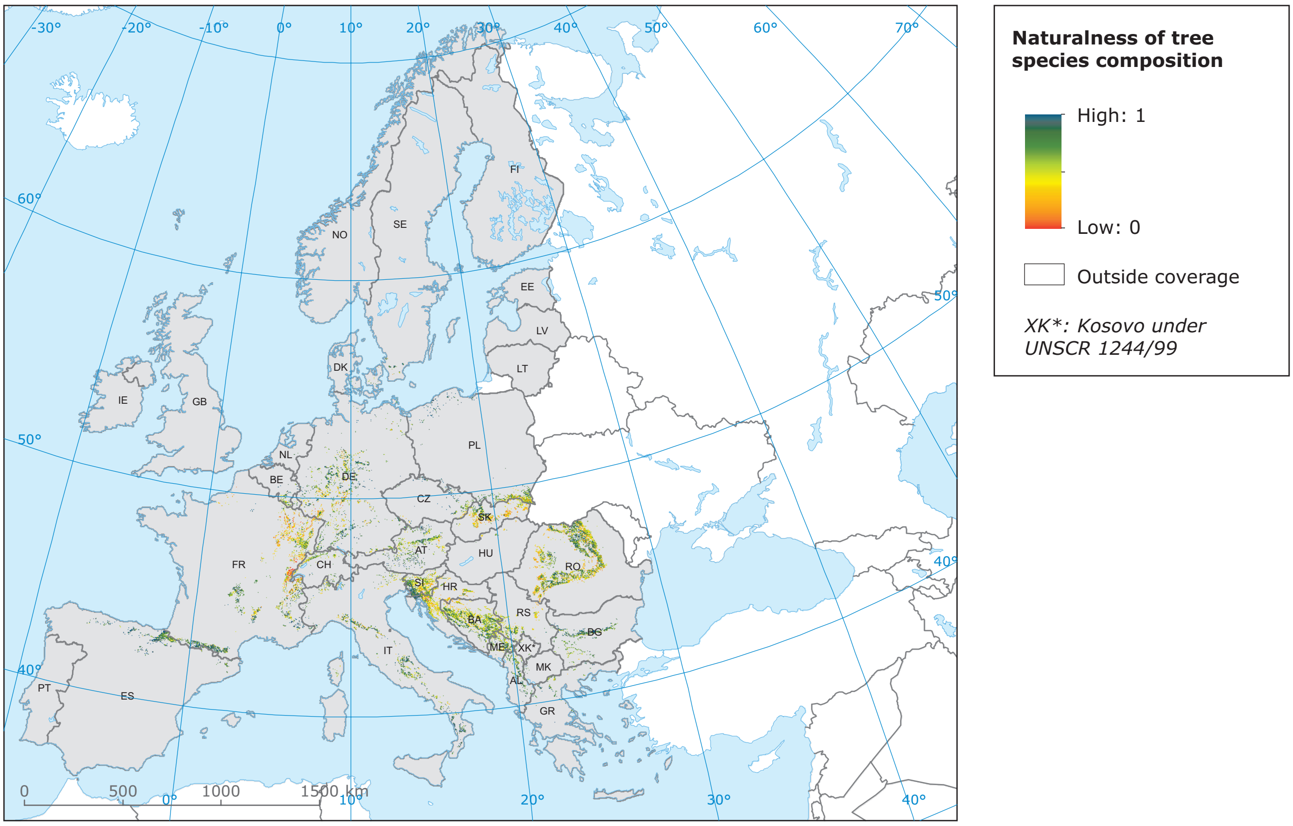
This indicator expresses the relationship between the current per cent presence of a tree species and the potential per cent presence. The rationale of using this variable to delineate a HNV forest area is that forest areas coherent in species composition with their potential habitat suitability are expected to be closer (in the ecological sense) to natural conditions (i.e. with a higher HNV likelihood value). This indicator alone cannot determine HNV forests: for instance, a species could be intensively cultivated, coherently with its habitat suitability distribution, but without having any other of the characteristics of a HNV forest.

For each pixel of the beech-dominated forest mask, the indicator was calculated by comparing the per cent presence of beech forests from Brus et al. (2012) with the habitat suitability value from the JRC (2012b) as follows:

$$N_i = 1 - \sqrt{(P_i - R_i)^2} \qquad \text{[Eq. 1]}$$

where N is the naturalness indicator value in the range between 0 and 1 for each i-th pixel of the 168 403 beech-dominated 1 km x 1 km pixels, P_i is the habitat suitability in the range between 0 and 1 from JRC (2012b) and R_i is the percentage presence of beech forest from Brus et al. (2012).

Map 2.3 The indicator 'naturalness of tree species composition' for the investigated 168 403 km² of beech-dominated forests



Indicator 2: Hemeroby

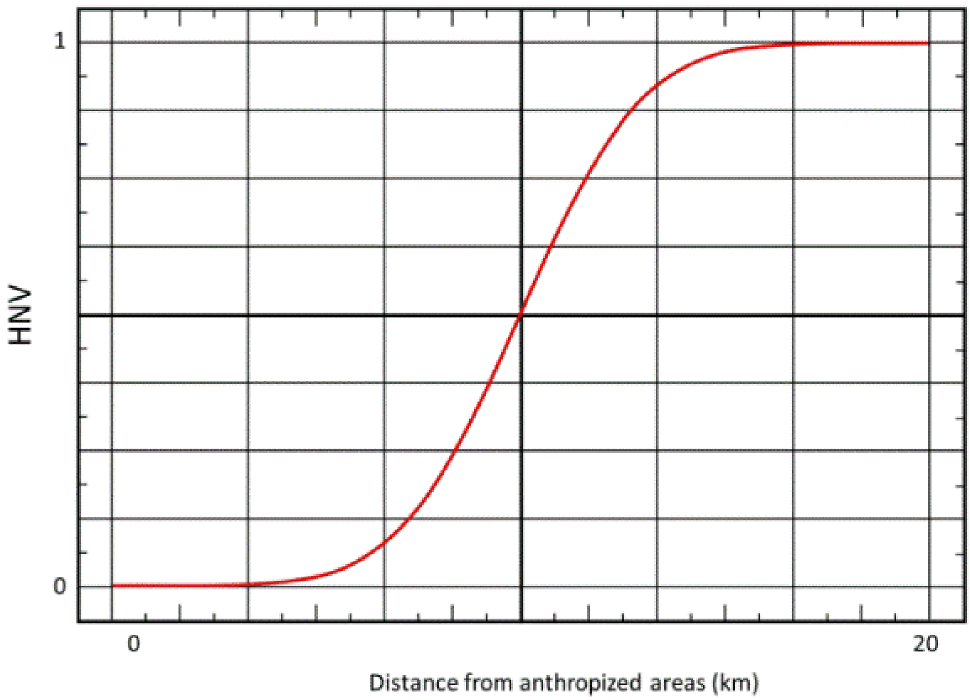
Hemeroby and naturalness, and thus HNV forest area likelihood, are inversely related: the lower the level of hemeroby, the higher the level of naturalness (and the likelihood of HNV forest area); see Figure 1.2.

This indicator expresses the potential anthropogenic disturbance to beech-dominated forests in terms of spatial proximity from disturbing sources. We tested this indicator assuming that potential natural conditions would be more probable in areas with limited conversion of open spaces, landscapes, and natural environments by human action, considering the conversion of forest systems as one of the main reasons for loss of naturalness.

The input layer to model hemeroby is based on class 1 from CLC (artificial surfaces), calculating the percentage of artificial surfaces in each 1 km^2 pixel. The distance from pixels with at least 75 % of artificial surfaces was calculated, and a monotonically increasing fuzzy membership function (Figure 2.4) and Eq. 2 and Eq. 3 were applied, with a threshold value of 20 km according to the results of Tonti et al. (2010) stating that the impact of anthropogenic activities on different naturalness indicators was considered negligible over the distance of 20 km.

The resulting map depicts areas of beech-dominated forest with higher potential HNV likelihood where hemeroby is low, and lower HNV likelihood where hemeroby is higher.

Figure 2.4 Logistic fuzzy membership function used to rescale distance from areas experiencing hemeroby (potential anthropogenic disturbance) to the HNV variable



Indicator 3: Growing stock volume

This indicator expresses the relationship between the existing growing stock volume in beech-dominated forests in Europe and the reference growing stock volume for natural beech forests. The rationale is that beech forest areas with high relative values in growing stock volume are expected to be closer (in the ecological sense) to natural conditions (more large and old trees, as compared to stands with low-growing stocks). It is important to note that growing stock reference values in European (beech) forests can change due to several local factors such as orientation, elevation, site fertility, climate and management. For this reason, reference values must be diversified on the basis of average values for dominant species or forest types. In this example, the reference value for beech forest was extracted from Annex 1 of the *State of European Forests* (Barbati et al., 2011). For simplicity in this test, the reference value was considered constant for all beech forests in Europe. In operational applications, reference values should be different, based on local information.

A logistic monotonically increasing fuzzy membership function Schmucker (1982) was adopted to rescale growing stock volume to HNV fuzzy likelihood:

$\mu = \cos^2\alpha$ [Eq. 2]

where:

$\alpha = (1-(x/300)) \times \pi/2$ [Eq. 3]

and 300 ($m^3\ ha^{-1}$) is the threshold growing stock volume that was adopted (Barbati et al., 2011).

Indicator 4: Accessibility

The potential intensity of forest management is considered a factor that potentially affects HNV likelihood. Forest management intensity was modelled using the slope from a digital elevation model (the higher the slope, the lower the potential management intensity, and thus the higher the expected naturalness). A monotonically increasing fuzzy membership function (see [2] and [3]) was applied to the slope map, with a threshold value of 20° on the basis of EEA (2006c).

Indicator 5: Landscape connectivity

Landscape ecology considers a landscape as a mosaic over which particular local ecosystems and land-uses recur and form a pattern (Forman, 1998). Fragmentation is a spatial pattern process that refers to the 'breaking apart' of a habitat (Betts, 2000). In a broader sense, the study of forest fragmentation is the study of habitat destruction (reduced habitat area) and isolation of the resulting remnants (change in spatial configuration) (Kupfer, 2006).

Several factors contribute to forest fragmentation, and therefore also to potentially increasing forest vulnerability. Besides human-induced forest fragmentation by clear-cutting, urban spread and development of infrastructure, natural disturbances such as fires and storms also cause forest fragmentation. Fragmented forests can be more vulnerable to natural disturbances. The effects of forest fragmentation are therefore connected not only to the survival capacity of forest-dwelling species, but also to the capacities of forests to resist and overcome natural disturbances. So even if the effects of fragmentation per se are as likely to be positive as they are negative (Fahrig, 2003) it can be concluded that forest resistance and resilience towards natural disturbances is higher for forests with little fragmentation, whereas highly fragmented forests are more vulnerable to such disturbances. Recently, these concepts were used for a global assessment of the intactness of forests carried out by Greenpeace; an forest was considered intact when large contiguous forest areas existed, without fragmentation due to human activities (Thies et al., 2011).

In this study, the connectivity of forest patches was measured with a network-based habitat availability index, the Root Probability of Connectivity (RPC), calculated by the JRC per landscape units of 25 km by 25 km. The map was resampled to 1 km spatial resolution and considered linearly, since it is already expressed in the range 0–1. For more information on the RPC index, see Estreguil et al. (2012).

3 Results and discussion

This chapter presents the results of the multicriteria analysis. As a first step, the average values of the five HNV indicators for naturalness of tree species composition, hemeroby, growing stock, accessibility and connectivity were calculated; see Table 3.1.

A first map of likelihood of HNV forest (beech-dominated) area was produced by simple averaging of the five indicators, all expressed in the interval from 0 to 1 — Map 3.1. This aggregation method is the simplest approach to MCE (Corona et al., 2008).

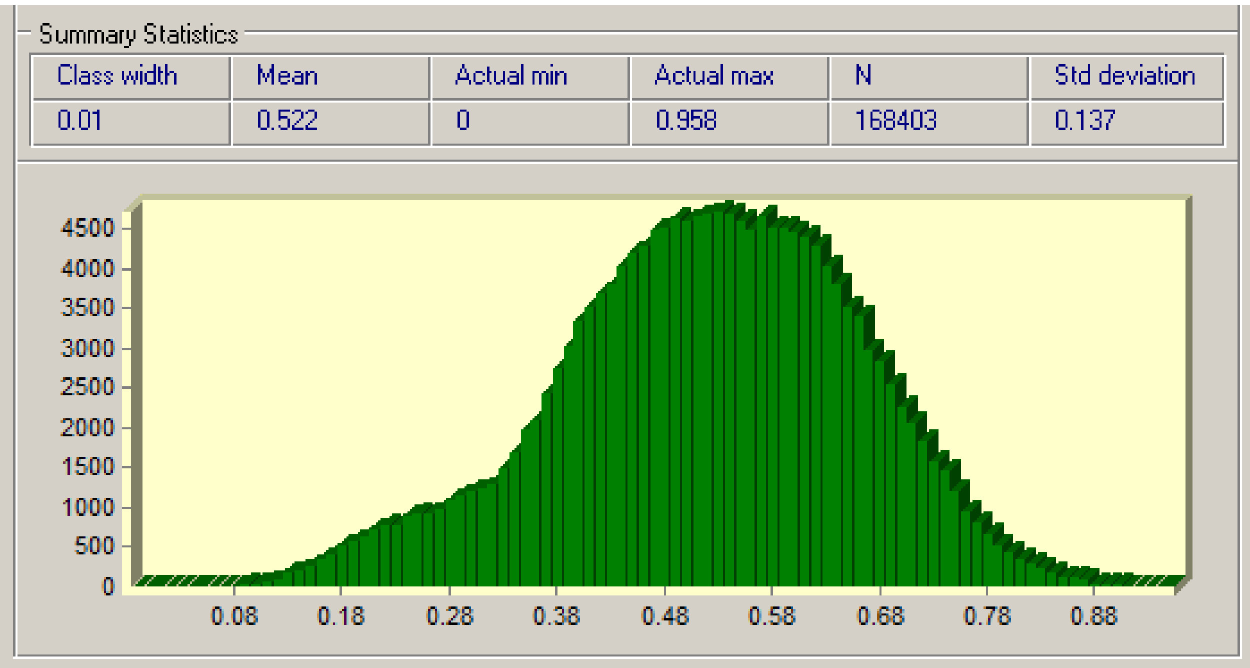
The histogram distribution of the resulting HNV values for the investigated 168 403 km² of beech forests in the study area can be viewed in Figure 3.1.

The continuous values of HNV likelihood ranging between 0 and 1 were classified on the basis of the average (0.522) and standard deviation (0.137) values in 3 classes: the intermediate class with values between the average ± the standard deviation, and two classes for values below and above these limits.

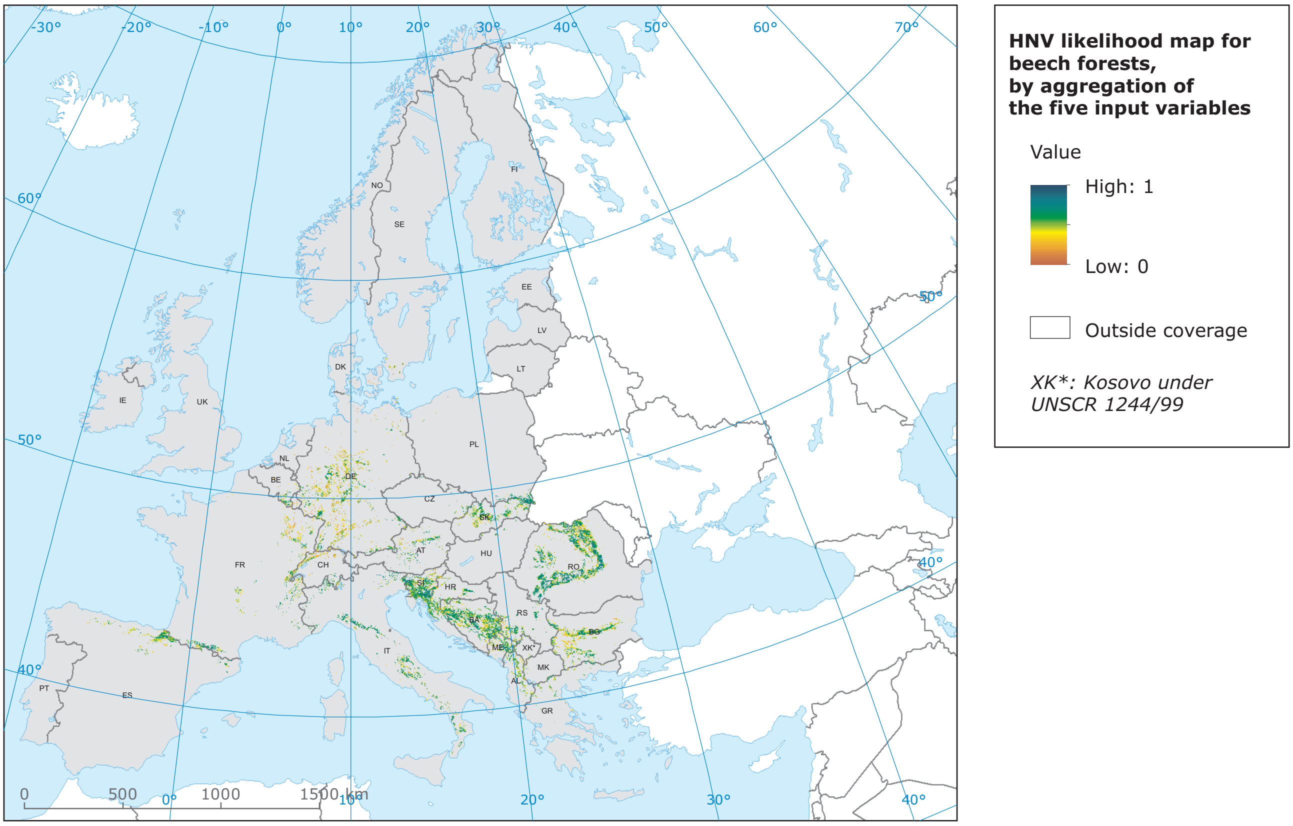
Table 3.1 Average values of the HNV indicators on the naturalness, hemeroby, growing stock, accessibility and connectivity for the investigated 168 403 km²

Variable	Naturalness	Hemeroby	Growing stock	Accessibility	Connectivity
Mean	0.59	0.664	0.59	0.229	0.455
Std deviation	0.156	0.336	0.425	0.249	0.183

Figure 3.1 Histogram distribution of the HNV values for the investigated 168 403 km² of beech forests in the study area



Map 3.1 HNV likelihood map for beech forests, by aggregation of the five input variables



3.1 Accuracy assessment

Old-growth forests are continuous woodlands where the absence of forest operations over at least several decades has allowed forest dynamics to return to successional pathways, and to be mainly driven by site potential and natural disturbances. Under these conditions, forests can develop diversified stand structures, compositions and functions and forest biodiversity may increase over the time, slowly approaching the level of a native forest (Frelich and Reich, 2003; Spies, 2004). Structures and processes associated with the maturation and senescence of a population of trees result in a relatively high degree of structural complexity (Spies, 2004).

In Europe, several studies were conducted on old-growth forests (Wirth et al., 2009), focusing on forest structure and composition (e.g. Kuuluvainen et al. (1998), Emborg et al. (2000) and Tabaku (2000)), dynamics and natural regeneration (e.g. Korpel (1982), Koop and Hilgen (1987), Björkman and Bradshaw (1996), Lindner et al. (1997), Linder (1998), Bobiec et al. (2000), Diaci et al. (2003) and Nagel et al. (2006)), age structure (e.g. Rozas (2003)) and deadwood occurrence (e.g. Jonsson (2000), Siitonen et al. (2000), and Saniga and Schütz (2002)). Research attention has been mainly directed towards boreal and temperate old-growth forests, where several remnants of 'virgin' forests have been protected in forest reserves for a long time, and were thus less influenced by human activities (Christensen et al., 2005).

Surprisingly few quantitative surveys have been devoted to old-growth forests, despite them actually constituting the most acknowledged forest biodiversity and naturalness icons. Perhaps most of the results concerning old-growth forest inventories are unpublished or inaccessible (Corona et al., 2010).

The HNV forest (beech-dominated) areas likelihood, developed in the present study at pan-European level and at moderate geographical resolution, was compared with field observation of old-growth forests, assuming that old-growth forests have HNV suitability values higher than the average values for the same forest category.

Information from a meta-analysis of scientific publications on old-growth forest in Europe has been produced as part of a cooperative project coordinated by the Italian Academy of Forest Sciences (AISF). The old-growth forest database is still progressively expanding. At the present time, it contains approximately 150 old-growth forests described in more than 80 scientific publications (see bibliography). The original database, which is the property of AISF, reports for each old-growth forest the following information: extension, geographical location, growing stock volume, deadwood volume, forest type, and date of the last disturbance or age. For validation, a total of 136 beech-dominated old-growth forests were used (Map 3.2). Most of the old-growth forests have a size smaller than the minimum mapping unit used in the HNV suitability analysis: only 24 forests are larger than 100 ha, and the 136 old-growth forests have an average size of 68 ha, ranging between 1 ha and 1 434 ha (with a standard deviation of 136).

The values of the 5 indicators used in the HNV likelihood analysis were extracted and averaged for the 136 pixels corresponding to the selected old-growth forests, obtaining an average value of 0.703. A Welch's t-test was applied, as the two population variances (from all the beech forest pixels and from those belonging to old-growth forests) are assumed to be different (different sample sizes), and hence must be estimated separately.

The difference between the averages of the 136 old-growth forests was significantly ($p < 0.001$) higher than the average of the beech forests used in the study (0.522).

The first tests against field truth thus confirmed the original hypothesis that the HNV likelihood values are related to the presence of old-growth or virgin forests. The size of remnant old-growth/virgin/pristine forests is usually smaller than the minimum mapping unit used by most of the input data-set available across Europe (1 km^2). For this reason, future implementation of the method in Europe with a wall-to-wall approach for all forest categories should include a downscaling procedure. Several methods exist in the literature (Puletti et al., 2010), and these could be based on a high-resolution forest maps available at pan-European level.

A more in-depth accuracy assessment was carried out using the ROC method (Receiver Operating Characteristic, see Pontius and Schneider, 2001). This method has been developed to assess the validity of a model that predicts the location of the occurrence of a class by comparing a suitability image depicting the likelihood of that class occurring (i.e. the beech HNV likelihood map) and a Boolean image showing where that class actually exists (i.e. the beech-dominated old-growth forests).

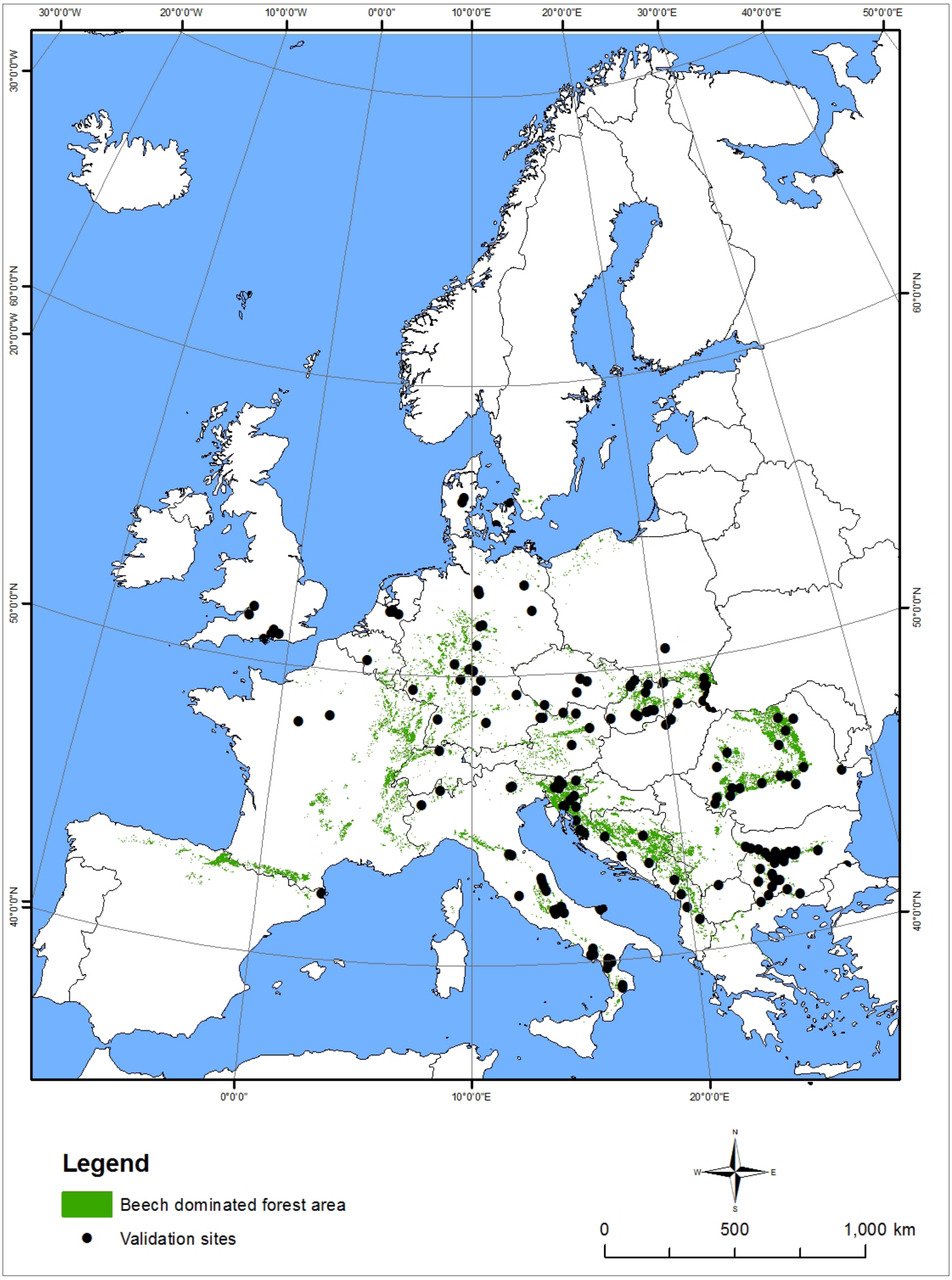
The ROC approach offers a statistical analysis that answers one important question: 'How well is the category of interest concentrated at the locations of relatively high suitability for that category?' The answer to this question allows one to answer the general question, 'How well do the pair of maps agree in terms of the location of cells in a category?' without needing to also answer the question 'How well do the pair of maps agree in terms of the quantity of cells in each category?' (Eastman, 2012). Thus a ROC analysis is useful when one wants to see how well the suitability map portrays the location of a particular category, but does not have an estimate of the quantity of the category. This is the case with old-growth forest locations, where we do not have an estimation of their level of relative naturalness (or state regarding old growth).

The ROC is a summary statistic derived from several two-by-two contingency tables (see Table 3.2), based on a comparison of the simulated image with the reference image. Each table corresponds to a different threshold in the likelihood map.

The true positive % value is derived from A/(A+C), while the false positive % value is derived from B/(B+D), where A, B, C, D are pixel counts in the contingency table for each threshold.

The ROC curve is a graphical plot which illustrates the performance of the binary classification, as its discrimination threshold is varied. Here, we used 50 different thresholds with 50 equal intervals between 0 and 100. A graph was created by plotting the fraction of true positives out of the positives (TPR = true positive rate) vs the fraction of false positives out of the negatives (FPR = false positive rate), for each one of the 50 threshold settings. TPR is also known as sensitivity (or recall in some fields), and FPR is one minus the specificity or true negative rate. The Area Under the ROC Curve (AUC) is equal to the probability that a classifier will rank a randomly chosen positive instance higher than a randomly chosen negative one (assuming that 'positive' ranks higher than 'negative').

Map 3.2 Old-growth forest locations used in the validation process



Source: Old-growth forest database of the Italian Academy of Forest Sciences (AISF).

Table 3.2 Contingency table used for ROC analysis

		Beech-dominated old-growth	
		In class of interest (1)	**Not in class of interest (0)**
HNV likelihood	In class of interest (within threshold)	A (true positive)	B (false positive)
	Not in class of interest (not within threshold)	C (false negative)	D (true negative)

Figure 3.2 shows the ROC curves and Figure 3.3 shows the AUC values calculated for each one of the five different input indicators and for the aggregated HNV likelihood.

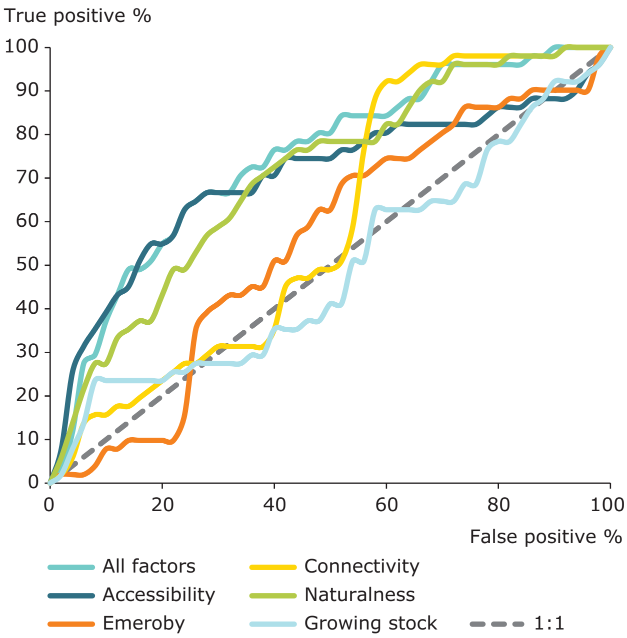
The 1:1 line in ROC graphs (Figure 3.2) shows a random relationship between the two variables (HNV likelihood and presence/absence of old-growth forests). If the graphs are above the 1:1 line, the relationship is proportional (the higher the variable, the higher the HNV likelihood); if they are below the 1:1 line, the relationship is inversely proportional.

The higher the distance of the graph from the 1:1 line, the higher the correlation between HNV likelihood and presence/absence of old-growth forests.

On the basis of the ROC validation analysis, all the considered factors, with the exception of growing stock, have AUC values greater than 0.5, showing a non-casual effect between the considered indicators and the presence/absence of old-growth forests.

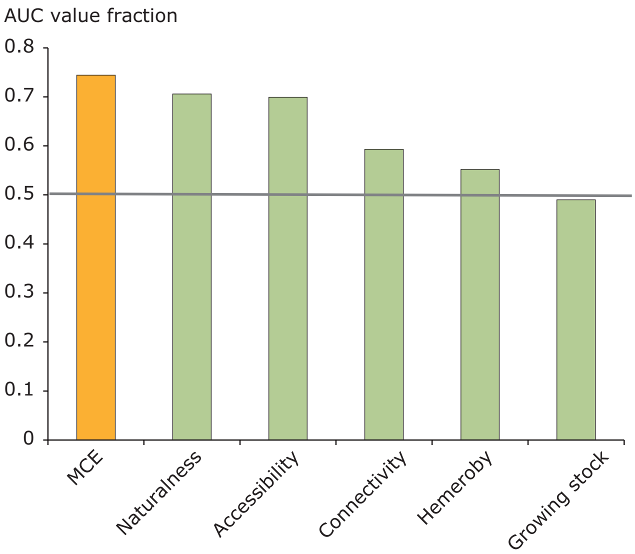
The highest AUC value (0.744) is obtained when all the input five input indicators are aggregated by simple average in the multicriteria evaluation (MCE), see Figure 3.3.

Figure 3.2 ROC curves



Note: MCE refers to multicriteria evaluation used to aggregate the five input factors resulting in HNV likelihood; naturalness refers here to naturalness of the beech tree species.

Figure 3.3 AUC values resulting from ROC analysis



Note: MCE refers to multicriteria evaluation used to aggregate the five input factors resulting in HNV likelihood

3.2 Sensitivity analysis and optimisation

On the basis of the first positive results obtained in the accuracy assessment, we considered whether the estimation model of HNV likelihood for beech forests could be optimised and refined. First, we studied potential redundancy within the indicators.

The correlation between the 5 input variables was limited; the Pearson coefficients of correlation for the 168 403 beech-dominated pixels in the study area obtained a maximum value of 0.167 between 'hemeroby' and 'accessibility'. Thus none of the five variables could be eliminated by the model for reasons of redundancy.

Subsequently, the ROC analysis was repeated, using only those indicators that demonstrated the highest AUC values. We found that the best combination was obtained with three variables. The AUC for naturalness alone was 0.706, for naturalness and accessibility 0.787, and for naturalness, accessibility and connectivity together, 0.809 (Figure 3.4).

The ROC methodology was then used to empirically to test whether the MCE approach could be optimised by weighting the different input factors.

For the best model (based on three input factors: naturalness of tree species composition, accessibility and connectivity) we recursively tested different weighted linear combinations by Monte Carlo simulations. The different combinations empirically led to the 'best' model having a weight for naturalness of 0.4, and of 0.3 for accessibility and connectivity. The model obtained an AUC with the ROC analysis of 0.833. This was considered the optimal model, and it was used as the final beech HNV likelihood map (see Map 3.3).

Figure 3.4 ROC curves for the best models

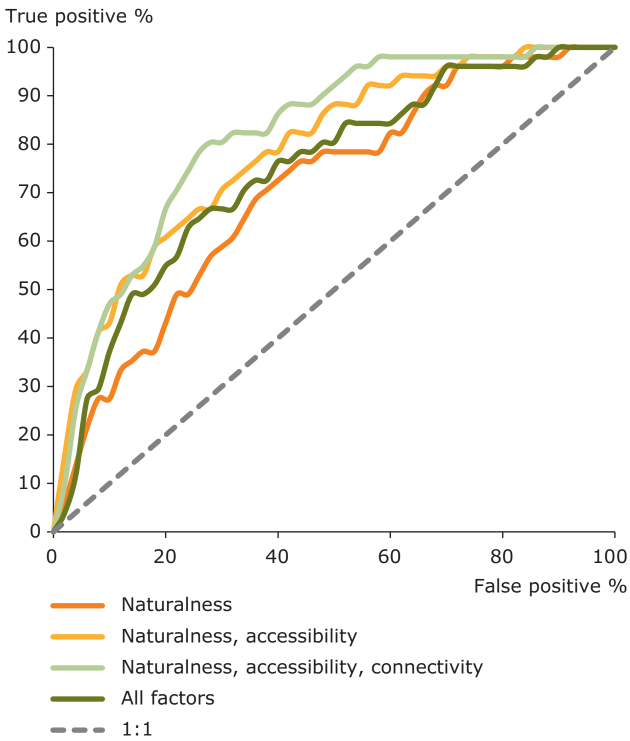
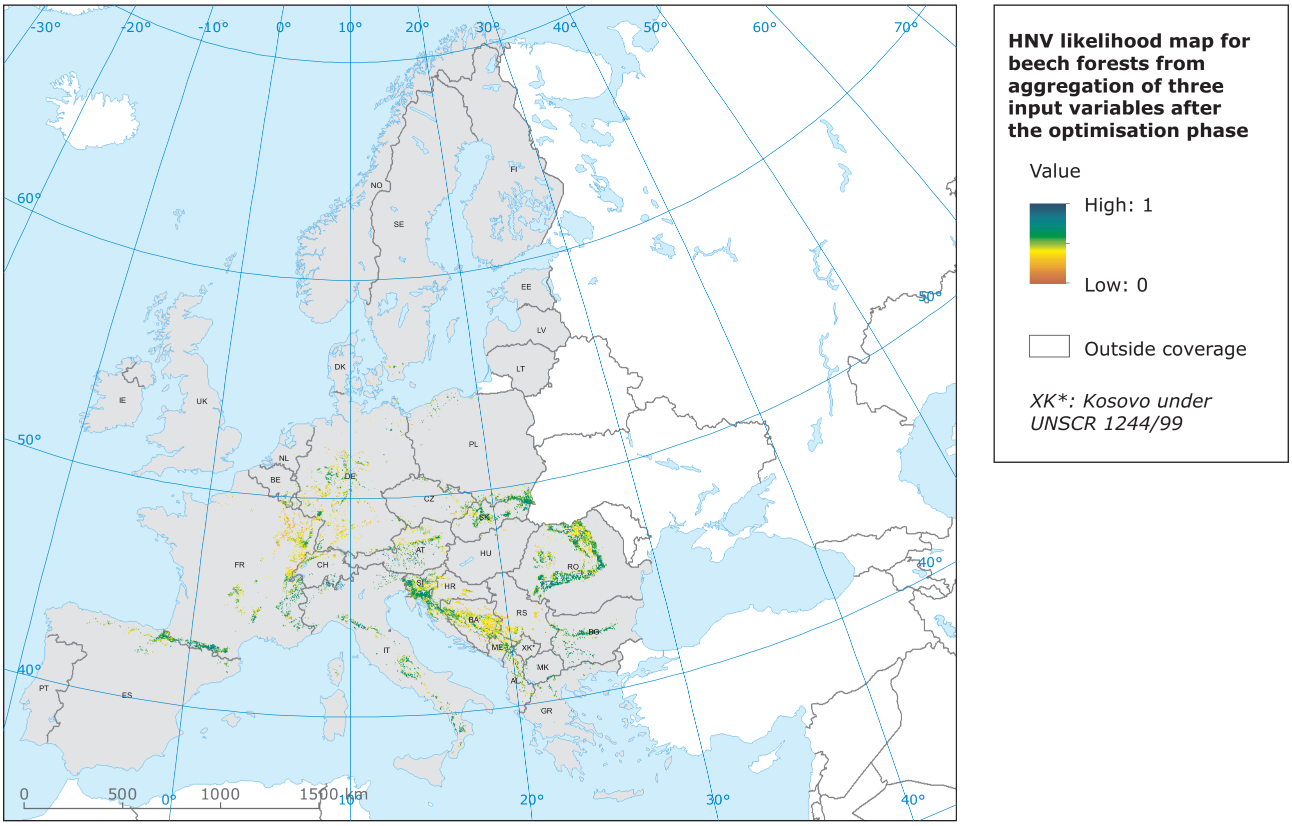


Table 3.3 Relationship between variables used for HNV suitability modelling, measured by coefficient of correlations

	Naturalness	Growing stock	Hemeroby	Accessibility	Connectivity
Naturalness	1				
Growing stock	– 0.142	1			
Hemeroby	0.065	– 0.085	1		
Accessibility	0.130	– 0.080	0.167	1	
Connectivity	– 0.009	0.177	0.158	– 0.011	1

Map 3.3 HNV likelihood map for beech forests from aggregation of three input variables after the optimisation phase (naturalness, accessibility and connectivity)



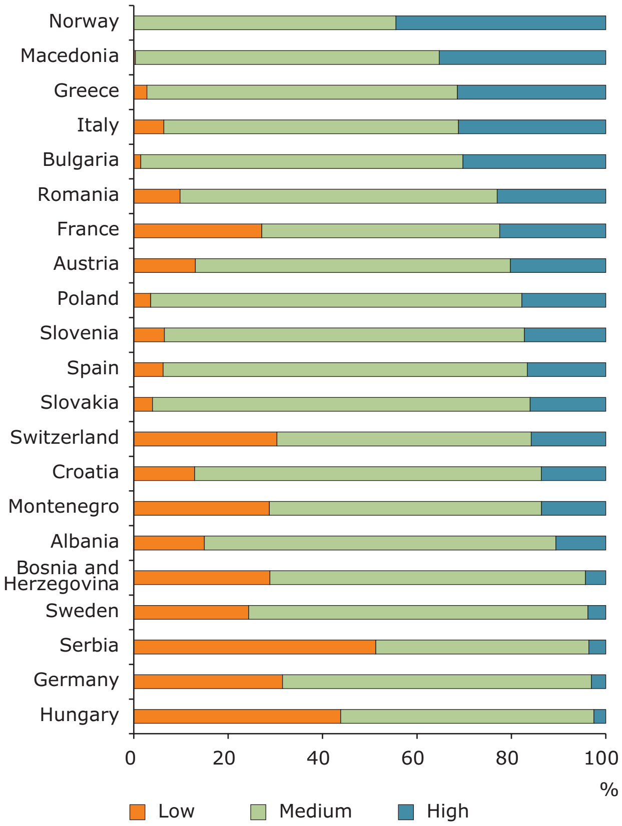
Finally, for comparison, a logistic regression approach was tested, in order to estimate the relative robustness of the MCE approach. Using all the five input indicators, the best model obtained a R^2 of 0.225 with a ROC of 0.425, thus confirming the superiority of the MCE approach for this specific test.

After the ROC optimisation, the best model based on three input indicators resulted in an average HNV likelihood value for the 168 403 beech-dominated pixels of 0.471 with a standard deviation of 0.124. We created three classes: the 'low' class ranging between 0 and the average — std. deviation (0.347), the 'intermediate' class between 0.348 and the average + std. deviation (0.595), the 'high' class between 0.596 and 1.

Of the overall beech forest area, 17 % falls into the 'low' class, 66 % is in the 'medium' class and 34 % in the 'high' class of HNV likelihood. The same classification was performed at country level (see Figure 3.5).

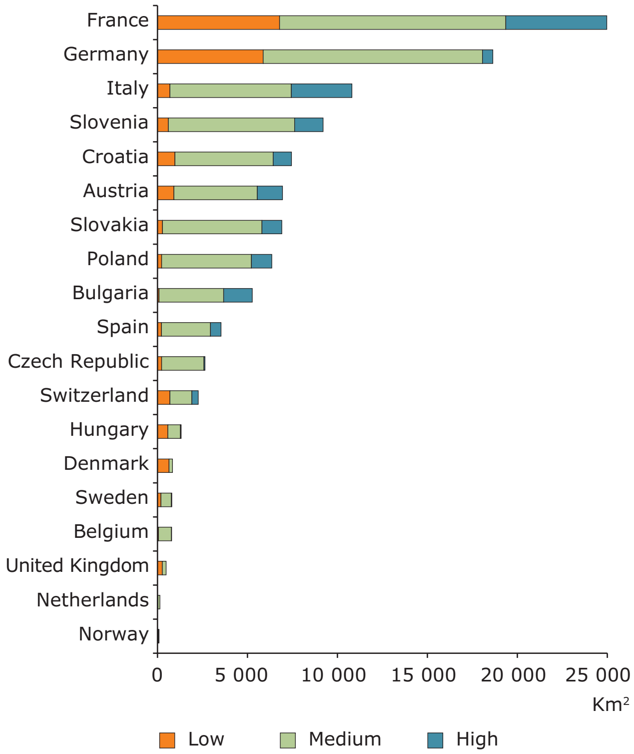
Finally, the area in absolute values is reported in Figure 3.6, only for those countries for which the beech forest area in the last *State of Europe's Forests* was reported (Forest Europe, UNECE and FAO, 2011).

Figure 3.5 Distribution of HNV likelihood values (percentage) for beech forests grouped in classes for selected countries



Note: Only those countries with at least 100 km² of beech forest area (on the basis of the map used in this study) are reported.

Figure 3.6 Distribution of HNV likelihood values (area in km²) for beech forests grouped in classes for selected countries



Note: Only countries for which the forest area is classified by forest types in Annex 1 of the *State of Europe's Forests* (Forest Europe, UNECE and FAO, 2011) are reported here.

3.3 Relationships with other spatial data sets

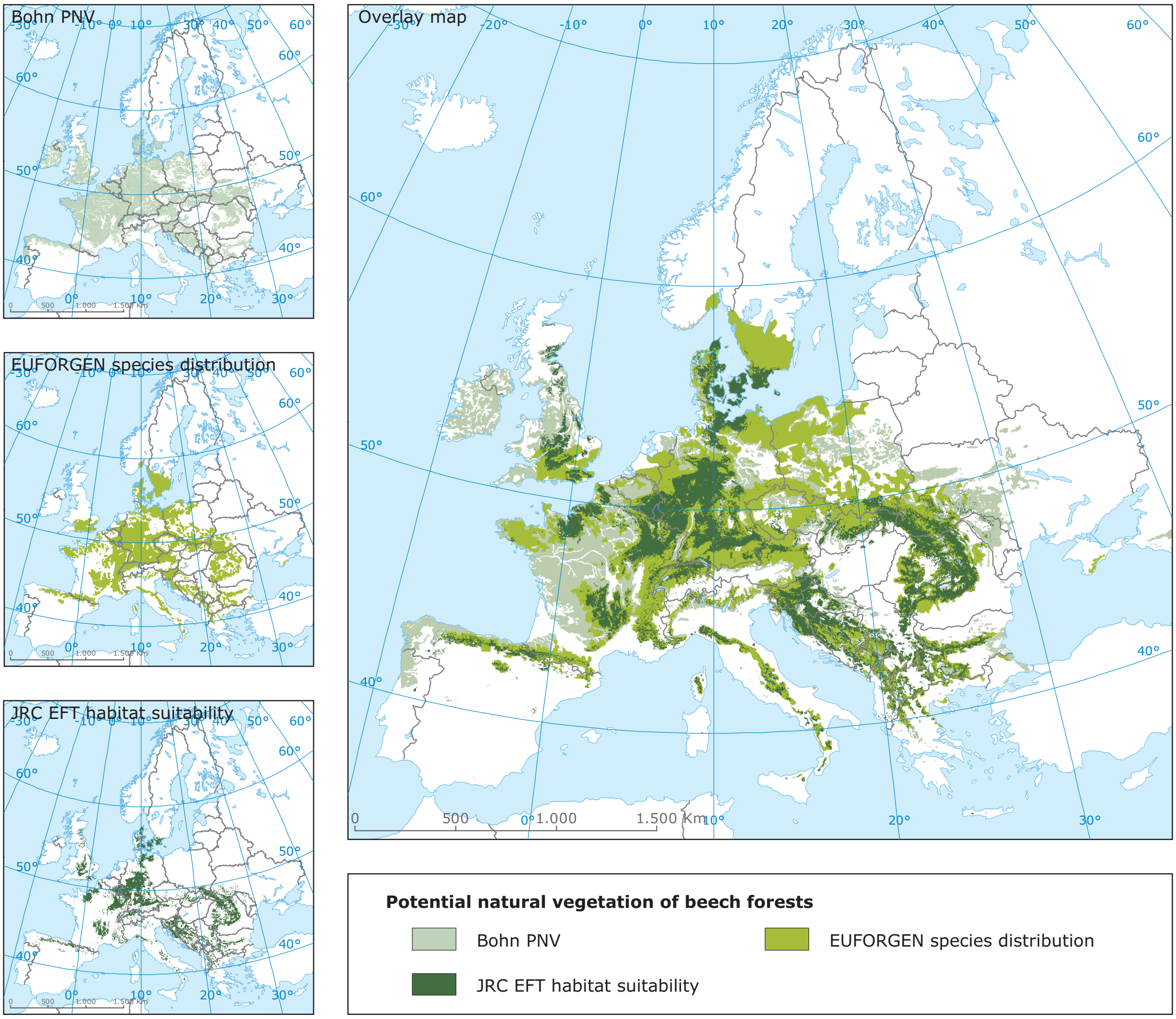
Intermediate and final outputs of the HNV analysis were contrasted and analysed against other spatial data sets available in Europe. The aim of these analyses is to show congruencies and differences between the different sources of information, and to gauge the potential use of HNV maps in the framework of the assessment of the relationship with protected areas. Regarding potential natural vegetation, several sources of information exist. Here, in Section 3.3.1 we compared three independent sources, from the EUFORGEN project, from the Habitat Suitability analysis carried out by the JRC for European Forest Types (JRC, 2012c) and from the Bohn map (Bohn et al., 2004). In Section 3.3.2 a first tentative example of gap analysis with existing networks of protected areas (IBAs, Natura 2000 and CDDA sites) is also presented.

3.3.1 Potential natural vegetation

We analysed three spatial data sets that could help identify the potential distribution of beech forests in Europe. The maps differ for the definitions adopted, the methods used for their creation and the spatial resolution. For more details and references, see Annex 1. The Bohn map of Potential Natural Vegetation of Europe (Bohn et al., 2004) was applied, being an available standardised Europe-wide data set. It was reclassified according to the European Forest Type system of nomenclature (EEA, 2006). Categories 6 and 7 for beech forests resulted in an area of 919 008 km².

The EUFORGEN potential geographical beech distribution (von Wühlisch, 2008) resulted in 1 267 940 km², and finally the European Forest Types habitat suitability map produced by the JRC (JRC, 2012c) resulted in 561 036 km².

Map 3.4 **Layers (left) and overlay analysis (right) of Bohn PNV map of Europe, EUFORGEN species distribution map and JRC EFT habitat suitability**



Note: The layers are on the left, respectively ordered from top to bottom, and are overlaid in the larger image on the right.

It is important to note that only the Bohn map and the JRC habitat suitability map specifically refer to the same definition of beech forests (categories 6 and 7 of the EFT system of nomenclature) from the EEA (2006).

The total area which is considered as suitable or congruent to potential natural vegetation (PNV) in at least one of the three maps is 1 498 729 km^2: for 23 % of this area the three maps are congruent, for 37 % only two of them are congruent, and the remaining 40 % is covered by only one of the three maps.

Table 3.4 **Congruency analysis between Bohn PNV map of Europe, EUFORGEN species distribution map, and JRC EFT habitat suitability**

	Bohn	EUFORGEN	JRC
Bohn	919 008		
EUFORGEN	775 346	1 267 940	
JRC	379 848	437 696	561 036

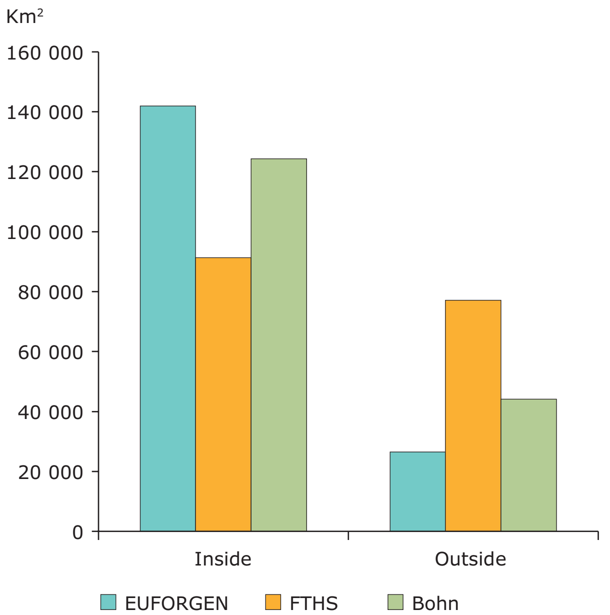
Note: The values in km^2 represent the spatial congruency for beech forests.

In future applications of HNV forest analysis for the overall forest area, the selection of one layer depicting the potential natural vegetation in Europe would be essential.

Unfortunately, a quantitative assessment of potential maps is difficult because reference data are not intrinsically applicable. The Bohn map is spatially detailed, and has been derived with long-term participation from many vegetation experts across Europe, but it is not available with separate layers for the different forest types. The EUFORGEN layers are available for different tree species, but the spatial detail (quantitatively unknown) is very poor. The layers from the JRC are at 1 km resolution, as fuzzy maps for the different forest types, and are derived with an objective and replicable suitability model. Unfortunately, the JRC habitat suitability maps are currently derived from field observations from the rather spatially limited data set of the ICP network. An option in future assessments is to use the NFI data sets available through the EFDAC for a reapplication of the model, to derive a new version of the EFT and tree species suitability maps.

The beech forest mask used in this study mainly fall in areas included inside potential vegetation maps; this is particularly true for EUFORGEN and the Bohn maps (Figure 3.7).

Figure 3.7 Area (km²) of beech forest falling inside the area of potential vegetation



Note: Derived from Brus et al. (2012), and the three potential and habitat suitability from EUFORGEN, the JRC European FT habitat suitability and the Bohn PNV map.

3.3.2 Conservation status

This is a first, simple example of comparative analysis between the HNV beech forests identified, and the best model presented in Section 3.2 with three different networks of valuable areas: Natura 2000 sites, the CDDA sites, also commonly known as Nationally designated areas (version 11) and IBAs acquired from BirdLife that have been recently used in the HNV farmland project (Paracchini et al., 2008).

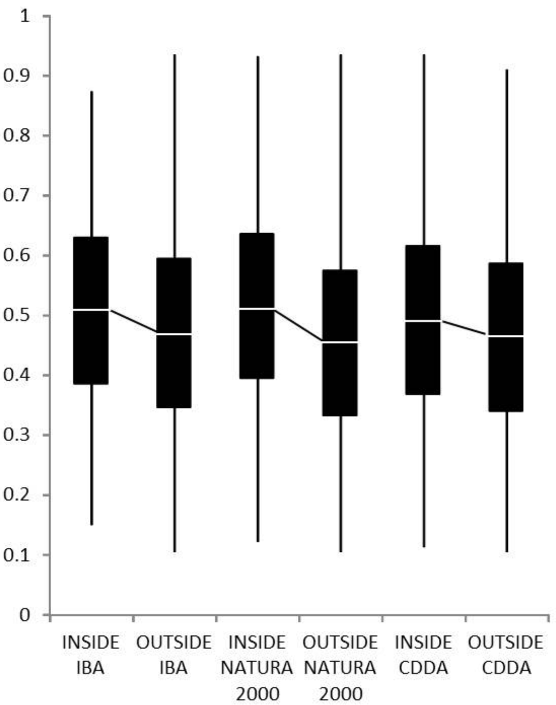
In order to work with the same spatial resolution for the HNV beech forest analysis, we considered those 1 km x 1 km pixels covered as a majority by the Natura 2000, CDDA or IBA sites as part of the respective protected sites in the study area. It is important to note that because of the coarse raster approach, the area of the different protected areas may differ from official statistics calculated on the basis of raw vector layers. Overlapping areas were not considered, so if, for example, one pixel is covered by two different designated areas of the CDDA, it is accounted for only once.

EMERALD sites corresponding to the EU Natura 2000 sites are not currently available for Albania, Bosnia and Herzegovina, Croatia, the former Yugoslav Republic of Macedonia, Montenegro, Norway, Serbia and Switzerland. So, without considering these countries, the total land in the study area is 4 261 894 km²; Natura 2000 sites cover 1 137 644 km² while IBA sites cover 190 703 km². The CDDA sites in the study area are not available for Hungary, and thus they cover 729 392 km² of total land in the study area of 4 781 461 km². The beech forest mask from Section 2.3 in those countries covered by the Natura 2000 sites for 48 486 km² (29 %) fall inside Natura 2000 sites, and for 119 917 km² fall outside (71 %). A total of 47 894 km² (28 %) fall inside CDDA sites, and of 120 509 km² (72 %) outside CDDA sites. Lastly, 4 367 km² (2.6 %) fall inside IBAs, and 164 036 km² (97.4 %) fall outside IBAs.

Beech forests inside protected areas tend to have greater values of HNV likelihood than those outside these areas. This is true for IBAs, and Natura 2000 and CDDA sites (Figure 3.8).

While 56 % of beech forests with higher values (> average + standard deviation) of the HNV likelihood index are included in at least one of the three networks of protected areas, this the case for 43 % of those beech forests with intermediate values (between average – standard deviation and average + standard deviation). This means that approximately 11 608 km² of beech-dominated

Figure 3.8 Average values of HNV likelihood of beech forests, inside and outside the three different networks of protected areas

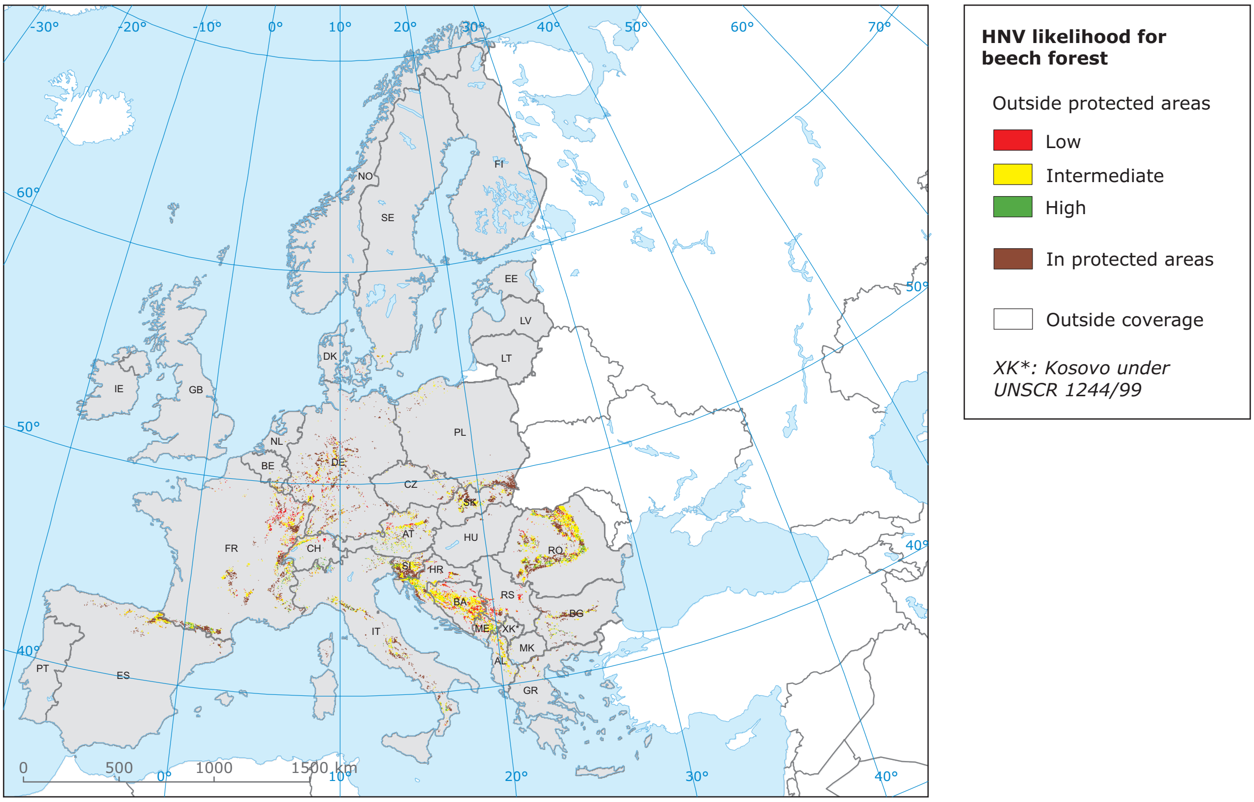


Note: Large black bars represent average plus and minus the standard deviations, while thin bars represent minimum and maximum values.

forests with high HNV likelihood and 64 259 km^2 with intermediate values were outside protected areas. Based on the data and the methodology used in this test, they represent around the 45 % of the total beech forest area (see Map 3.5).

The next steps should include HNV assessments for all forest areas in Europe which are operatively analysed in combination with existing networks of protected areas. This will help assess whether protected areas are protecting hotspots of naturalness, thus reducing the risk of biodiversity loss. The approach proposed is somewhat similar to that one used in the Gap Analysis programme successfully implemented in the United States (see http://gapanalysis.usgs.gov).

Map 3.5 Result of comparison analysis on HNV likelihood for beech forest



3.4 Discussion

In Europe, the definition of the HNV as proposed by IEEP (2007) combines several concepts, rendering the set-up of a monitoring framework rather complex. The IEEP (2007) document's backbone is the extension of the HNV indicator originally developed by Andersen et al. (2003) for farmlands to forest areas. At least five criteria are included in the IEEP (2007) HNV forest definition: (i) the definition of natural/seminatural forests, (ii) the intensity of forest management, (iii) biodiversity, (iv) the presence of European native species, and (v) the presence of species relevant for conservation purposes in Europe.

The approach followed by Forest Europe, UNECE and FAO for assessing forest naturalness is simplified, as it is based on the classification of forest area in three categories: plantations; seminatural (for Forest Europe) or other naturally regenerated forests (for FAO); and natural (for Forest Europe) or primary (for FAO). In Europe, around 87 % of forest areas are seminatural (Forest Europe, 2011). A more detailed classification is needed to identify the different levels of naturalness of those forests labelled as seminatural (or naturally regenerated). This is essential in order to detect the spatial location of temporal changes of forest naturalness in Europe.

The EEA studies resulted in a proposal to separate these very different concepts, and to simplify the possible assessment of HNV forests. The criteria biodiversity, forest management, and presence of species relevant for conservation purposes already have definitions and monitoring frameworks. Most of them (especially biodiversity) are frequently defined following a multicriteria approach through the use of indicators. The criteria natural/seminatural forests, and presence of native species used in IEEP (2007) are more clearly related to the concept of forest naturalness, and thus should be maintained as a basis for the definition of HNV forests.

The monitoring of HNV forest areas should be based on the assessment of the **naturalness** of forest habitats themselves (Winter, 2012). Following this approach, a HNV forest can be defined as *the area covered by forests or other wooded lands having a current ecosystem state similar to its natural state*. The conservation relevance and status should be monitored separately. This definition clearly identifies a specific methodology for its assessment, but also requires the definition of other concepts.

Forests and other wooded land are subject to the well-consolidated reference definition from Vidal et al. (2008) that is currently in use in most NFIs in Europe (Tomppo et al., 2011). Unfortunately, the scientific community has still not agreed on a standard methodology to measure the similarity between the current state of an ecosystem and its natural state. In this report, several country studies based on different approaches are reviewed; see Winter (2012) for a state-of-the-art review.

At least three basic lessons have been learned from previous experiences: i) naturalness cannot be measured directly but must be estimated through the use of indicators; ii) naturalness indicators always have to be referred to potential reference benchmarks values typical of a natural state; iii) naturalness should be monitored as a continuous variable ranging between the extremes: between totally artificial (for example, a plantation with exotic species) and totally natural (a pristine or virgin forest).

Reference benchmarks of naturalness indicators should be acquired through the study of natural forests (also defined as untouched, pristine, virgin, or undisturbed by man) or of old-growth forests. However, very few places in Europe are undisturbed by human activity — there has been some kind of management of forests across most of Europe.

The present results support a clearer delineation of HNV forests (in the sense of forest naturalness) in relation to the forest **biodiversity** concept. These two concepts are very much related (loss of biodiversity is mainly attributable to loss of naturalness), and thus they are commonly confused. Frequently, old-growth forests (especially in central Europe) also harbour the highest levels of forest biodiversity (Wirth et al., 2011). But this is not always true for all forest types and biogeographical conditions.

Naturalness is typically a relative approach (actual forest conditions must be compared with potential benchmark values), while biodiversity is an absolute approach. But both have to be monitored through the use of indicators. An indicator for measuring HNV (in the sense of forest naturalness) could thus be the level of biodiversity (as has also been expressed in the HNV farmland indicator), if referred to as a benchmark potential value.

The test carried out for beech forests demonstrated that some pan-European data sets exist for developing a wall-to-wall spatially explicit multicriteria analysis of forest naturalness. The results for beech forests were contrasted against field observations in old-growth forests, demonstrating that some of the tested indicators (at least for the geographical scale used here) have a promising predicting capability for monitoring forest naturalness, and thus for identifying HNV forests.

However, the test also highlighted the complexity of a multicriteria approach based on several indicators. Input layers needed to derive the different indicators used for naturalness assessment are not error-free, and their spatial and thematic accuracy is frequently unknown. Thus a formal analysis of error propagation is almost impossible. The different indicators are discussed in more specific terms below.

The concept of **hemeroby**, originally developed to describe the degree of disturbance to the soil (Jalas, 1955), expresses the level of present and past anthropogenic disturbances. In the study, hemeroby was modelled with a proxy calculated as the distance from urban areas. The variable calculated for beech forests through the ROC validation demonstrated a limited relationship with the presence of old-growth forests. Forests closer to urban areas did not necessarily have more disturbances than those located far from urban areas, at least under the conditions of the specific test.

Another way of expressing hemeroby would be to refer to the level of forest management and the type of silvicultural activities. In the context of the 'Visions of Land Use Transitions in Europe' (VOLANTE) project, maps at pan-European level for forest management systems and forest-harvesting intensity are currently under development, and could be used as a proxy of hemeroby in the analysis (see http://www.volante-project.eu). It is important to underline that the measure of hemeroby cannot replace the naturalness assessment, despite naturalness and hemeroby being highly inversely correlated (Winter, 2012).

Growing stock is theoretically a relevant indicator for assessing forest naturalness, and is one of the most frequently used indicators for defining old-growth forests (Wirth et al., 2011). Unfortunately, the input data available at pan-European level from Gallaun et al. (2010) are limited to a maximum value of 300 m^3ha^{-1}, which, in the case of the evaluation of beech forest naturalness, is probably too low.

Furthermore, this indicator should be used in conjunction with benchmark values related to forest types, site fertility and sylvigenetic phases. Acquiring this information at pan-European level is difficult, although an interesting method based on satellite LiDAR data for correcting the Gallaun et al. (2010) map was presented by Maselli et al. (2014). Hopefully, data from the NFIs for this variable will be available through EFDAC at the JRC in the near future.

Accessibility was selected as a proxy for the degree of forest management. It was assumed that the intensity of forest management and operations is reduced by the increasing slope. However, intensive management is in principle feasible everywhere, and depends mostly on local market characteristics of wood products. Accessibility could also be considered a component of hemeroby: in future applications, a better optimisation of the mathematical relationship between slope, eventually distance to roads, and forest roads, and accessibility should be tested — see the Swiss biodiversity monitoring (http://www.biodiversitymonitoring.ch/en/data/indicators/e/e3.html).

The analysis carried out for the VOLANTE project is based on the same approach. If available, more direct forest management indicators should be considered that would replace or complement accessibility.

Connectivity is considered to be an extremely relevant variable for the delineation of the HNV forest area. The same approach has recently been adopted by Greenpeace for global mapping of intact forests (Thies et al., 2011). The main issue with the use of the connectivity was the very coarse resolution of 25 km^2 of the input layer produced by the JRC. A map of connectivity could be produced, by species (conifer, broadleaved) and for forests in general, down to a spatial resolution of 1 km, on the basis of most recent forest/non-forest maps available in Europe at a resolution of 20 m.

In future, other indicators for assessing the spatial structure of forest areas could also be tested (core area, distance from the borders, patch area, patch shape, etc.).

The **naturalness of tree species compositions** measures the congruency of current forest species composition with potential species composition. Currently, two pan-European species composition layers are available: i) from the JRC (2012a), as a result of the spatial interpolation of the point data from the ICP plots; ii) from EFI-Alterra (Brus et al., 2012), as a combination of several data sets including a database from the NFIs.

Both are available for tree species or tree species groups in Europe, even if for several of these species, the quality of the maps (in terms of user and producer accuracy) is not yet sufficient for an operational use. The maps from EFI-Alterra have a better spatial outlook at the moment — as a result of the interpolation method, the JRC maps are characterised by anomalous clustered values around the ICP plots. A better data set will be made available from NFI data through EFDAC at the JRC. For potential conditions, several maps are available, both for present climate conditions and for future climate change scenarios. We tested data from habitat suitability modelling (JRC, 2012b), EUFORGEN (2012), and the PNV from Bohn et al. (2004). It is important to note that there is a long tradition in vegetation sciences of comparisons between current vegetation and the PNV. The first definition of the PNV dates back to Tüxen (1956). However, in recent years, this concept has been strongly debated (see, for example, Chiarucci et al. (2010)), and should therefore be used with caution. As a result of our tests for beech forests (see Section 3.3.1), we can confirm that naturalness of tree species composition, calculated as the relationship between current and potential conditions, is considered the most relevant and informative direct indicator for assessment of HNV forests.

Testing all the possible combinations and weights of the five different indicators, we found that the best results in predicting the presence/absence of old-growth beech forests were generated by using a model with three of the five original indicators, i.e. excluding hemeroby and growing stock. Unfortunately, we still do not know if this result is attributable to the limited quality of input layers used for calculating the two indicators we excluded, or to the poor relationship between these indicators and the presence/absence of old growth.

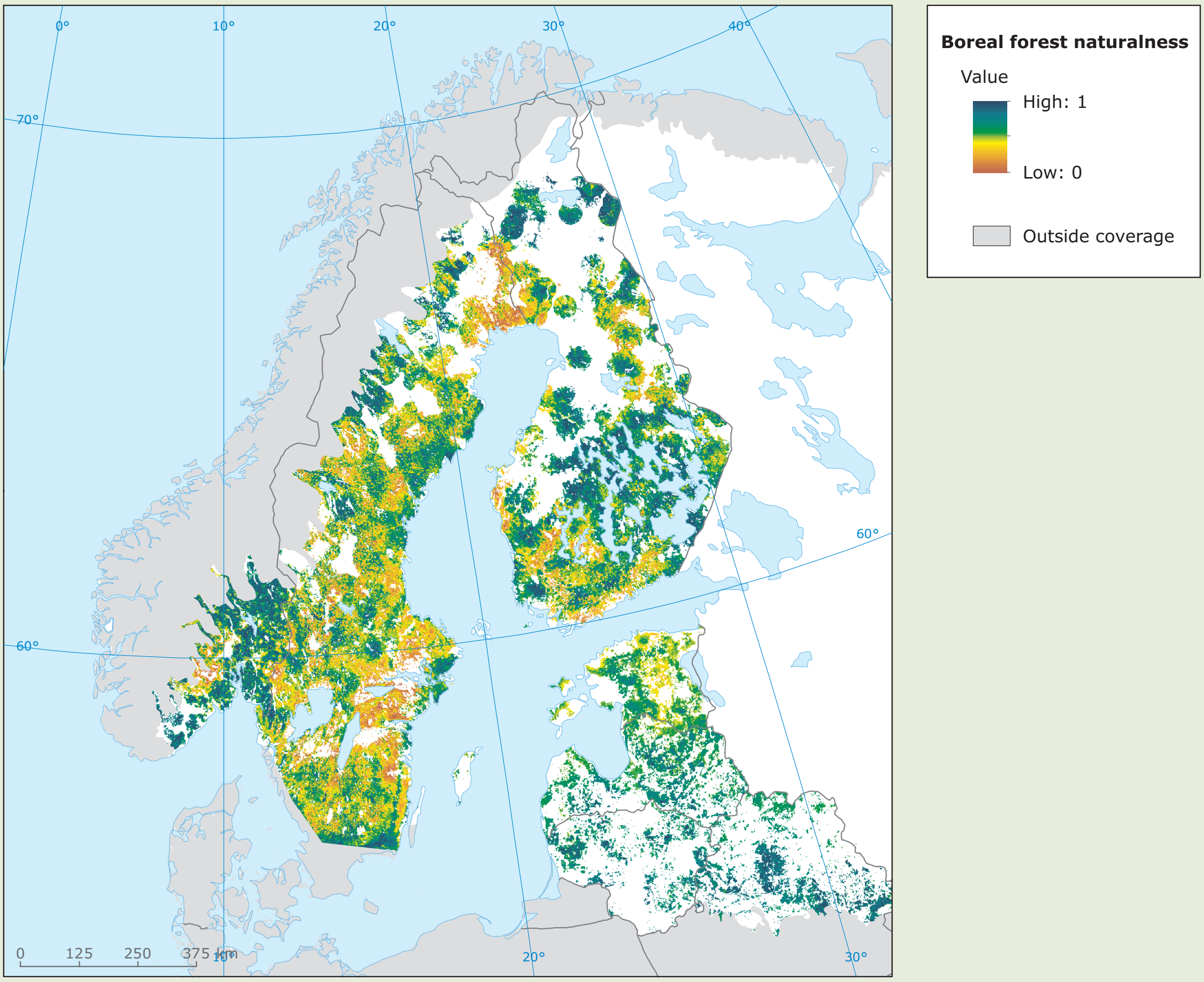
The 2012 study proved useful for simplifying the approach to naturalness assessment, by selecting one indicator at a time. An immediate follow-up involves applying the approach, considering only the naturalness of tree species composition, and expanding the analysis to include the overall forest area instead of only the beech forest area. A first tentative test in this direction has already been carried out for the boreal region (see Box 3.1).

Box 3.1 Naturalness of tree species composition

A simplified version of the methodology for HNV forests, based only on the indicator naturalness of tree species composition, was tentatively tested in the boreal region. The boreal area was defined according to the map of biogeographical regions (see Annex 1 for more information). The three dominant tree species (or tree species groups) of the boreal region, according to the European Forest Type classification (EEA, 2006), were considered: *Picea* spp., *Pinus sylvestris* and *Betula* spp. Their cumulative percent presence for each pixel in the boreal area was calculated on the total of all the tree species (or tree species groups) available in the EFI-Alterra layer.

The analysis was limited to dominant boreal forests, and thus to pixels having a cumulative per cent presence of at least 70 %. The threshold was selected following the methodology presented in Section 2.3 in order to minimise the difference with the forest area reported in Annex 1 of the 2011 *State of Europe's Forests* (Forest Europe, UNECE and FAO, 2011). For each pixel, the per cent of the selected three species was calculated on the basis of the habitat suitability maps available from the JRC (2012b) and the naturalness was calculated on the basis of Eq. 1. The first draft result is shown in Map 3.6.

Map 3.6 Naturalness of tree species in boreal-dominated forests



Note: This is a first, tentative example of possible simplification of the methodology, and as such, is not intended to be a conclusive analysis of naturalness of boreal forests.

4 Conclusions and next steps

This first contribution for developing the HNV forest concept and a methodology for its spatial assessment at European level resulted in an improved definition of HNV forests and a better understanding of its relationship to related concepts such as biodiversity and naturalness.

From the time of the EU 2020 Biodiversity Strategy, and even from the CMEF (2006), there was clearly a need for a forest naturalness indicator to describe the ecological state of forest ecosystems, and to evaluate the management of biodiversity maintenance and conservation at European level, while considering forest areas regardless of their management and protection status.

There is currently very little information on the real relationship between the areas in Europe likely to have high naturalness values in forests, and their inclusion/exclusion in protected forest areas such as Natura 2000/Emerald, IBA, IPA, or CDDA networks. The UNECE/FAO and Forest Europe process on criteria and indicators of sustainable forest management (Forest Europe, UNECE and FAO, 2011) reports on the state of forests in Europe every 4 years, and includes a simple naturalness indicator. This information is compiled at country level, and does not provide information on the distribution of naturalness across the EEA region. In many countries, data are generated by the NFIs conducting regular inventorying of forest resources in a dense grid. These data are usually not available at plot level or in aggregated form, and are not presented in a harmonised way across Europe.

A first initiative was launched in 2011 by the EEA to define and develop a forest naturalness indicator expressed as a HNV forest indicator. Countries carried out nine case studies to explore possible methodologies for the operative implementation of HNV forest monitoring. The case studies successfully demonstrated the feasibility of assessing HNV forest areas at European level.

The conclusions are presented below.

- Firstly, it is proposed that HNV forests be defined as the most natural forest areas, i.e. in close to natural conditions. The definition of HNV forests is based on the concept of naturalness in order to avoid confusing it with other indicators based on the concepts of biodiversity, such as HCVFs and BIFs. The assessment of the conservation status of forest areas should be carried out separately, in the framework of a gap analysis protocol. This is a different approach from the definitions, indicators, and methods developed for HNV farmland, which is associated with farmland with high biodiversity. This cannot be directly replicated in forest areas.

- Secondly, forest naturalness should be monitored with a multicriteria approach, adopting indicators that should always refer to benchmark values defined as the reference values typical of natural (pristine, virgin, untouched, undisturbed) forests. Benchmarks should be defined by forest types and biogeographical regions, since indicators may reach different threshold values, depending on the local characteristics of ecological factors (mainly soil characteristics and climate). In future, benchmark values could be expressed for each European forest type on the basis of ecological studies in old-growth and residual pristine forests. Naturalness indicators are partially coincident with indicators selected for monitoring biodiversity, HCVFs or BIFs.

- Thirdly, the optimal calculation of naturalness indicators should be based on country data such as those from the NFIs, in order to be able to calculate HNV forest area with statistically sound estimators. In the near future, harmonised information from the NFIs related to tree species composition, deadwood, structural diversity, and forest management regimes will be fully and freely available for European assessments and for scientific analyses. The European National Forest Inventory Network (ENFIN) is working alongside the European Forest Data Centre at the JRC in Ispra to achieve this.

- Fourthly, since national products developed for the assessment of HNV forests or conterminous concepts (HCVFs or BIFs) are for the moment heterogeneous, their harmonisation appears extremely complicated. For this reason, the evaluation of HNV forests should be carried out at European level and based on standard definitions.

- Lastly, a pan-European HNV forest assessment should be overlaid with the existing networks of protected areas for comparisons and assessments of HNV forest areas within the protected areas — this will allow for possible differentiated forest management and forest planning alternatives.

The study was continued in 2012 and 2013, to further develop the HNV forest area concept and methodology.

The study conducted a wall-to-wall European assessment of HNV forests based on available Europe-wide data sets and following a top-down approach. Several data sets available at pan-European level were explored. The very low accessibility of valuable data was confirmed. Beech forests were selected as the target in this study because of the large number of studies on old-growth and virgin beech forests for validation of the HNV forest analysis. This meany that not all countries were included in this first test. In future applications of the HNV concept for all forest areas, all EEA and collaborating countries will be included.

A multicriteria analysis of five indicators was carried out; indicators were selected according to relevance for assessing HNV forests and availability at European level. The five indicators were naturalness, hemeroby, growing stock, accessibility, and connectivity. A map of the presence/absence of HNV beech forests was produced at European level.

The beech forests study demonstrated that some pan-European data sets exist for developing a wall-to-wall spatially explicit multicriteria analysis of forest naturalness.

The beech forests results were contrasted with field observations in old-growth forests, demonstrating that some of the tested indicators (at least for the geographical scale used in this instance) possess a promising predicting capability for monitoring forest naturalness, and thus for identifying HNV forests. However, the test also highlighted the complexity of a multicriteria approach based on several indicators. The input layers needed to derive the different indicators used for naturalness assessment are not error-free, and their spatial and thematic accuracy is frequently unknown. Therefore, a formal analysis of error propagation is almost impossible.

Based on the results achieved, concluding comments on the different indicators are as follows:

- the multicriteria approach and the use of fuzzy membership functions for calculating indicators referred to benchmark values is interesting and can be easily replicated;

- the aggregation of the indicators led to a first HNV beech forest assessment that was successfully validated through ROC analysis against a geodata set with 136 old-growth forests;

- the ROC analysis was also successfully used for calculating, by Monte Carlo simulations, the weights to be associated to the different indicators.

After testing combinations and weights of the five indicators, we found that the best results for predicting the presence/absence of old-growth beech forests were generated by using a model with three of the five original indicators, i.e. excluding hemeroby and growing stock. An outcome of the 2012 study was the simplification of the approach for naturalness assessment, by selecting one indicator at a time. An immediate follow-up study considered the naturalness of tree species composition only, and expanded the analysis, considering the overall forest area. A first tentative test and map were carried out for the boreal region.

Considerations and next steps

Regarding the selection of indicators, the present study has produced a simplified approach, based mainly on the naturalness indicator. This should be considered a first step in developing a HNV forest-area indicator which can be assessed at European level, with a top-down approach using the limited European data sets available. This approach is considered an acceptable option, as long as the required country data are not available and not harmonised. More indicators will be included in the HNV methodology when country data from forest inventories are available and harmonised. This will present a more nuanced picture of HNV in forests, mirroring the variations in the state and naturalness of forests across different parts of Europe and in the respective biogeographic regions.

Unfortunately, the available geographical pan-European data set for the variables used to calculate the naturalness indicators frequently have limited accuracy. The use of high-resolution layers will improve the outcome; the accuracy should also be improved by using the NFI data set from the EFDAC.

Another approach is the bottom-up one, based on aggregation of country data and information likewise from forest inventories. This option will broaden the choice of indicators for a better description and delineation of HNV forest areas, as with smaller scale indicators. Deadwood is an appropriate indicator to include in the bottom-up approach based on country data, as it is measured in most NFIs. Another option would be indicators included in the definition of HNV farmland: forests associated with high species and habitat diversity, or the presence of species of European conservation concern, or both.

Further validation and evaluation of the presented HNV methodology for Europe needs to be carried out on selected case studies and regions where country-specific forest HNV data can be provided nationally. Such a quality assessment will improve the robustness of the approach, and is essential for future use of the indicator.

This first implementation of the methodology is aimed at developing the methodology, and as such, is not exhaustive: it includes beech forests only, and does not cover all countries. All countries in the EEA region, as well as cooperating countries, will be included in the follow-up work on HNV forest areas in 2013 and 2014. The EMERALD sites will be included in further validations of the HNV forests.

Challenges

One drawback of Europe-wide approaches based on maps with minimum mapping units of 1 km^2 is that only large sites with potential HNV forests are identified. In the current approach based on rather rough maps, small patches of HNV forest areas like small 'untouched' pockets in the production forests, and regions with a high content of such patches spread out in landscape with a mosaic of land uses, are likely not to be recognised. This restricts the use of the maps at national level and provides an argument for using harmonised country data whenever available. Application of high-resolution layer maps for forests, such as the GIO-land forest maps with a resolution of 20 m to 100 m, will help in recognising these pockets of HNV forest areas.

In Europe, a certain type of seminatural forest characterised by extensive traditional land-use forms such as forest grazing, pollarding or coppicing, may have very high biodiversity values as well as many of the desired qualities of HNV forests. In countries like Spain, where such types of wooded land cover large areas, the HNV forest analysis may overlook them, posing a substantial problem. The present approach, being based mainly on naturalness, does not recognise this type of woodland as being atypical; however, these are valuable sites from a biodiversity point of view. Similar examples of high biodiversity richness but low naturalness are artificial forests, which could be very useful from a biodiversity perspective, as is increasingly the case in the Sitka spruce forests. It is important to emphasise that the methodology development is focused on naturalness; many other initiatives have focused on biodiversity. In future, the HNV forest area methodology should include both biodiversity and naturalness evaluations.

Other challenging issues are applicability of the HNV indicator to mixed forests and whether the present HNV forest-area approach would be able to identify 'real' HNV forests, in relation to mature production forest stands established by plantations after a continuity break.

All these elements will be taken into consideration in the next steps, when applying the methodology to other tree species and to forests as a whole.

Annex 1 Meta-information

Input data sets

The annexes contain the data sets used in the analysis and presented in this report. Each data set is accompanied by a short technical description of the source, the characteristics of the data, the accuracy and the pre-elaboration.

1 *Current beech forest distribution (JRC, 2012a)*

Values ranging between 0 and 1 for beech relative presence for each 1 km x 1 km pixel. Obtained with inverse weighted distance (IWD) and nearest neighbour applied to field samples from the Forest Focus database, and subsequently filtered with the pan-European forest/non-forest map of year 2000 rescaled to 1 km grid size. Downloaded from 'Tree species distribution' at http://forest.jrc.ec.europa.eu/activities/climate-change/species-distribution.

2 *Current beech forest distribution (Brus et al., 2012)*

Values ranging between 0 and 1 for beech relative presence for each 1 km x 1 km pixel. Obtained by the ICP-Forest Level-I plot data with the NFI plot data of 18 countries. In areas with NFI plot data, the proportions of the land area covered by the tree species were mapped by kriging. Outside these areas, these proportions were mapped with a multinomial multiple logistic regression model. A soil map, a biogeographical map and bioindicators derived from temperature and precipitation data were used as predictors. Downloaded (after registration) from http://www.efi.int/projects/tree-species-map/register.php.

3 *Habitat suitability for beech forest (JRC, 2012b)*

Values ranging between 0 and 1 for beech habitat suitability for each 1 km x 1 km pixel. Obtained with the random forest (RF) algorithm. Presence/absence records were used to produce a RF regression in order to predict continuous habitat suitability values from absence to presence (Casalegno et al., 2010). The model performance for beech was considered 'good', with $0.60<K<0.80$. The list of input variables used in RF regression and data for download for 'Tree Species Suitability' is at http://forest.jrc.ec.europa.eu/activities/climate-change/species-suitability.

4 *Habitat suitability for beech forest type (JRC, 2012c)*

Same as above but with the use of RF as classifier applied to the European Forest Types system of nomenclature (EEA, 2006). Both the pixels for 'beech' and 'mountain beech' were considered. The model performance for 'beech' was considered 'fair', with 0.30< error <0.45, and 'poor' for 'mountain beech' with 0.55< error <1. The list of input variables used in RF regression and data for download for 'Forest Type Suitability' is at http://forest.jrc.ec.europa.eu/activities/climate-change/forest-type-suitability.

5 *Growing stock volume (Gallaun et al., 2010)*

For the classification, data from the Moderate Resolution Imaging Spectroradiometer (MODIS) were used with field measurement data from the NFIs, for 98 979 locations from 16 countries. The original map, at 500 m, was resampled to 1 000 m by bilinear interpolation.

6 *Artificial surfaces*

The CLC class 1 from CLC 2006 and 2000 for was rasterised with pixels of 100 m. Continuous values were calculated, in the range between 0 and 1 depending on the percentage of presence of class 1 in each 1 km pixel.

7 *Natura 2000*

Same as above on the basis of Natura 2000 data set v. end-2012, downloaded from http://www.eea.europa.eu. SPA-SCI overlaps were not considered.

8 *Nationally designated areas (CDDA)*

The CDDA sites are areas designated under national legislation for the purpose of nature protection, including sites such as national parks and nature reserves. Download from http://www.eea.europa.eu, v.11.

9 *Official country boundaries in vector format*

Same as above on the basis of EUROSTAT NUT data set v.2010, at 1:10 ***million. Downloaded*** from http://epp.eurostat.ec.europa.eu/portal/page/portal/gisco_Geographical_information_maps/popups/references/administrative_units_statistical_units_1.

10 *EUFORGEN beech map*

Same as above; downloaded from http://www.euforgen.org/.

11 *Potential natural vegetation (Bohn et al., 2004)*

Same as above; download from http://www.floraweb.de/vegetation/dnld_eurovegmap.html.

12 *European important bird area*

The map was available from the EEA, with a spatial resolution of 1 km.

13 *Digital Elevation Model*

From GTOPO30; see http://www1.gsi.go.jp/geowww/globalmap-gsi/gtopo30/gtopo30.html.

14 *Biogeographical regions*

Downloaded from http://www.eea.europa.eu, version 2011, Rev. 1. The biogeographical regions data set contains the official delineations used in the Habitats Directive and for the EMERALD Network set up under the Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention).

Additional data sets

Additional data sets might be used in future refinements of the HNV likelihood method, to contribute aspects of biodiversity protection that are not well covered in the first five variables included in this study. Candidates for this are as follows.

Distribution of mammals (IUCN, 2010)

Information of species assessed for the International Union for Conservation of Nature (IUCN) Red List of Threatened Species™. The maps are developed as part of a comprehensive assessment of global biodiversity, in order to highlight taxa threatened with extinction, and thereby promote their conservation. See http://www.iucnredlist.org/technical-documents/spatial-data#mammals.

Important Plant Areas (IPAs) in Europe

Natural or seminatural sites exhibiting exceptional botanical richness and/or supporting an outstanding assemblage of rare, threatened and/or endemic plant species and/or vegetation of high botanic value. In describing IPAs, the word plant encompasses algae, fungi, lichens, liverworts, mosses, and wild vascular plants (Plantlife, 2010).

Map of Riparian areas in Europe

These areas often have high biodiversity values.

Wetland areas

Wetlands are outside the scope of a HNV forest indicator. However, woodland areas in the transitional zone between wetlands and forests may contain characteristics of HNV forest and show aspects important to biodiversity. These areas may be prone to temporary flooding, and they comprise an ecological gradient from very moist to drier sites. This creates a range of varying environmental and microclimatic conditions which may be beneficial to biodiversity. The Ramsar Sites Information Service provides access to information on wetlands designated as internationally important under the Convention on Wetlands (Ramsar, 1971). These wetlands are commonly known as Ramsar Sites. The Ramsar database is a tool for viewing Ramsar Sites across geographic and thematic boundaries, for maintaining an overview of a global network of well over 1 900 internationally important wetlands from 160 countries. See http://ramsar.wetlands.org.

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