

# Indicators of sustainable forest management: application and assessment

Project reporting

Ettore D'Andrea, Fabrizio Ferretti, Livia Zapponi, eds.

## Table of Contents

<b>Indicators of sustainable forest management: a European overview</b> .....	32
Corezzola S., D'Andrea E., Zapponi L.	
<b>The Life project ManFor C.BD. Managing forests for multiple purposes: carbon, biodiversity and socio-economic wellbeing</b> .....	36
Matteucci G.	
<b>Implementing forest management options for the Life project ManFor C.BD.</b>	
<b>Description of the test areas</b> .....	40
Di Salvatore U., Becagli C., Bertini G., Cantiani P., Chiavetta U., Fabbio G., Ferretti F., Kopal M., Kobler A., Kovač M., Kutnar L., Sansone D., Skudnik M., Simončič P.	
<b>Data collection and new indicators of sustainable forest management: the Life project ManFor C.BD</b> .....	52
D'Andrea E., Ferretti F., Matteucci G., Zapponi L.	
<b>Assessing the maintenance of forest resources and their contribution to carbon cycles</b> .....	55
Becagli C., Bertini G., Cammarano M., Cantiani P., Čater M., Chiavetta U., Coletta V., Conforti M., D'Andrea E., Di Salvatore U., Fabbio G., Ferlan M., Ferreira A., Ferretti F., Giovannozzi Sermanni A., Kobler A., Kovač M., Marinšek A., Micali M., Pellicone G., Planinšek Š., Rezaei N., Sicuriello F., Skudnik M., Tonti D.	
<b>Assessing indicators of forest ecosystem health</b> .....	64
Bertolotto P., Calienno L., Conforti M., D'Andrea E., Lo Monaco A., Magnani E., Marinšek A., Micali M., Picchio R., Sicuriello F., Spina R., Venanzi R.	
<b>Assessing indicators of forest productive functions</b> .....	70
D'Andrea E., Di Salvatore U., Ferretti F., Fabbio G.	
<b>Assessing indicators of forest vegetation diversity, stand structure complexity and tree canopy arrangement</b> .....	72
Becagli C., Bertini G., Cantiani P., Chiavetta U., Di Salvatore U., Fabbio G., Ferretti F., Kutnar L., Skudnik M.	
<b>Assessing indicators of deadwood and microhabitats</b> .....	86
Lombardi F., Mali B., Skudnik M.	
<b>Assessing indicators of animal diversity</b> .....	88
Badano D., Balestrieri R., Basile M., Birtele D., Cistrone L., Corezzola S., Costa A., de Groot M., Jurc M., Mason F., Meterc G., Posillico M., Romano A., Zapponi L.	
<b>Applying indicators of vegetation diversity</b> .....	98
Kutnar L., Marinšek A., Eler K.	

**LIFE+ ManFor C.BD (LIFE09 ENV/IT/000078)**

## Indicators of sustainable forest management: a European overview

Corezzola S.<sup>1,2</sup>, D'Andrea E.<sup>1</sup>, Zapponi L.<sup>1,2</sup>

Received 16/03/2016 - Accepted 06/04/2016 - Published online 19/07/2016

Forests play a crucial role in various aspects, providing multiple products, goods and services that contribute both to the economy and to the protection of the environment. Forests, in fact, provide not only timber and non-wood forest products, but also a number of ecological and environmental services such as water regulation and quality, carbon storage, erosion control, nature conservation including protection of biological diversity and recreation (FAO 2015a). The multi-functional role of forests has to be carefully considered when planning their management.

One of the main challenges for forest policies and planning is to conciliate many different interests, finding a balance in order to satisfy the economical requests without compromising the integrity of forests ecological functions (e.g. MacDicken et al. 2015). This idea is at the core of the Sustainable Forest Management (SFM) concept, “an approach that balances environmental, socio-cultural and economic objectives of management in line with the *Forest Principles* adopted at the United Nations Conference on Environment and Development (UNCED<sup>1</sup>) in 1992” (FAO 2003). Sustainable forest management is also defined as “stewardship and use of forests and forest land in a way, and at a rate, that maintains their biodiversity, productivity, generation capacity, vitality, and their potential to fulfill now and in the future, relevant ecological, economic, and social functions at local, national, and global levels [ . . . ]” (MCPFE 1993).

Since the 1990s, SFM has become a highly relevant topic both in forest and environmental policy (Wolfslehner et al. 2005), receiving increasing attention at national and international level. Intergovernmental organizations such as the Food and Agricultural Organization of the United Nations (FAO), the United Nations Economic Commission for Europe (UNECE), and the United Nations Fo-

rum on Forests (UNFF) have been contributing in many ways to promote management, conservation and sustainable development of forestry. For example, since 1948, FAO, in cooperation with its member countries, coordinates the Global Forest Resources Assessments (FRA), which every 5 to 10 years provide comprehensive reporting on forests worldwide (e.g. FAO 2010, FAO 2015a). The last FRA (FAO 2015a) covers 234 countries and territories, underlying how forest resources changed over a twenty-five year period. In particular it reports an encouraging tendency towards a reduction in the rates of deforestation and carbon emissions from forests, and increases in capacity for sustainable forest management, with 99% of the world's forests covered by both policies and legislation supporting SFM at national and subnational level.

Data collecting, reporting and verification are needed to monitor and analyze global forest trends, and are of crucial importance to improve SFM worldwide, which requires empirical evidence that forests are actually well managed and protected (Siry et al. 2005). The demand to measure and monitor the sustainability of forest management has led countries throughout the world to develop a regional and international set of criteria and indicators, which are commonly recognized as appropriate tools for defining, assessing and monitoring progress towards SFM (Van Bueren and Blom 1997, Mendoza and Prabhu 2003, Siry et al. 2005, Wolfslehner et al. 2005). According to Prabhu et al. (1999) a criterion is “a principle or standard that an issue is judged by” and an indicator is defined as “any variable or component of the forest ecosystem used to infer the status of a particular criterion”. In order to directly account criteria, each criterion is defined by a set of quantitative or qualitative indicators, which have to be measured and monitored regularly to determine the effects of forest management interventions, or

<sup>1</sup> CNR-IBAF, National Research Council of Italy, Institute for Agro-environmental and Forest Biology, Monterotondo (RM), Italy

<sup>2</sup> CNBF National Centre for the Study and Conservation of Forest Biodiversity 'Bosco Fontana', Marmirolo (MN), Italy

<sup>1</sup> United Nations Agenda 21: Rio Declaration and Forest Principles. Post-Rio Edition (United Nations, New York, 1993)

non-intervention, over time (Castañeda 2000, FAO 2003). The principle behind the indicator concept is that the characteristics of an easily measured feature convey information about more than itself, summarizing and communicating complex information in a way that can be quickly understood (UNESCO-SCOPE 2006, Biodiversity Indicators Partnership 2011). Thus indicators are of crucial importance because they can be used for a variety of purposes, such as: describe and diagnose a situation; check the effectiveness of management practices, discriminating among alternative policies, forecast future trends (Linser 2001, Failing and Gregory 2003). In this way they support sound decision making and connect policy to science (Biodiversity Indicators Partnership 2011).

Several political initiatives are aimed at developing scientifically rigorous criteria and indicators, such as: the Montreal Process (Anonymous 1995), the International Tropical Timber Organization (ITTO 1992) and the Pan-European (Helsinki) Process (MCPFE 1998). From these events emerged a set of seven globally agreed national level criteria, which serves as the framework for all ongoing international Processes (Castañeda 2000, Wijewardana 2008, European Forest Institute 2013). These criteria cover the following topics: the extent of forest resources, the biological diversity, the forest health and vitality, the productive functions of forest resources, the protective functions of forest resources, the socio-economic functions and the legal, policy and institutional framework. However, since the concept of SFM has to be formulated at different scales, such as global, regional, national and forest management unit, there is no globally agreed set of indicators for those criteria, as indicators need to be adapted to the ecological, economic, social and institutional conditions and needs of each country (Lammerts van Bueren and Blom 1999, Castañeda 2000, Wijewardana 2008). National level indicators may be used by decision-makers to guide countrywide policies, regulations and legislation in support to SFM, while indicators at the forest management unit level favour the adjustment of forest management prescriptions, and thus need to be practical, strongly simplified and adapted to specific user groups and purposes (Castañeda 2000, Similä et al. 2006, FAO 2015b). Sustainable management has therefore to be defined separately for different scales (Mäkelä et al. 2012). For instance forest biodiversity indicators, which generally measure biological or other features of the environment (e.g. Lindenmayer et al. 2000, Smith et al. 2008), may be found at many organization levels including species, stands and landscapes. To mention some examples, indicators at the species level have targeted species or groups

of species (e.g. guilds, number of threatened forest species) (Noss 1999, Lindenmayer et al. 2000); at the stand level, may focus on elements of forest structure important to promote biodiversity, such as volume of deadwood and density of habitat trees (Smith et al. 2008, Kraus and Krumm 2013); at the landscape level they include the spatial pattern of forest cover (MCPFE 2003).

SFM is a process in continual improvement: as understanding of forest ecosystems evolves, and knowledge, data collection procedures and information needs are progressively developing, objectives, strategies for forest management change and indicators should evolve as well. This implies that, given the important role they play, indicators need to be continuously implemented and adjusted over time, and validation and testing of criteria and indicators should continue at all levels (Yamasaki et al. 2002, European Forest Institute 2013).

## The European context

The State of Europe's Forests (FOREST EUROPE 2015) reports that, in Europe, forests cover a surface of 215 million ha, which represents around 33% of the Europe's total land area. Of this surface, more than 30 million ha are under protection with the main objective to conserve biodiversity and landscape. Furthermore, more than 110 million ha are designated for the protection of water, soil, ecosystems, infrastructure, natural resources and other services. Since 1990, forests area has continuously increased, together with the total growing stock, which increased, in the last 25 years, at an annual rate of 1.4%. Tree biomass growth, together with photosynthesis processes, has contributed, between 2005-2015, to remove from the atmosphere about 9% of the net greenhouse gas emissions for the European region and the EU-28. Moreover, over the last 15 years, the extent of protected forest areas has increased by 0.5 million ha/year, enhancing biodiversity and landscape conservation.

On the other hand, the forest sector contributes on average to the 0.8% of GDP (gross domestic product) in the region as a whole. Even if harvesting of wood has decreased since the previous reporting period (up to 2010), Europe's forests are still one of the main roundwood producers in the world. The demand for wood fuel is also increasing at a high rate, especially in some Western European countries. The overall value of marketed roundwood reached more than € 18,000 million in 2010 and is still increasing. The value of marketed non-wood goods, which sometimes provide an important source of income at local level, is also significant (FOREST EUROPE 2015).

Within this framework, a sustainable forest management is crucial to preserve the multi-functional role of European forests. Since the early 1990s, simultaneously with forest-related policy processes worldwide, also in Europe a political process, embodied by the Ministerial Conference on the Protection of Forests in Europe (MCPFE), initiated proposals and actions leading towards SFM. The MCPFE, now known as FOREST EUROPE, is a voluntary and non-institutionalized platform for dialogue and decision making on forest issues at the political level, with the aim to protect and sustainably manage forests (Buszko-Briggs 2010). It involves 46 European countries and the European Community, and around 40 organizations as well as several intergovernmental observer organisations. FOREST EUROPE is based on Ministerial Conferences, Expert Level Meetings (ELM), Round Table Meetings, Workshops and Working Groups (EFI 2013). Up to now, seven Ministerial Conferences have been held. The First MCPFE was held in Strasbourg in 1990, on the initiative of France and Finland. Recognising the need for cross-border protection of forests in Europe, the participants agreed on six resolutions. These "Strasbourg Resolutions" focused particularly on technical and scientific co-operation, in order to provide the necessary data for common measures concerning European forests.

The concept of SFM was further developed in the Second MCPFE that took place in Helsinki in 1993, through political commitments, resolutions and declarations, including policy guidelines for the sustainable management of forests in Europe (MCPFE 1993). The General Declaration and the four "Helsinki Resolutions" promulgated, reflected Europe's approaches to global environmental issues, namely 1) the promotion of SFM, 2) the conservation of biological diversity, 3) strategies regarding the consequences of possible climate change for the forest sector, and 4) increasing co-operation with countries in transition to market economies.

At the Third MCPFE, in Lisbon 1998, the first set of "Pan-European Indicators for Sustainable Forest Management" were politically agreed and adopted. An Advisory Group (AG), representing relevant organisations in Europe, was established to ensure the best use of the existing knowledge on indicators and data collection aspects, and to assist the MCPFE during the improvement process (EFI 2013). The AG consulted with a wide range of experts through a series of four workshops, held between 2001 and 2002. The indicators under all criteria are the result of these workshops and of the work of the AG. In line with the seven key thematic elements of SFM mentioned before, the improved pan-European set consists of six criteria that include 1) the maintenance

and appropriate enhancement of forest resources and their contribution to global carbon cycles, 2) the maintenance of forest ecosystems health and vitality, 3) the maintenance and encouragement of productive functions of forests (wood and non-wood), 4) the maintenance, conservation and appropriate enhancement of biological diversity in forest ecosystems, 5) the maintenance, conservation and appropriate enhancement of protective functions in forest management (notably soil and water) and 6) the maintenance of other socio-economic functions and conditions. The related indicators (35 quantitative and 17 qualitative) were further improved and endorsed by the following MCPFE, in Vienna in 2003. Up to now, the improved pan-European set has been used as a basis for information collection, analysis and reporting in the State of Europe's Forests (MCPFE 2003, MCPFE 2007, FOREST EUROPE 2011, FOREST EUROPE 2015). On January 2015, the Expert Level Meeting (ELM) decided to update the existing set of Pan-European Indicators for SFM, based on the continuous improvement of knowledge and data collection systems. The updated list of indicators is a result of a participatory process and the work of the AG.

## References

- Anonymous 1995 - *Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests. The Montreal Process*. Canadian Forest Service. Hull, Quebec.
- Biodiversity Indicators Partnership 2011 - *Guidance for national biodiversity indicator development and use*. UNEP World Conservation Monitoring Centre, Cambridge, UK. 40 p.
- Buszko-Briggs M. 2010 - *Contribution by the MCPFE to Good Forest Governance in the Pan-European Region*. In Tuomasjukka T. (ed.) *Forest Policy and Economics in Support of Good Governance*. EFI Proceedings N° 58.
- Castañeda F. 2000 - *Criteria and Indicators for Sustainable Forest Management: International Processes, Current Status and The Way Ahead*. FAO Rome Unasylva No. 203 p.
- European Forest Institute 2013 - *Implementing Criteria and Indicators for Sustainable Forest Management in Europe*.
- Failing L., Gregory R. 2003 - *Ten common mistakes in designing biodiversity indicators for forest policy*. *Journal of Environmental Management* 68: 121-132.
- FAO 2003 - *Sustainable forest management and the ecosystem approach: two concept, one goal*. Wilkie M.L., Holmgren P., Castañeda F. *Forest Management Working Papers, Working Paper FM 25*. Forest Resource Development Services, Forest Resources Division. FAO Rome Italy (unpublished).
- FAO 2010 - *Global Forest Resources Assessment 2000*. Rome, Italy.
- FAO 2015a - *Global Forest Resources Assessment 2015: How have the world's forest changed?* Rome, Italy.
- FAO 2015b - *Strengthening Criteria and Indicators (C&I)*

- for Sustainable Forest Management (SFM) in Policy and Practice. Executive Summary. Global FAO C&I Expert Workshop, FAO Rome, Italy 15-16 January, 2015.
- FOREST EUROPE 2011 - *State of Europe's Forests 2011*. Ministerial Conference on the Protection of Forests in Europe, FOREST EUROPE Liaison Unit Oslo.
- FOREST EUROPE 2015 - *State of Europe's Forests 2015*. Ministerial Conference on the Protection of Forests in Europe, FOREST EUROPE Liaison Unit Madrid.
- ITTO 1992 - *Criteria and indicators for the measurement of sustainable tropical forest management*. ITTO Policy Development Series No. 3.
- Kraus D., Krumm F. (eds) 2013 - *Integrative approaches as an opportunity for the conservation of forest biodiversity*. European Forest Institute. 284 p.
- Lammerts van Bueren E.M., Blom E.M. 1997 - *Hierarchical framework for the formulation of sustainable forest management standards*. The Tropenbos Foundation. Backhuys Publishers, The Netherlands. 82 p.
- Lindenmayer D.B., Margules C.R., Botkin D.B. 2000 - *Indicators of biodiversity for ecologically sustainable forest management*. Conservation biology 14(4): 941-950.
- Linser S. 2001 - *Critical Analysis of the Basics for the Assessment of Sustainable Development by Indicators*. Freiburg: SchriftenreiheFreiburgerForstlicheForschung, Band 17.
- MacDicken K.G., Sola P., Hall J.E., Sabogal C., Tadoum M., de Wasseige C. 2015 - *Global progress toward sustainable forest management*. Forest Ecology and Management 352: 47-56.
- Mäkelä A., del Río M., Hynynen J., Hawkins M.J., Reyer C., Soares P., van Oijen M., Tomé M. 2012 - *Using stand-scale forest models for estimating indicators of sustainable forest management*. Forest Ecology and Management 285: 164-178.
- MCPFE 1993 - *Ministerial Conference on Protection of Forests in Europe. Conference Proceedings*. Ministry of Agriculture and Forestry, Helsinki, Finland.
- MCPFE 1998 - *Pan-European criteria and indicators for sustainable forest management*. In: Annex 1 of Resolution L2, Third Ministerial Conference on the Protection of Forests in Europe, 2-4 June 1998, Lisbon, Portugal. MCPFE Liaison Unit, Vienna.
- MCPFE 2003 - *Improved pan-European indicators for sustainable forest management. Fourth Ministerial Conference on the Protection of Forests in Europe*. Ministerial Conference on the Protection of Forests in Europe, Vienna Liaison Unit, Austria.
- MCPFE 2007 - *State of Europe's forests 2007*. The MCPFE Report on Sustainable Forest Management in Europe. Ministerial Conference on the Protection of Forests in Europe, Liaison Unit Warsaw, Poland.
- Mendoza G.A., Prabhu R. 2003 - *Fuzzy methods for assessing criteria and indicators of sustainable forest management*. Ecological Indicators 3: 227-236.
- Noss R.F. 1999 - *Assessing and monitoring forest biodiversity: A suggested framework and indicators*. Forest Ecology and Management 115: 135-146.
- Prabhu R., Colfer C.J.P., Dudley R.G. 1999 - *Guidelines for Developing, Testing and Selecting Criteria and Indicators for Sustainable Forest Management*. Center for International Forestry Research, Jakarta. 186 p.
- Similä M., Kouki J., Mönkkönen M., Sippola A.L., Huhta E. 2006 - *Co-variation and indicators of species diversity: can richness of forest-dwelling species be predicted in northern boreal forests?* Ecological Indicators 6(4): 686-700.
- Siry J.P., Cubbage F.W., Ahmed M.R. 2005 - *Sustainable forest management: global trends and opportunities*. Forest Policy and Economics 7: 551-561.
- Smith G.F., Gittings T., Wilson M., French L., Oxbrough A., O'donoghue S., O'Halloran J., Kelly D.L., Fraser J.G., Mitchell F.J.G., Kelly T., Iremonger S., McKee A.-M., Giller P. 2008 - *Identifying practical indicators of biodiversity for stand-level management of plantation forests*. Biodiversity Conservation 17: 991-1015.
- UNESCO-SCOPE 2006 - *Indicators of sustainability: Reliable tools for decision making*. UNESCO-SCOPE Policy Briefs May 2006 - No.1. UNESCO-SCOPE, Paris.
- Wijewardana D. 2008 - *Criteria and indicators for sustainable forest management: The road travelled and the way ahead*. Ecological Indicator 8: 115-122.
- Wolfslehner B., Vacik H., Lexer M.J. 2005 - *Application of the analytic network process in multi-criteria analysis of sustainable forest management*. Forest Ecology and Management 207(1): 157-170.
- Yamasaki S.H., Kneeshaw D.D., Munson A.D., Dorion F. 2002 - *Bridging boundaries among disciplines and institutions for effective implementation of criteria and indicators*. Forest Chronicle 78 (4): 487-491.

# The Life project ManFor C.BD. Managing forests for multiple purposes: carbon, biodiversity and socio-economic wellbeing

Matteucci G.<sup>1</sup>

Received 16/03/2016- Accepted 06/04/2016 - Published online 19/07/2016

## Introduction

The EU forest sector is characterised by a great diversity of forest types, extent of forest cover, ownership structure and socio-economic conditions. In total, forests and other wooded land occupy roughly 160 million ha or 35% of the EU's land area. Moreover, as a result of afforestation programmes and due to the natural succession of vegetation, forest cover in the EU is increasing. EU forests are situated in very different ecological environments, ranging from boreal to Mediterranean, and from alpine to lowlands. Of all biotopes in Europe, forests are home to the largest number of species on the continent and provide important environmental functions, such as the conservation of biodiversity and the protection of water and soil. Approximately 12% of the forest area is designated as protected forests. Forests contribute to scenic and cultural values, and support other activities, such as recreation, hunting and tourism (COM 2005/84 EU Forest Strategy), as well as to the Natura 2000 biodiversity and environmental policy, in terms of conservation of priority species and habitats, thus providing a sound methods to halting the loss of biodiversity.

Forests are a key component of the global carbon cycle. It has been estimated that of the 480 Gt of carbon emitted by anthropogenic activities (fossil fuel and land-use change related emissions) since the start of industrial revolution, 166 GtC (35%) have been absorbed by forest ecosystems, 124 GtC by oceans (25%), while 190 GtC (40%) remained in the atmosphere, causing the relevant increase of CO<sub>2</sub> concentrations that is the main driver of climate change (House et al. 2002). In this respect, the role of managed forests is crucial as several studies attributed to the forests of the Northern hemisphere, a large part of which is managed, a prominent role in the carbon cycle of the last 20 to 30 years (Schimel et al 2001). Nevertheless, the productivity of man-

aged forests has increased in the last years, both at European (Spiecker et al 2003) and on a global scale (Boisvenue and Running 2006). About the possible causes of increased productivity, a model analysis attributed 100% of the variation in temperate forests to management and land-use history. Forest management has gained further importance for mitigation of climate change following the approval of the Kyoto Protocol (1997, entered into force in 2005), where articles 3.3 (Afforestation – Deforestation - Reforestation) and 3.4 (forest management and other land-use practices) attributes an important role to human-induced land-based activities that can be used to generate carbon credits to compensate emission reductions.

At European level, the adoption of the Improved Pan-European Indicators for Sustainable Forest Management by the Ministerial Conference on the Protection of Forests in Europe (MCPFE 2003) with Criterion 1 “Maintenance and Appropriate Enhancement of Forest Resources and their Contribution to Global Carbon Cycles” related to carbon and Criterion 4 “Maintenance, Conservation and Appropriate Enhancement of Biological Diversity in Forest Ecosystems” to biodiversity and later, the development of the EU Forest Strategy (COM (2005) 84) and of the EU Forest Action Plan (COM (2006) 302) has lead to an improved consideration and awareness on the importance of forests and forest management to maintain and appropriately enhance biodiversity, carbon sequestration, integrity, health and resilience of forest ecosystems at multiple geographical scales (multifunctional role of forests).

Since the early 70s, management applied into public-owned forests, but also in a share of private ownership, shifted from the traditional production-driven goal (timber and fuelwood) to a less intensive practice, due both to the less profitable practice of forestry and to the emerging environmental forest functions. This trend made adult stands getting

<sup>1</sup> CNR-ISAFOM, National Research Council, Institute for Agriculture and Forest Mediterranean Systems, Ercolano (NA), Italy.

older, some of them being no more harvested at the ages of the former rotation or thinned regularly; many forests are therefore exploring, as a matter of fact, a post-cultivation life-cycle. Such a dynamics meets some basic requirements with reference to the pan-European quantitative indicators for SFM (MCPFE 2003): i.e. a more prolonged stand lifespan, higher growing and carbon stocks in the standing trees and in the forest soil (1.2, 1.4), a less disturbed functioning of forest ecosystems and the triggering of semi-natural evolutive patterns as for structural compositional diversities and deadwood enrichment (1.3, 4.1, 4.3, 4.5). In the medium run, it is to be ascertained if this pattern will get less sustainable, because this sole option will be widespread on large forest areas grouped together and aged likewise. It means that scenarios of large-scale uniformity are becoming foreseeable, this implying a loss of biological diversity at all types (compositional, structural, functional) and scales (stand, ecosystem, landscape), independently of locally prevailing functions. The same basic requirements of “health and vitality” of forest ecosystems, addressing important roles as carbon sequestration rate and stocking ability, could be threatened by the suspension of forest management. At present, the monitored rates of regular mortality and inter-tree competition are often higher than in the past; the current mass growth could be therefore reduced and the amount of deadwood lying on the forest floor is getting thicker. The risk of forest fires is being increased into sensitive environments and the occurrence of severe stresses from pest outbreaks or storm damages may become, in a future perspective, the main pressure acting dramatically on over-mature stands. Furthermore, the regeneration patterns are not completely clear. Since the 90s, the protective (e.g. Natura 2000, Special Protection Zones, nature reserves) and carbon sequestration function of managed forests became more and more important. Hence, forest managers, forest owners, public authorities are requested to set up management plans that consider the multifunctional role of forests, taking into proper consideration the new emerging needs in medium- to long-term perspectives.

The awareness that new criteria of forest management are needed, is anyway far to be reached at technical and much more at stakeholders’ and public opinion level. Furthermore, National and Regional forest regulations are generally rather conservative, it is not simple to change them in the short time without a targeted action and this shortcoming may limit the concrete fulfilment of all the basic Sustainable Forest Management (SFM) requirements. This diffused condition and the current lack of new options besides the traditional management,

now out-of-date as for the preferential criterion of wood production, call for the dissemination of targeted silvicultural systems and practices better fitting the balance between forest production, forest conservation, maintenance and enhancement of biological diversity and carbon stocking rate. At the same time, an enhanced information flow has to be established between stakeholders and ongoing regulatory activity has to be flexible enough to acknowledge and incorporate the outcomes of the applied management and the feedback from monitoring activity.

Practically speaking, all European forests can be considered as managed. Also the European forest area that is designated as protected became so after an act of law or similar enforcement that can be considered as a “management” decision. Historically, forests have fulfilled manifold human needs, from wood production to hunting places, up to areas for recreation, protection of the environment, provision of “non-material” services (biodiversity, landscape, carbon sequestration) in the recent decades. Hence, the objectives of forest management have become more and more complex and it is needed to extend management criteria to consider new issues. In the project, after a thorough analysis of current situation, traditional and new management options were applied in test areas and their outcome was followed by detailed surveys, targeting forest structure, ecosystem diversity, ecological connectivity between landscape and forest patches and carbon-related parameters. The design of management options has followed the consultation of local and national stakeholders for forest policy, ensuring that the proposed option had considered at the same time the local and the emerging needs in forest management.

Several indicators have been proposed to assess Sustainable Forest Management. At European level, the 35 quantitative indicators subdivided in six criteria developed by the MCPFE are well known. However, detailed information on those indicators is generally lacking and their collection is currently connected to reporting to international bodies such as Food and Agriculture Organisation. Furthermore, some of the indicators are of a basic character while processes in forest ecosystems are generally complex. Hence there is the need to collect data on SFM indicators and to relate them to specific forest management practices. During the project, indicators were assessed into practice, connecting the more basic ones, available from large-scale inventories, to other, process-oriented, indicators. New indicators were developed and tested, coupling of inventory, monitoring and research approaches (e.g. carbon stocks and carbon fluxes, assessment of various aspects of diversity, connection with forest

intensive monitoring and research sites). For one of the first times, local managers, forest services and expert from research and technical institute worked together for an in-depth analysis of SFM indicators.

The project has been implemented in two countries along transects (from North to South in Italy, from West to East between Italy and Slovenia) on target species and ecosystems (beech, fir, spruce, other managed forests) of relevance to the European context. Furthermore almost all project's areas were included or were completely Natura 2000 sites. This has provided the opportunity to consider the peculiar objectives of management in Natura 2000 sites into the management options that were designed and applied in the test areas. Important knowledge on multipurpose-oriented management, with specific consideration of biodiversity conservation was gathered. The transect approach has allowed also to address the response of ecosystems of the same species to environmental gradient and to assess how SFM indicators may assume different importance and/or values along the investigated transect.

The project has connected "medium to large" scale forest management (in test areas) to the surrounding landscape to intensive forest monitoring (ICP-Forests level 2 sites nearby, on same target species) and intensive experimental sites (research institutes, permanent forest plots, etc.). In this way, a "network" of test areas and experimental sites has been created that can be used, in the future for more in-depth investigation of processes in forest ecosystems.

## Objectives

The project aimed at testing and verifying in the field the effectiveness of forest management options in meeting multiple objectives (production, protection, biodiversity, etc.), providing data, guidance and indications of best-practice.

Data related to the main Pan-European indicators for Sustainable Forest Management adopted by the Ministerial Conference on Protection of Forests in Europe (MCPFE) in 2003 was collected, with a particular emphasis on those indicators related to carbon cycle/sequestration and biodiversity (Criterion 1 and 4 of the indicators' list). Additional indicators were also developed and tested (e.g. carbon sequestration and fluxes, number of species under different management systems, etc.).

The project addressed these issues in different areas, from production to protected forests, including Natura 2000 sites and priority habitats and species.

In the selected areas, owned by State, Regions or other public bodies, and regularly managed and/

or monitored, the project evaluated the traditional management practices and designed, implemented, evaluated and compared new management practices at the same forests. Test areas included also no-managed and "undisturbed" forests to provide terms of comparison.

The demonstration-extension character of the project has been relevant and focused on providing information on forest management, forest inventories and landscape patterns to local, regional and national communities and in setting-up demonstration areas for forest management and forest inventories.

The objectives of the project can be summarized as follows:

**Objective 1.** Get, analyse and disseminate data and policy relevant information to document the impact of different forest management options on carbon cycling and biodiversity of selected forest ecosystems along a North-South transect in Italy and an East-West transect between Italy and Slovenia.

**Objective 2.** Collect, compare and disseminate updated data related to the Pan-European indicators for Sustainable Forest Management, with a particular emphasis on those indicators related to carbon cycle/sequestration and biodiversity.

**Objective 3.** Define, test and evaluate additional quantitative indicators related to forest management in order to fulfil the needs of International Conventions and European Action Plans (UNFCCC, UNCBD, EU Forest Action Plan, Halting the loss of biodiversity by 2010 – and beyond, etc.).

**Objective 4.** Evaluate carbon sequestration, structural features and biodiversity of managed forests at the forest patch and landscape scales, taking into account the ecological connectivity, the ecosystem fragmentation and the interactions with the man-made component.

**Objective 5.** Provide a list of "good practices" on forest management options suited for conserving and enhancing carbon stocks, increase carbon sequestration, protect and possibly enhance biodiversity and improve diversity at forest patch and landscape scales and ecosystems' connectivity.

**Objective 6.** Inform the communities concerned at different levels on the objectives, results and the long-term perspective of forest management by implementing large-sized demonstration plots inside the test areas.

## Actions related to Sustainable Forest Management Indicators

**Action ForC** - Assessment of indicators related to carbon cycle of managed forests. This action was particularly devoted to measure how forest management can influence carbon cycling of forests. The



different silvicultural practice applied in Action IMP (implementation of forest management options in the test areas) were compared in terms of their effect on the indicators related to carbon in forest ecosystems. Methods ranged from the classic forest inventory approach (structure, stocks, increment) for both biomass and soil compartments to carbon fluxes using mobile systems and soil cuvettes.

**Action ForBD** - Assessment of indicators related to forest biodiversity. Biodiversity was assessed for its different aspects and scales: structural diversity (both at forest patch and at landscape scale), plant and faunal diversity and deadwood. Many of the test areas are within Natura 2000 sites and also priority habitats (App.I Habitats Directive), where the conservation of diversity may have priority with respect to other objectives of forest management. Among the selected vertebrate and invertebrate taxa selected to be monitored there were several species (community importance or priority species, Appendix I Bird Directive, App. II Habitats Directive). Assessed indicators ranged from some of those listed under Criterion 4 of Sustainable Forest Management in Europe to more specific and new ones.

**Action ECo** - Ecological connectivity, landscape patterns and representativeness of test areas: This Action used remote sensing techniques and mapping tools to assess the landscape patterns and the ecological connectivity of the test areas with the neighbouring ecosystems/landscape. Action Eco

was performed before implementing the management operations, to verify the ex-ante situation. These results were crucial to assess whether the test areas could be considered as representative of a larger area. In the second half of the project, the Action dealt with the evaluation of potential remote-sensing indexes related to Sustainable Forest Management indicators such those connected to carbon stocks/sequestration and structural biodiversity and checked how the management operations influenced ecological connectivity.

## References

- MCPFE 2003 - *Improved pan-European indicators for sustainable forest management*. Fourth Ministerial Conference on the Protection of Forests in Europe. Ministerial Conference on the Protection of Forests in Europe, Vienna Liaison Unit, Austria.
- Boisvenue C. & Running S.W., 2006 - *Impacts of climate change on natural forest productivity - evidence since the middle of the 20th century*. *Global Change Biology* 12: 862- 888.
- House J. I., Colin Prentice I., Le Quéré C. 2002 - *Maximum impacts of future reforestation or deforestation on atmospheric CO<sub>2</sub>*. *Global Change Biology* 8: 1047- 1052.
- Schimel D.S., House J.I., Hibbard K.A. et al. 2001 - *Recent patterns and mechanisms of carbon exchange by terrestrial ecosystems*. *Nature* 414: 169–172.
- Spiecker H. 2003 - *Silvicultural management in maintaining biodiversity and resistance of forests in Europe-temperate zone*. *Journal of Environmental Management* 67: 55–65.

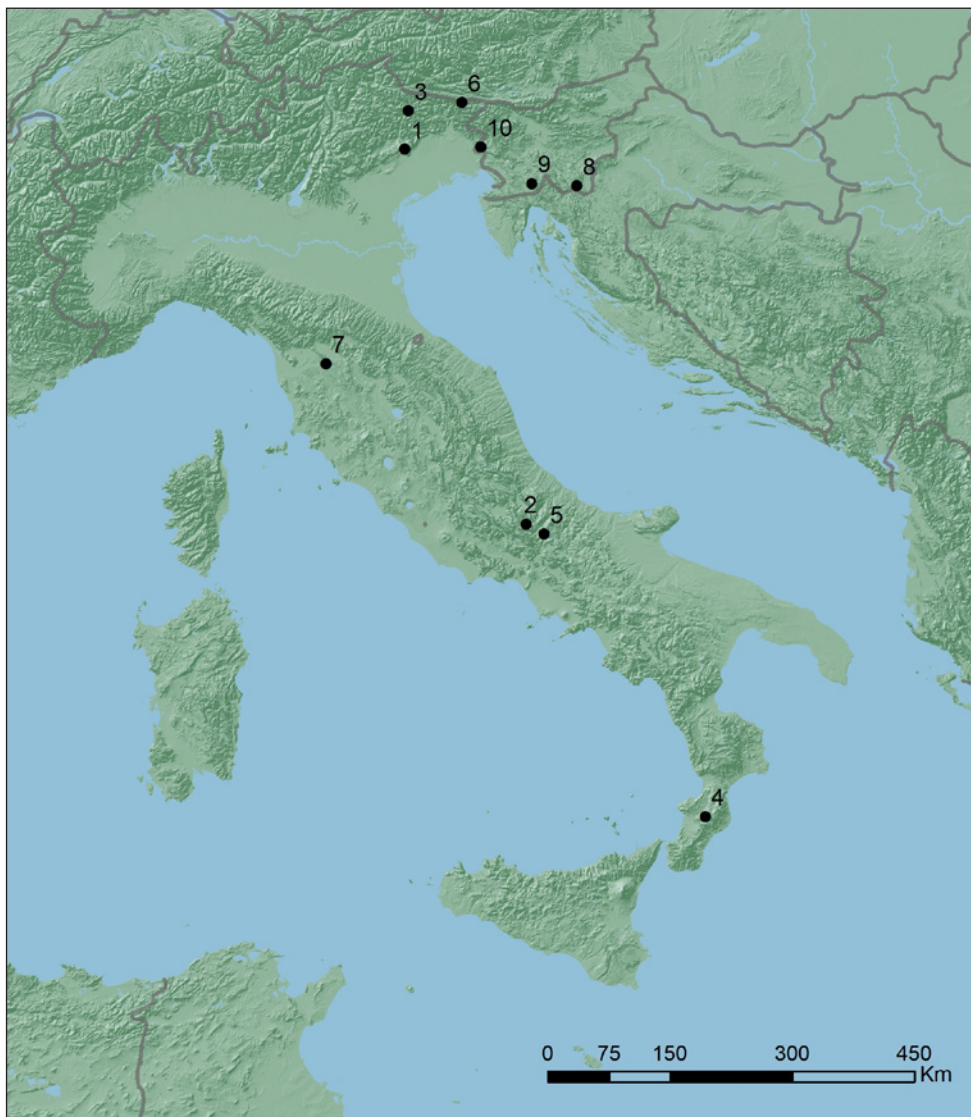
## Implementing forest management options for the Life project ManFor C.BD. Description of the test areas

Di Salvatore U.<sup>1</sup>, Becagli C.<sup>1</sup>, Bertini G.<sup>1</sup>, Cantiani P.<sup>1</sup>, Chiavetta U.<sup>1</sup>, Fabbio G.<sup>1</sup>, Ferretti F.<sup>1</sup>, Kobal M.<sup>2</sup>, Kobler A.<sup>3</sup>, Kovač M.<sup>3</sup>, Kutnar L.<sup>2</sup>, Sansone D.<sup>1</sup>, Skudnik M.<sup>3</sup>, Simončič P.<sup>2</sup>

Received 16/03/2016- Accepted 06/04/2016 - Published online 19/07/2016

Manfor C.BD. project carried out its activities in 7 Italian and 3 Slovenian forests (Fig. 1) where different management options were applied. Public forests managed by public bodies were selected to ensure a monitoring of the results in the future.

A brief description of the study sites and management options are reported by Di Salvatore et al. (2016). In Slovenian sites three similar management options were performed consisting in 100%, 50% and 0% removal of standing trees.



**Figure 1** - Location of the study sites: 1. Cansiglio, 2. Chiarano Sparvera, 3. Lorenzago di Cadore, 4. Mongiana, 5. Montedimezzo-Pennataro, 6. Tarvisio, 7. Vallombrosa, 8. Kočevski Rog, 9. Snežnik, 10. Trnovo.

<sup>1</sup> Consiglio per la ricerca in agricoltura e l'analisi dell'economia agraria, Forestry Research Centre (CREA-SEL), Arezzo, Italy

<sup>2</sup> Department of Forest Ecology, Slovenian Forestry Institute, Ljubljana, Slovenia

<sup>3</sup> Department of Forest and Landscape Planning and Monitoring, Slovenian Forestry Institute, Ljubljana, Slovenia

## Site 1 – Cansiglio (It)

### *Site description*

The area is located in the Veneto Region, in Province of Belluno (at the border with the Province of Treviso).

The management is directly carried out by the National Forest Service of Italy. It is included in the Natural Biogenetic Reserve Pian Parrocchia-Campo di Mezzo (established in 1977).

The total area is 667 ha and the dominant species is beech (*Fagus sylvatica*). The main management type is high forest treated with shelterwood cuttings. Generally 700 to 1000 m<sup>3</sup> of wood are extracted per intervention, over 10 to 15 ha.

The forest is listed as Special Protection Zone (ZPS, 79/409/CEE) and as Sites of Community Importance (SIC, 92/43/CEE). Since 1996, the forest is also included in the Italian network of the forest ecosystem monitoring (CONECOFOR), part of the of the UN/ECE International Cooperative Programme of Forests (ICP Forests, <http://www.icpforest.org>) that, in 2009-2010, was monitored under LIFE+ FutMon (<http://www.futmon.org>).

Total area of Forest Management Unit (FMU) is 35 ha. Altitude within FMU ranges from 1100 m to 1200 m a.s.l.

The designated site lies in a beech high forest compartment aged 120 to 145 years. The forest has a long tradition of forest management: basic rules applied are moderate thinnings from below or mixed, repeated every 20 years, while stand regeneration is by group shelterwood system. Currently, the age of final cutting is being shifted to a not-definite (at now) stand age, matching the emerging recreational, landscape and mitigation functions. Site parameters (elevation, position, soil, rainfall amount and pattern) are optimal for beech growth and such conditions allow the prolongation of standing crop permanence time (rotation length).

### *Description of the traditional silvicultural system*

The traditional system has been optimal when framed into the classical rotation up to the age of 120-140 years (Muzzi 1953, Hoffman 1967, Bessega 2007). Current shift well-addresses the emerging functions but no updating of silvicultural techniques has been proposed to face up to longer rotations. The achievement of older stand ages implies to maintain as long as possible the current sequestration ability and higher growing stocks, as well. Furthermore, the present homogeneous structure of cultivated beech forests clashes with structural diversity connected to the landscape and functional values of mature forest stands.

### *The innovative criteria applied*

The demonstrative/innovative criterion con-

sisted of the identification of a not-fixed number of scattered, well-shaped trees (usually in the predominant-dominant social classes) and crown thinning of neighbouring competitors in order to promote the future growth ability of selected trees at crown, stem and root level. These will be the main key-specimen able to reach the final, overmature stages and to regenerate the forest. The resulting harvested wood amount is not far from that extracted by traditional thinning, but its spatial arrangement is quite diverse on the ground and at crown level. Shape, size and distribution of canopy gaps is also different between the traditional and new practice. The remaining standing crop is fully maintained and will produce differentiation in crown layer, stem distribution and size. Mortality of dominated or defective trees will promote the establishment of snags and lying deadwood, at present understocked. A higher complexity of stand structure and habitats may be reached through consistent practices, and support the diverse, concurrent demands currently addressed to forest management. The trial compares traditional and innovative technique, plus the no-intervention or delayed-intervention thesis that, in the context of beech high forests, has sound reasons to be tested because of its wide application in similar conditions. In this forest, an additional “ageing patch” has also been planned.

In addition, a further area has been planned where implement an “ageing patch” literally from french “îlot de sénescence”. It consists of an area of a few hectares where trees are left to an indefinite ageing, up to their death and decay. Part of living stems were girdled to create standing dead trees or felled and left on the ground to establish microhabitats, niches and corridors for saproxylic insects and micro-fauna.

## Site 2 – Chiarano Sparvera (It)

### *Site description*

The area is located in the Abruzzi Region, province of L'Aquila in a Regional Forest, included in the external protection zone of the National Park of Abruzzo-Lazio-Molise and partially in Natura 2000 sites.

The total area is 766 ha and the main forest species is beech (95%).

The main historical management type is coppice with standards. The forest area is now under conversion to high forest. In the last 20 years, the treatments were aimed at converting coppice to high forest and at thinnings to increase structural diversity (also under LIFE NAT/IT/006244 and LIFE04 NAT/IT/00190). The selected stand is not listed as Site of Community Importance (SIC) nor as Special Protection Zone (ZPS) of Natura 2000 network.

Total area of Forest Management Unit is roughly 30 ha, the area consist of 2 parts separated by a stripe of meadow and rocks. Altitude within FMU ranges from 1700 m to 1800 m a.s.l.

The site lies in a beech forest located at the upper tree vegetation layer in the Central Apennines and managed under the coppice system up to mid 19th century. Following the suspension of fuelwood harvesting, the conversion into high forest has been undertaken on two-thirds of the original coppice cover, whilst the remaining forest is made up of aged coppice structures. The designated area, aged 70, is included into a wide compartment under conversion. The practice of coppice conversion into high forest consists of low to mixed thinnings of the transitory crop, repeated every 20-30 years, usually performed the first time a few years after the end of former rotation and up to the age of regeneration from seed. This step closes the conversion stage and opens the high forest cycle. The above-mentioned silvicultural system is applied throughout the Apennines and pre-Alpine area.

#### **Description of the traditional silvicultural system**

The traditional system works well if site-index is high enough (as in the case), but the resulting structures are very simplified because of mass selection operated by thinning system applied all over the conversion cycle (La Marca 1980). Stands are usually one-storied, show a limited dbh range and an homogeneous distribution of trees and crown volumes.

#### **The innovative criteria applied**

The demonstrative/innovative criteria applied consisted of the preliminary choice of a number of 40-80 well-shaped phenotypes per hectare (stem form and crown development are the relevant attributes) and cutting of all surrounding competitors. Intercropping trees are being fully released or removed only along hauling courses. In this way, the overall stand structure is being moved both at stem and crown level. The high tree density of intercropped stand will promote regular mortality and deadwood enrichment; the establishments of further habitats and related niches will be favoured. The trial compares the traditional technique and two innovative theses different as for the selected tree number (40-80) per unit area.

### **Site 3 – Lorenzago di Cadore (It)**

#### **Site description**

The area is located in the territory of the town of Lorenzago di Cadore, province of Belluno and the forest is owned by the village of Lorenzago di Cadore

The total area is 1100 ha. It is bordering Friuli Venezia Giulia Region. The climate is of Mesalpic

type and the altitudinal range is 800 – 1800 m a.s.l.

According to altitude, the forest types are different:

fir (*Abies alba*) forests of carbonatic and siliceous soils (800 – 1300 m);

secondary montane (*Picea abies*) spruce forests (1000 – 1350 m);

spruce forests on carbonatic and siliceous soils (1300 – 1800 m)

The main management type applied is selection cuttings (from single-tree to small groups) and natural regeneration is present in all treatment variants. Annual cuttings: 1660 m<sup>3</sup> (26% of annual increment). The Lorenzago di Cadore area is included in one of the largest Special Protection Zone of the Alps (ZPS IT3230089 “Dolomiti di Cadore and Comelico”) and contains two Sites of Community.

Total area of Forest Management Unit is 25 ha. Altitude within FMU ranges from 925 m to 1220 m a.s.l.

The site lies in a mixed, uneven-aged coniferous forest (silver fir 51%, Norway spruce 46%, European larch 2%, beech 1%) traditionally managed according to the selection system. Every n years the practice includes the contemporary: (i) harvesting of mature trees; (ii) thinning in the intermediate storey; (iii) progressive side cuttings around the already-established regeneration patches to promote their successful growth; (iv) felling of defective stems and withering trees throughout. The less-intensive harvesting over the last period has promoted the increase of growing stock over the threshold usual to the uneven-aged type. This results in a less-balanced distribution of mature and intermediate age classes (i.e. large and medium sized trees), currently prevailing on young classes and the regeneration layer.

#### **Description of the traditional silvicultural system**

Mature trees and groups of dense intermediate-sized trees, determine growing stock exceeding regular stocking. Such condition raises shading, affecting survival and growth of the established regeneration and preventing the establishment of new regeneration patches. The hauling system with horses used in the past allowed the frequent harvesting of scattered mature trees; the use of tractors nowadays makes harvest feasible, but needs to concentrate fellings on the ground somehow (Bortoluzzi 2002).

#### **The innovative criteria applied**

The contemporary harvesting of a few mature trees and thinning of intermediate-sized trees all of them being arranged into small groups, make possible a minimum degree of mechanized harvesting. Such demonstrative/innovative practice has been implemented by the opening of strip clear-cuttings 60 m long (1½ top height) and 20 m wide (½ top

height). This practice contributes to a more balanced equilibrium of the storied structure, triggering regeneration establishment (canopy opening) and allowing to concentrate log harvesting along each strip. These “light thinnings” are NW-SE oriented along the direction of maximum slope. Broadleaved trees and young regeneration on the strips are being released. Cutting as usual gets strips connected. Beech regeneration (eradicated in the past because not valuable as compared with fir and spruce timber), is always favoured to enhance tree specific diversity.

#### Site 4 – Mongiana (It)

##### Site description

The area is located in the Calabria Region, Province of Vibo Valentia. The management is directly carried on by the National Forest Service of Italy (CFS).

The selected forest area is included in the Marchesale Biogenetic Reserve, Natura 2000 sites

The total area is 1257 ha and the altitudinal range is 750 ÷ 1170 m (a.s.l.)

The forest types are beech managed as high forest and chestnut (*Castanea sativa*) stands managed as coppice (a number of stands are aged coppices. There is a small fraction of mixed beech-fir high forest (5%). From 2000 to 2009, silvicultural intervention were implemented over 108 ha.

Total area of Forest Management Unit is roughly 30 ha. Altitude within FMU ranges from 1000 m to 1100 m a.s.l.

The site lies in a beech high forest originated from regeneration following the final cutting by the shelterwood system or clear-cut or clear-cut with reserves, performed at mid 19th century close the end of 2nd World War. The designated compartment is aged about 70. Its location in the upper part of the mountain system is typical of beech forests in Southern Apennines. The interception of fogs, wet winds and rain originated on the sea makes the physical environment wet enough all over the year. As for stand structure, older trees, scattered or grouped along streams, are remnants of previous cycle; tree density is variable and small patches of silver fir consisting of mother trees and their regeneration cohorts, are present in a few sectors of the compartment.

##### Description of the traditional silvicultural system

The traditional system made up of periodical low thinnings is rather conservative and only occasionally opens the canopy. It makes, as already stated for other beech forests, the stand structure homogeneous, besides its former, natural discrepancy (CFS – UTB Mongiana 2011, Mercurio e Spampinato 2006)

#### The innovative criteria applied

The demonstrative/innovative criterion consisted of the identification of 45-50 trees per hectare i.e. “the candidate trees” and removal of direct competitors. Also couples of neighbouring trees have been selected at the purpose. No thinning has been applied in the space between candidates or where groups of older trees have naturally spaced the structure. Silver fir patches have been set free all around from beech crown cover. The applied criterion and the aim of practice is similar to that applied at the Cansiglio forest. The stand age is about one-half here and that is why a predetermined number of trees has been fixed. The thesis of delaying any intervention is also addressed here because of the young age of standing crop and of the variable stand texture made of different tree densities. Traditional and innovative technique, plus the delayed-intervention are being compared in Marchesale forest.

#### Site 5 – Montedimezzo-Pennataro (It)

##### Site description

The area is located in the Molise Region, Province of Isernia, and it is included in the Montedimezzo Natural State Reserve, established 1971; MAB-UNESCO Biosphere Reserve; Natura 2000 SIC and ZPS sites.

The total area is ~400 ha and its altitudinal range is 900 - 1300 m (a.s.l.)

The forest type is: Turkey oak (*Quercus cerris*) pure or mixed stands (lower elevation) and beech forest, generally mono-layered (higher elevation). The main management type is high forest.

The future management plan includes measures especially designed for experimental and educational purposes, in four separate units: i) coppice: thinning and small cuttings; ii) high forest above coppice: natural evolution; iii) monoplane high forest: interventions only on battered old or sick trees, control of the regeneration, experimental plantation of yew (*Taxus baccata*); iv) biplane-multiplane high forest: small cuttings inside 5 ha management units with the formation of gaps not exceeding 200-300 m<sup>2</sup> experimental plant of yew.

Total area of Forest Management Unit is roughly 30 ha. Altitude within FMU ranges from 900 m to 1000 m a.s.l.

The experimental area has been settled in a Turkey oak forest. Other complementary broadleaves (maples, hornbeam, beech, other minor spp.) are scattered or grouped within the main oak layer. The terrain is not homogeneous as for slope and presence of large rocky outcrops which make the forest less dense. Remnants of grazed areas under forest cover are still perceptible with light canopies

and large-sized, open-grown trees. Stand structure, generally dense, is anyway irregular per patches depending on tree size and arrangement of standing structure. Standing and lying dead trees are present. Two are the main stand ages: young and overgrown forest, originated from the coppice system applied in the past and from the management under the high forest system, as well.

The prevalent age is 60-70 years, but there are also several individuals of turkey oak estimated age between 130-140 years originated as a result of a clear cut with reserves made at the end of 1800.

#### **Description of the traditional silvicultural system**

The traditional system made up of extensive low thinnings performed over the last 40 years and a few seed cuttings in the more aged forest patches - not followed by the removal of seed trees - has as a matter of fact suspended any active forest management at these forest types. This condition, favoured the vegetation of the others than oak sp., the natural evolutive pattern moving towards a mixed forest. The main management type is high forest and aged coppice, partly in conversion to high forest (Garfi and Marchetti 2011, Marchetti 2008).

#### **The innovative criteria applied**

Two pro-active theses are being tested within the experimental area. One aimed at maintaining the structure and composition typical of the "cerreta", i.e. the oak-dominated forest and the historical model of management in these inner areas of Central Apennines. The other thesis is aimed at better addressing natural evolution towards a mixed forest as in the criterion at now prevailing under the extensive management applied. The option one is aimed at maintaining the structure and composition typical of the "cerreta", i.e. the oak-dominated forest and the historical model of management in these inner areas of Central Apennines. The treatment consists of the identification of 60 trees per hectare, i.e. "tree candidate", of Turkey oak among the best individuals. Around the candidate make a selective thinning in order to facilitate the expansion of the crown and thus growth; while individuals of Turkey oak which do not create competition to the candidates are not affected by the cut. Low to crown thinning has been applied in the space between candidates or where groups of older trees have naturally spaced the structure. In the low strata stumps are treated by releasing the dominated shoot, while monocormic individuals will not be affected by the cut to avoid a new growth from the stump. The option two is aimed at better addressing natural evolution towards a mixed forest as in the criterion at now prevailing under the extensive management applied. The treatment consists of the identification of tree candidates

of different species from the turkey oak and making a selective thinning to improve the expansion of the canopy and the full development of the tree. In the low strata stumps are treated by releasing better and dominant shoot, while monocormic individuals will not be affected by the cut to avoid a new growth from the stump. In order to improve the biodiversity, in both options are not affected by the cutting live or dead trees that provide ecological niches (microhabitats) such as cavities, bark pockets, large dead branches, epiphytes, cracks, sap runs, or trunk rot.

### **Site 6 – Tarvisio (It)**

#### **Site description**

The area is located in the Friuli-Venezia Giulia Region, Province of Udine. It is owned by "Fondo Edifici del Culto" of Ministry of Internal Affairs, under direct management by National Forest Service of Italy, Local Office for Biodiversity (UTB) of Tarvisio

The total area is 23'362 ha, 15'152 ha with forests. The altitudinal range is 750÷2750 m (a.s.l.).

There are two main forest types: mixed forests of spruce, beech, pine (8946 ha), subalpine spruce (1263 ha). Main management type is high forest with close-to-nature silviculture. Forests are treated with border-shelterwood or group-shelterwood (Femelschlag) cuttings. Long history of forest management plans (1888) is present in the area. It is a mixed forest of spruce (*Picea abies*) (54%), beech (*Fagus sylvatica*) (29%), silver fir (*Abies alba*) (7%), larch (*Larix decidua*) (5,5%), black pine (*Pinus nigra*) and Scot's pine (*P. sylvestris*) (4,5%). The average growing stock is 280 m<sup>3</sup> ha<sup>-1</sup>, the increment 4.58 m<sup>3</sup> ha<sup>-1</sup> yr<sup>-1</sup>. Annual cuttings are about 30'000 m<sup>3</sup>. The forest is partly included in Special Protection Zones (ZPS, 79/409/CEE) and in Sites of Community Importance (SIC, 92/43/CEE).

Total area of Foret Management Unit is ~30 ha. Altitude within FMU ranges from 1000 m to 1100 m a.s.l.

The designated forest compartment is a Norway spruce and silver fir pole stage originated from regeneration following harvesting of the previous crop. A few other species are scattered within the standing crop, mainly larch and beech. Specific composition in terms of growing stock is as follows: 91% Norway spruce, 2% silver fir, 1% larch, 6% beech and other broadleaves (source: management plan). Stand structure is naturally dense with many standing and lying dead trees under the main storey; living crowns inserted in the upper part only; Scattered broadleaves (mainly beech) reach the main crop layer (co-dominant and dominant trees).

#### **Description of the traditional silvicultural system**

This stage of the life cycle was traditionally sub-

mitted to pre-commercial thinnings to reduce inter-tree competition and manage the release of main crop population. At now, no practices are feasible at this stage because of the high cost of manpower as compared with a quite null revenue (Hoffmann 1971). The only way to implement a sustainable silviculture is the mechanization of thinnings. This practice has been already addressed in neighbouring countries as in Austria, where specific machineries for Alpine forests have been developed and tested successfully.

### ***The innovative criteria applied***

Local forest responsables already experienced a positive result with equipment suited to work into pole stage stands and flexible enough to vary the harvesting pattern on the ground. The resulting tree spacing is not systematic because the release of designated trees may be accounted by a skilled operator. Following the inspection to the test area, the decision was taken to base the demonstrative/innovative trials on the use of above machinery (innovative for our country). The design will compare the thesis of mechanization with two different densities of tree release: (i) a prevailing pre-commercial thinning criterion resulting in a lower density release and with an estimated time of repetition of 40 years; (ii) a more ecologically-based thinning criterion resulting in a higher density release and a shorter time of repetition. Instructions to the operator will include in both cases the full release of canopy trees whenever a dendrological diversity occurs (e.g. broadleaved trees). A supplementary thesis will compare: (a) a manually-implemented thinning in one of patches of compositional diversity randomly occurring throughout the predominant coniferous texture and: (b) a mechanically-implemented (but always oriented to preserve tree diversity) thinning, into an adjacent patch. Both patches will be analytically described *ex ante* to allow the comparison of *ex post* results. Adjacent forest areas characterized by different, both earlier and more adult stages and specific habitats (e.g. wet areas or natural clearings in the tree texture), will be reserved untouched to make possible further comparisons with neighbouring forest environments.

## **Site 7 – Vallombrosa (It)**

### ***Site description***

The area is located in the Toscana Region, Province of Firenze. The management is carried out directly by the National Forest Service of Italy – Local Office for Biodiversity (UTB) of Vallombrosa. The area is included in a Biogenetic reserve of Vallombrosa (Natura 2000), established in 1977

The total area is 1279 ha (forest cover: 99%). The altitudinal range is 450 ÷ 1.450 m (a.s.l.) and the

forest types are: i) pure fir forests (50%); ii) beech in higher zones; iii) calabrian pine (*Pinus laricio*) in lower areas; iv) deciduous forests dominated by chestnut (*Castanea sativa*).

The main management type is high forest. Forest management is carried out following the Management Plan 2006 – 2025 with the main objective of re-naturalise the today simplified forest stands. An area of 100 ha of pure fir is included in the “Silvomuseo” (silvicultural museum), where the traditional management of clear-cut and artificial regeneration is carried on. Average annual cuttings performed directly by UTB - Vallombrosa are 1500 m<sup>3</sup>, mainly of conifers.

The Vallombrosa forest is widely-known because of the age-old management history closely linked to forestry practiced by the local Benedictine Abbey. Current standing crops originate from the natural beech cover, from coppice conversion into high forest at mid eighteenth century as well as from the reforestation of pastures beyond the pristine forest edge.

Physiognomies vary between the more regular structure of the evenaged crops, grown dense and one-layered with reduced, upper-inserted crowns, and the less homogeneous structure of the former coppice crop. This is made of the scattered, grown-up standards and the stems selected on the original stools, now indiscernible from trees originated from seed. This composite heritage is still readable in the current physiognomy of beech forest, aged 110 to 160 at the test area. At Vallombrosa, similarly to other public-owned forests, the age of final cutting is being shifted, it matching the emerging recreational, scenic and mitigation functions. Site parameters (elevation, position, soil, rainfall amount and pattern) are optimal to beech vegetation and such conditions well support the prolongation of stand permanence time.

Total area of Forest Management Unit is roughly 30 ha. Altitude within FMU ranges from 900 m to 1000 m a.s.l.

The study area is positioned within a grown up beech high forest compartment aged 100 to 170 years. The forest of Vallombrosa has a long tradition of forest management up to the early sixties of 1900, in accordance with silvicultural criteria ruling the productive beech forests, i.e. periodical moderate thinnings from below or mixed up to the rotation time, usually occurring at 90-100 years as a function of site-class and according to the “maximum yield rotation”. Stand regeneration was performed by the group shelterwood system. As in other public forests managed by the National Forest Service, the age of final cutting is being shifted since the second half of 1900 to a not-definite (at now) stand age, this match-

ing at best the emerging recreational, landscape and mitigation functions. Site parameters (elevation, position, soil, rainfall amount and pattern) are optimal for beech growth and these conditions allow the prolongation of standing crop permanence time.

#### **Description of the traditional silvicultural system**

The traditional silvicultural system has been optimal when framed into the classical rotation up to the age of 100 years. Even if current shift well-addresses the emerging functions, no updating of silvicultural techniques has been proposed to match longer rotations at now. The achievement of older stand ages implies to maintain as far as possible the status of “health and vitality” both at individual and at stand level, to ensure current sequestration ability and higher growing stocks, as well. It clashes with the present, homogeneous structure, heritage of beech forests previously cultivated for production purposes. The achievement of an individual structural diversity by spotty interventions, seems to be the first, basic step to meet the awaited functional goal (Ciancio 2009).

#### **The innovative criteria applied**

The demonstrative/innovative criterion consisted of the identification of a not-fixed number of scattered, well-shaped trees (usually in the predominant-dominant social classes) and of crown thinning of neighbouring competitors in order to promote the future development of selected trees at crown, stem and root level. These will be the main key-points able to reach the final, overmature stages and to regenerate the forest. The resulting harvested wood amount is not far from that extracted by traditional thinning, but its spatial arrangement is quite diverse on the ground and at crown level. Shape, size and distribution of canopy gaps is also different between the traditional and new practice. The remaining standing crop is fully maintained and will produce differentiation in crown layer, stem distribution and size. Mortality of dominated or defective trees will promote the establishment of snags and lying deadwood, at present understocked. A higher complexity of stand structure and habitats may be reached through consistent practices, and support the diverse, concurrent demands currently addressed to forest management. The trial compares traditional and innovative technique, plus the no-intervention or delayed-intervention thesis that, in the context of beech high forests, has sound reasons to be tested because of its wide application in similar conditions

#### **Site 8 - Kočevski Rog (SI)**

##### **Site description**

The area is located in the southeastern part of

Slovenian Dinaric region. The majority of forest area is owned by Slovenian state. Research plots are located within forest management unit FMU Črmošnjice within forest compartments N° 3, 6 and 12.

Total area of FMU is 6580.08 ha (5910.39 ha of forest – 89.8 %). Altitude ranges from 230 m to 1077 m (Kopa). Average yearly precipitation is 1590 mm. Parent material is limestone and dolomite, where leptosols, cambisols and luvisols are present. Predominant forest type is *Omphalodo-Fagetum* with European beech, silver fir and Norway spruce as main tree species. Elm and Sycamore are also present. The average growing stock is 351.6 m<sup>3</sup> ha<sup>-1</sup> and the increment is 9.4 m<sup>3</sup> ha<sup>-1</sup> yr<sup>-1</sup>. The forests are partly included in NATURA 2000 network (Slovenian Forest Service, Forest management plan FMU Črmošnjice 2007-2016).

#### **Description of the traditional silvicultural system**

The area around this test site has been intensively managed for several centuries. After long-lasting practice of clear-cutting and some other irregular forms of harvesting, in 1892 Hufnagel introduced the selection system, which became the main management system in the region (Hufnagel 1982). That system was practiced until the late 1950s. The loss of vitality of silver fir between the 1960s and late 1980s, omnipresent ungulate browsing as well as the gradual shift from selection silviculture system to improved irregular shelterwood system resulted in the decline of fir and its insufficient ingrowth (Šubic et al. 2007, Šubic 2007).

#### **Site 9 - Snežnik (SI)**

##### **Site description**

The area is located in the Southern part of Slovenian Dinaric region. The majority of forest area is owned by Slovenian state. Research plots are located within forest management unit FMU Snežnik within forest compartments N° 1 and 2.

Total area of FMU is 1983.02 ha (1894.22 ha of forest – 95.5 %). Altitude ranges from 600 m to 1095 m. Average yearly precipitation is from 2000 to 3000 mm. Parent material is limestone and dolomite, where leptosols, cambisols and luvisols is present. Predominant forest type is *Omphalodo-Fagetum* with European beech, silver fir and Norway spruce as main tree species. Elm and Sycamore is also present. The average growing stock is 442 m<sup>3</sup> ha<sup>-1</sup> and the increment is 8.3 m<sup>3</sup> ha<sup>-1</sup> yr<sup>-1</sup>. The forests are mainly included in NATURA 2000 network (Slovenian Forest Service, Forest management plan FMU Snežnik 2005-2014).



### **Description of the traditional silvicultural system**

The main management type is high forest with close-to nature silviculture. Forests are treated with group-shelterwood (Femmelschlag) cuttings. Long history of forest management plans (since 1906) is present in the area (Schollmayer 1906).

### **Site 10 - Trnovo (S1)**

#### **Site description**

The area is located in the Southwestern part of Slovenian Dinaric region. The majority of forest area is owned by Slovenian state. Research plots are located within forest management unit FMU Trnovo within forest compartment N° 30.

Total area of FMU is 4614.18 ha (4325.04 ha of forest – 93.7 %). Altitude ranges from 550 m to 1445 m. Average yearly precipitation is from 2000 to 3000 mm. Parent material is limestone and dolomite, where leptosols, cambisols and luvisols are present. Predominant forest type is *Omphalodo-Fagetum* with European beech, silver fir and Norway spruce as main tree species. Elm and Sycamore are also present. The average growing stock is 292.0 m<sup>3</sup> ha<sup>-1</sup> and the increment is 6.2 m<sup>3</sup> ha<sup>-1</sup> yr<sup>-1</sup>. The forests are mainly included in NATURA 2000 network (Slovenian Forest Service, Forest management plan FMU Trnovo 2003-2012).

### **Description of the traditional silvicultural system**

The main management type is high forest with close-to nature silviculture. Forests are treated with group-shelterwood (Femmelschlag) cuttings. Long history of forest management plans (since 1769 / 1771) is present in the area (Flamek 1771).

### **Innovative criteria (all Slovenian sites - 8, 9, 10)**

The innovative criteria are being referred to the intensity of the regeneration cuts. In terms of natural disturbances the experiment mimics three types of disturbances resulting in small regeneration gaps (control = solely diffuse light), medium-sized (half cut = diffuse and direct light) and large-sized regeneration areas (full cut = direct light). It is assumed that the sizes will make possible to determine the best way of regeneration for the dominant species as well as to make trade-offs between different ecosystem services such as wood production, carbon storage, biodiversity and many others.

### **References**

- Bessegga A. 2008 - *Evoluzione storica delle tecniche selvicolturali nella Foresta del Cansiglio*. Tesi di laurea. Università defli Stidi di Udine. Facoltà di Agraria
- Bortoluzzi A. 2002 - *Piano economico di riassetto forestale dei beni silvo-pastorali del comune di Lorenzago di Cadore*. 2002-2011.
- CFS UTB Mongiana (Vibo Valenzia) 2011 - *Piano A.I.B. per la R.S.N. Biogenetica Cropani-Micone e per la R.N. S. Biogenetica Marchesale per il periodo 2012-2016*.
- Ciancio O. 2009. *Riserva Naturale Statale Biogenetica di Vallombrosa. Piano di Gestione e Silvomuseo 2006-2025*. CFS. 438 p.
- Di Salvatore U., Tonti D., Chiavetta U., Cantiani P., Fabbio G., Becagli C., Bertini G., Sansone D., Skudnik M., Kobal M., Kutnar L., Kobler A., Kovač M., Simončič P., Ferretti F. 2016 - *ManFor C.BD sites and the drivers of forest functions*. Ital. J. Agron. 10(s1): 23-32.
- Garfi V., Marchetti M. 2011 - *Tipi forestali e preforestali della Regione Molise*. Edizioni dell'Orso. 277 p.
- Flamek F., 1771 - *Holz-schätz oder Überschlagung auch Geometrische Einteilung in die Stallungen oder Jährliche Gehau sammentlicher Ternovaner Landesfürstlichen Hoch und Schwartz Waldungen*. Manuscript.
- Hofman A. 1967 - *Piano di Assestamento per il quindicennio 1967-1981, regione Friuli Venezia Giulia, foresta del Cansiglio*.
- Hofmann A., 1971 - *Piano di Assestamento per il quindicennio 1971-1985. Distretto di Rutte. A.S.F.D. Tarvisio*
- Hufnagel L., 1892 - *Wirtschaftsplan der Betriebsklasse I: Göttenitzer Gebirge*. Gottschee, pp. 228.
- La Marca O. 1980 - *Piano di gestione naturalistic della foresta di Chiarano Sparvera per il decennio 1980 1989*. Firenze Tip. Coppini. 84 p.
- Marchetti M. 2008. *Piano di gestione della Foresta demaniale Regionale "Pennataro" di Vastogirardi (Isernia) 2008-2017*
- Mercurio R., Spampinato G. 2006. *I tipi forestali delle Serre calabresi*. Laruffa ed. 205 p.
- Muzzi S. 1953 - *Vicende storiche ed economiche della foresta inalienabile del Cansiglio*. Annali Accademia Italiana di Scienze Forestali 146-159.
- Schollmayer H., 1906 - *Direktiven für die Bestandesaufnahme und die Betriebseinrichtung auf der F.C. Herrschaft Schneeberg*. Kleinmayr-Bamberg, Ljubljana.
- Šubic J, 2007 - *Stanje in razvoj prebiralnega gozda Volčji štant v GG Ravne*. [The state and development of the selection forest Volčji štant in the FMU Ravne]. Degree Diss., University of Ljubljana.
- Šubic J, Klopčič M, Bončina A, 2010 - *Struktura prebiralnih goz dov v raziskovalnem objektu Volčja preža na Goteniški gori*. Gozd V 68:347-360.



**Figure 2** - The Cansiglio forest (Photo courtesy of F. Sicuriello).



**Figure 3** - The Chiarano-Sparvera forest (Photo courtesy of G. Matteucci).



**Figure 4** - The Lorenzago di Cadore forest (Photo courtesy of U. Di Salvatore).



**Figure 5** - The Mongiana forest (Photo courtesy of U. Di Salvatore).



**Figure 6** - The Pennataro forest (Photo courtesy of U. Di Salvatore).



**Figure 7** - The Tarvisio forest (Photo courtesy of A. Romano).



**Figure 8** - The Vallombrosa forest (Photo courtesy of L.Zapponi).



**Figure 9** - The Kočevski Rog forest (Photo courtesy of L. Kutnar).



**Figure 10** - The Snežnik forest (Photo courtesy of L. Kutnar).



**Figure 11** - The Trnovo forest (Photo courtesy of L. Kutnar).



**Figure 12** - Malaise trap in Vallombrosa beech forest (Photo courtesy of L. Zapponi).



**Figure 13** - Wood hauling by mules in Chiarano - Sparvera beech forest (Photo courtesy of G. Matteucci).

# Data collection and new indicators of sustainable forest management: the Life project ManFor C.BD.

D'Andrea E.<sup>1</sup>, Ferretti F.<sup>2</sup>, Matteucci G.<sup>3</sup>, Zapponi L.<sup>1,4</sup>

Received 16/03/2016- Accepted 06/04/2016 - Published online 19/07/2016

## Rationale

The criteria and indicators for Sustainable Forest Management (SFM) were first adopted in the Third Ministerial Conference, held in Lisbon (1998). They were further improved in 2002 in Vienna, and updated and endorsed at the 7<sup>th</sup> Ministerial Conference in Madrid 2015 (FOREST EUROPE 2015). They represent the consensus achieved by European countries on the most important aspects of SFM and provide guidance for developing policies and help assess progress on SFM. All these indicators have a great significance at Regional and National level. However, their ability to describe phenomena that influence the forest ecosystem at the forest management scale should be tested. In this context, the Life project ManFor C.BD. can offer to stakeholders and practitioners a practical account of the effect of management on carbon cycle, biodiversity and landscape. Forest management cannot be evaluated using a single indicator because sustainability is connected to several factors related to production, carbon cycle, biodiversity and landscape. Hence all the different criteria and scales should be taken into account, as a network of processes, to assess the sustainability of different management options.

## Criteria and indicators

The quantitative indicators of sustainable forest managements are subdivided in the following criteria (FOREST EUROPE 2015):

- Criterion 1: Maintenance and appropriate enhancement of forest resources and their contribution to global carbon cycles;
- Criterion 2: Maintenance of forest ecosystem health and vitality;

- Criterion 3: Maintenance and encouragement of productive functions of forests (wood and non-wood);
- Criterion 4: Maintenance, conservation and appropriate enhancement of biological diversity in forest ecosystems;
- Criterion 5: Maintenance and appropriate enhancement of protective functions in forest management (notably soil and water);
- Criterion 6: Maintenance of other socioeconomic functions and conditions.

### Criterion 1

The first criterion supports SFM considering the expansion and evolution of European forests and their contribution to carbon cycles. It includes the following indicators:

- 1.1 Forest area. Area of forest and other wooded land, classified by forest type and by availability for wood supply, and share of forest and other wooded land in total land area.
- 1.2 Growing stock. Growing stock on forest and other wooded land, classified by forest type and by availability for wood supply.
- 1.3 Age structure and/or diameter distribution. Age structure and/or diameter distribution of forest and other wooded land, classified by availability for wood supply.
- 1.4 Forest carbon. Carbon stock and carbon stock changes in forest biomass, forest soils and in harvested wood products.

### Criterion 2

Both biotic and abiotic factors influence the health and vitality, and thus the resistance and resilience of forest to disturbance. This criterion includes the issues that may affect forests (e.g. air

<sup>1</sup> CNR-IBAF, National Research Council of Italy, Institute for Agro-environmental and Forest Biology, Monterotondo (RM), Italy

<sup>2</sup> Consiglio per la ricerca in agricoltura e l'analisi dell'economia agraria, Forestry Research Centre (CREA-SEL), Arezzo, Italy

<sup>3</sup> CNR-ISAFO, National Research Council, Institute for Agriculture and Forest Mediterranean Systems, Ercolano (NA), Italy

<sup>4</sup> CNBF National Centre for the Study and Conservation of Forest Biodiversity 'Bosco Fontana', Marmirolo (MN), Italy

pollution, soil acidification), the factors that allow to evaluate forest health (e.g. defoliation) and an account of the damaging events that may occur (e.g. diseases, storms). It includes the following indicators:

- 2.1 Deposition of air pollutants.
- 2.2 Soil condition. Chemical soil properties (pH, CEC, C/N, organic C, base saturation) on forest and other wooded land related to soil acidity and eutrophication, classified by main soil types
- 2.3 Defoliation. Defoliation of one or more main tree species on forest and other wooded land in each of the defoliation classes “moderate”, “severe” and “dead”
- 2.4 Forest damage. Forest and other wooded land with damage, classified by primary damaging agent (abiotic, biotic and human induced) and by forest type.

### **Criterion 3**

Forests provide socio-economic resources to nations and stakeholders: this criterion lists different parameters which monitoring should support the maintenance of forest products and services for present and future generations. It includes the following indicators:

- 3.1 Increment and fellings. Balance between net annual increment and annual fellings of wood on forest available for wood supply.
- 3.2 Roundwood. Quantity and market value of roundwood.
- 3.3 Non-wood goods. Quantity and market value of non-wood goods from forest and other wooded land.
- 3.4 Services. Value of marketed services on forest and other wooded land.

### **Criterion 4**

A fundamental goal of sustainable forest management is the maintenance of forest biodiversity. This criterion includes all forest life forms, the ecological roles they perform and the genetic diversity they hold. It includes the following indicators:

- 4.1 Diversity of tree species. Area of forest and other wooded land, classified by number of tree species occurring.
- 4.2 Regeneration. Total forest area by stand origin and area of annual forest regeneration and expansion.
- 4.3 Naturalness Area. of forest and other wooded land by class of naturalness.
- 4.4 Introduced tree species. Area of forest and other wooded land dominated by introduced tree species.
- 4.5 Deadwood. Volume of standing deadwood and of lying deadwood on forest and other

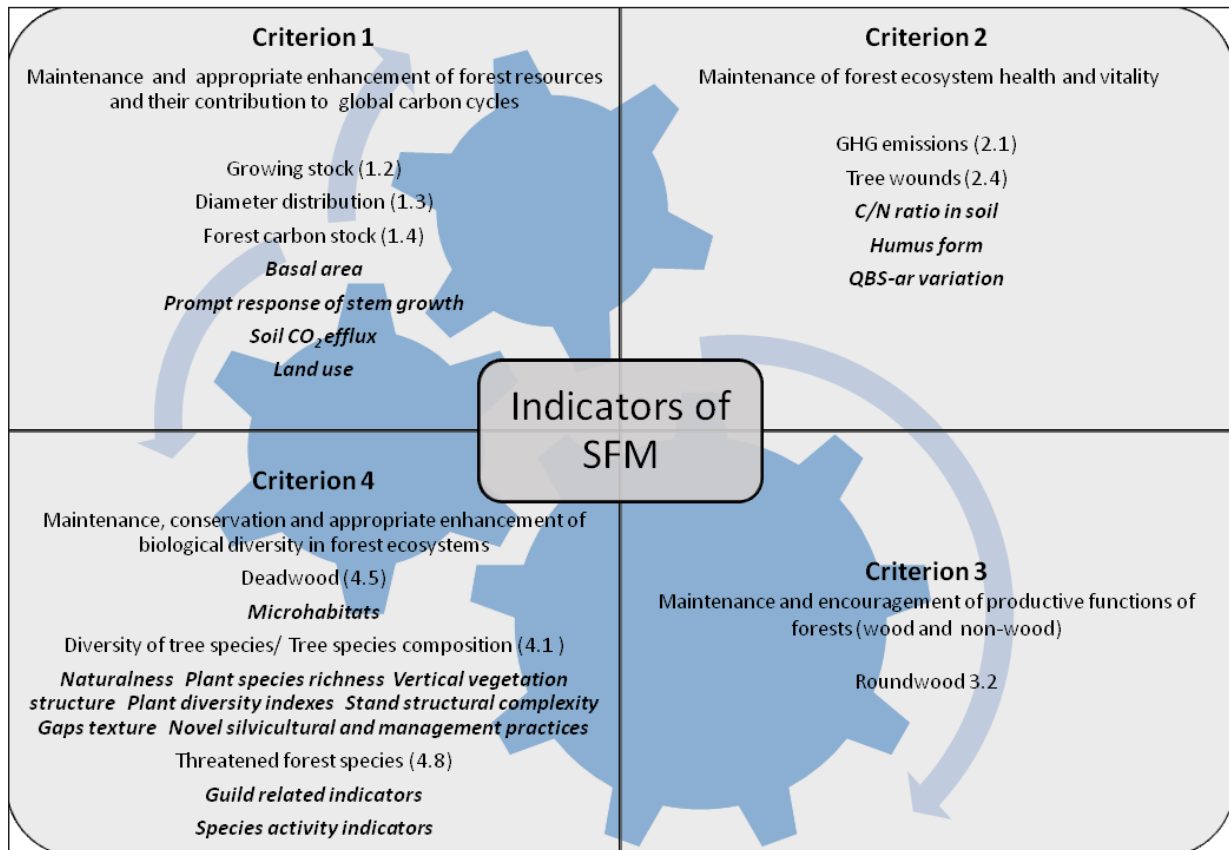
wooded land.

- 4.6 Genetic resources. Area managed for conservation and utilisation of forest tree genetic resources (in situ and ex situ genetic conservation) and area managed for seed production.
- 4.7 Forest fragmentation. Area of continuous forest and of patches of forest separated by non-forest lands.
- 4.8 Threatened forest species. Number of threatened forest species, classified according to IUCN Red List categories in relation to total number of forest species, where forest species is any species that depend on a forest for part or all of its requirements, or for its reproductive requirements (MCPFE 2002).
- 4.9 Protected forests. Area of forest and other wooded land protected to conserve biodiversity, landscapes and specific natural elements, according to MCPFE categories.
- 4.10 Common forest bird species. Occurrence of common breeding bird species related to forest ecosystems. This indicator requires further development and testing for consideration.

## **Methods**

When the spatial and temporal scales of the data collected for the project ManFor C.BD. were suitable, the corresponding MCPFE indicator (FOREST EUROPE 2015) was applied. The results of the application of the Pan-European indicators are summarised in the following pages, together with other indicators developed and/or tested by the project. Finally, indicators that required a longer time frame but were otherwise considered suitable, are listed as well. The information regarding each indicator was gathered in a summary sheet, containing the following points:

- The indicator name, with a reference, if applicable, to the MCPFE indicator according to FOREST EUROPE (2015).
- Full text: brief description of the indicator.
- Rationale: description and justification of the indicator.
- Method: how the indicator may be measured.
- Measurement units.
- Measurement time: special timing issues related to indicator and/or if it should be measured before and/or after silvicultural treatments:
  - Before [Y/N]
  - After [Y/N]
- The feasibility of application of each indicator, evaluated as the combination of three



The traditional (numbered, in Roman) and the new Indicators (bold Italics) assessed for each Criterion.

factors:

Scale of application: plot, stand, compartment, landscape, regional

Specific knowledge required: 1 (no specific background needed)- 5 (specialized technician)

Costs: 1-5 (minimum-maximum)

The potential interaction of the considered indicator with other indicators (which may be used as proxies), was also noted.

- Results and conclusions from ManFor C.BD.: application of the indicator with the data gathered within the project.

## References

- FOREST EUROPE 2015 - *Updated Pan-European indicators for sustainable forest management, as adopted by the FOREST EUROPE Expert Level Meeting 30 June – 2 July 2015*. Madrid, Spain. The final report of the Advisory Group, the supplementary documents and related information of the updating process can be found at: <http://www.foresteurope.org/content/updating-pan-european-set-indicators-sfm>.
- MCPFE 2002 - *Relevant definitions used for the improved Pan-European indicators for sustainable forest management*. Ministerial Conference on the Protection of Forests in Europe. Liason Unit Vienna. <http://www.foresteurope.org/documentos/guidelines/VienaIndiDef.pdf>



# Assessing the maintenance of forest resources and their contribution to carbon cycles

Becagli C. <sup>1</sup>, Bertini G. <sup>1</sup>, Cammarano M. <sup>2</sup>, Cantiani P. <sup>1</sup>, Cater M. <sup>3</sup>, Chiavetta U. <sup>1</sup>, Coletta V. <sup>4</sup>, Conforti M. <sup>4</sup>, D'Andrea E. <sup>2</sup>, Di Salvatore U. <sup>1</sup>, Fabbio G. <sup>1</sup>, Ferlan M. <sup>3</sup>, Ferreira A. <sup>5</sup>, Ferretti F. <sup>1</sup>, Giovannozzi Sermanni A. <sup>2</sup>, Kobler A. <sup>5</sup>, Kovač M. <sup>5</sup>, Marinsek A. <sup>3</sup>, Micali M. <sup>2</sup>, Pellicone G. <sup>5</sup>, Planinšek Š. <sup>5</sup>, Rezaei N. <sup>2</sup>, Sicuriello F. <sup>2</sup>, Skudnik M. <sup>5</sup>, Tonti D. <sup>6</sup>

Received 16/03/2016 - Accepted 06/04/2016 - Published online 19/07/2016

## Growing stock – 1.2

The Criterion 1 (Maintenance and Appropriate Enhancement of Forest Resources and their Contribution to Global Carbon Cycles) includes the “Growing stock on forest and other wooded land, classified by forest type and by availability for wood supply” (FOREST EUROPE 2015).

**Full text** Growing stock on forest and other wooded land, classified by forest type and by availability for wood supply.

**Rationale** This indicator is one of the basic figures of any forest inventory and useful for various purposes.

The standing volume of growing stock is closely related to the above ground woody biomass and provides data for calculating carbon budgets (link to indicator 1.4 (carbon stock)).

Further on this indicator is mainly linked to indi-

cator 1.3, 2.3 and 2.4. There is also a cross-reference to Criterion 4 (Biodiversity).

## Methods

Permanent plots to measure and compare the Growing stock change in progress. Measurements have to be repeated every five years and before and after any silvicultural operations to determine their impact on the parameter.

We measured dbh, total height and estimate the standing timber volume by volume tables.

## Measurement units

- Status: m<sup>3</sup>
- Changes: m<sup>3</sup> per yr.
- Status: m<sup>3</sup> ha<sup>-1</sup>
- Changes: m<sup>3</sup> ha<sup>-1</sup> per yr.

## Measurement time

Before [Y]

After [Y]

## Feasibility

Scale of application	Specific knowledge	Costs	Interaction with other indicators
Stand	2 (inventory technician)	2	Carbon stock, Basal Area, Diameter distribution

## Results from ManFor C.BD.

Indicator name	Site	Before	After
Stem volume (m <sup>3</sup> ha <sup>-1</sup> )	Cansiglio Innovative	561.2	360.1
Stem volume (m <sup>3</sup> ha <sup>-1</sup> )	Cansiglio Traditional	524.0	397.1
Stem volume (m <sup>3</sup> ha <sup>-1</sup> )	Chiarano Traditional	267.3	177.2
Stem volume (m <sup>3</sup> ha <sup>-1</sup> )	Chiarano Innovative 80	303.9	192.1
Stem volume (m <sup>3</sup> ha <sup>-1</sup> )	Chiarano Innovative 40	296.6	177.1
Stem volume (m <sup>3</sup> ha <sup>-1</sup> )	Lorenzago Area 1 Innovative	748.1	596.5
Stem volume (m <sup>3</sup> ha <sup>-1</sup> )	Lorenzago Area 1 Traditional	937.0	719.6
Stem volume (m <sup>3</sup> ha <sup>-1</sup> )	Lorenzago Area 2 Innovative	828.2	424.1
Stem volume (m <sup>3</sup> ha <sup>-1</sup> )	Lorenzago Area 2 Traditional	904.2	693.1
Stem volume (m <sup>3</sup> ha <sup>-1</sup> )	Mongiana Innovative	484.3	380.2
Stem volume (m <sup>3</sup> ha <sup>-1</sup> )	Mongiana Traditional	471.7	381.3
Stem volume (m <sup>3</sup> ha <sup>-1</sup> )	Pennataro Mixed forest	402.6	275.1
Stem volume (m <sup>3</sup> ha <sup>-1</sup> )	Pennataro Turkey oak forest	457.1	274.1
Stem volume (m <sup>3</sup> ha <sup>-1</sup> )	Tarvisio Innovative 1	424.7	246.7
Stem volume (m <sup>3</sup> ha <sup>-1</sup> )	Tarvisio Innovative 2	326.6	219.6
Stem volume (m <sup>3</sup> ha <sup>-1</sup> )	Tarvisio Traditional	320.4	259.5
Stem volume (m <sup>3</sup> ha <sup>-1</sup> )	Vallombrosa Innovative	826.9	538.2
Stem volume (m <sup>3</sup> ha <sup>-1</sup> )	Vallombrosa Traditional	751.9	737.4
Stem volume (m <sup>3</sup> ha <sup>-1</sup> )	Kočevski Rog 100	403.2	0
Stem volume (m <sup>3</sup> ha <sup>-1</sup> )	Kočevski Rog 50	389.7	221.9
Stem volume (m <sup>3</sup> ha <sup>-1</sup> )	Snežnik 100	605.8	0
Stem volume (m <sup>3</sup> ha <sup>-1</sup> )	Snežnik 50	628.5	364.4
Stem volume (m <sup>3</sup> ha <sup>-1</sup> )	Trnovo 100	599.1	0
Stem volume (m <sup>3</sup> ha <sup>-1</sup> )	Trnovo 50	622.3	278.5

<sup>1</sup> Consiglio per la Ricerca in Agricoltura e l'Analisi dell'Economia Agraria, Forestry Research Centre (CREA-SEL), Arezzo, Italy

<sup>2</sup> CNR-IBAF, National Research Council of Italy, Institute for Agro-environmental and Forest Biology, Monterotondo (RM), Italy

<sup>3</sup> Department of Yield and Silviculture, Slovenian Forestry Institute, Ljubljana, Slovenia

<sup>4</sup> CNR-ISAFOM, National Research Council of Italy, Institute for Agriculture and Forest Mediterranean Systems, Rende (CS), Italy

<sup>5</sup> Department of Forest and Landscape Planning and Monitoring, Slovenian Forestry Institute, Ljubljana, Slovenia

<sup>6</sup> UNIMOL, Dipartimento di Bio-scienze e Territorio, Università degli Studi del Molise, Pesche (IS), Italy

### Diameter distribution – 1.3

The Criterion 1 (Maintenance and Appropriate Enhancement of Forest Resources and their Contribution to Global Carbon Cycles) includes the “Age structure and/or diameter distribution of forest and other wooded land, classified by availability for wood supply” (FOREST EUROPE 2015).

**Full text** Diameter distribution of forest and other wooded land, classified by forest type and by availability for wood supply.

**Rationale** Diameter distributions provide an insight in the future development of forests and are a prerequisite for SFM. The diameter distribution is appropriate to describe the stand level structure. It is the most traditional forest indicators and it is easy to measure in the field.

This indicator is mainly linked to other indicators describing forest resources, health and vitality, productive and protective functions as well as biodiversity. Diameter distribution supports especially the interpretation of indicator 1.2 (growing stock) and also indicates the stability of forests (e.g. over-

mature forests might collapse). In combination with figures on current state and changes of growing stock, the indicator enables the evaluation of future potential growth and sustainable timber supply.

The results are also linked with the number of thick trees, which may be important as habitat trees.

There is also a cross-reference to Criterion 4 (Biodiversity).

#### Methods

Permanent plots to measure and compare the change in progress in the diameter distribution. Measurements have to be repeated every five years and before and after any silvicultural operations to determine their impact on the parameters.

#### Measurement units

- Diameter distribution
- Status: Diameter class n ha<sup>-1</sup>
- Changes: Diameter class n ha<sup>-1</sup> per yr.

#### Measurement time

Before [Y]

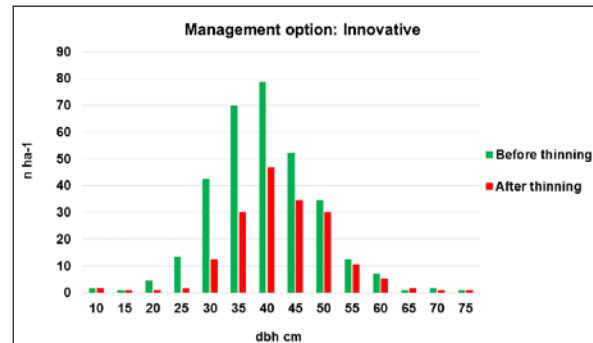
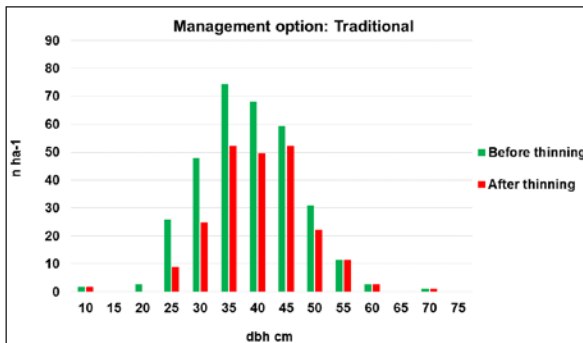
After [Y]

#### Feasibility

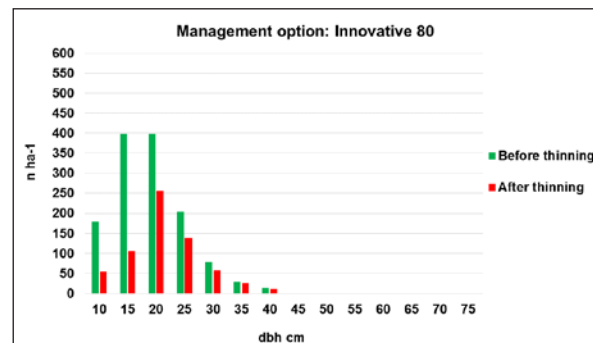
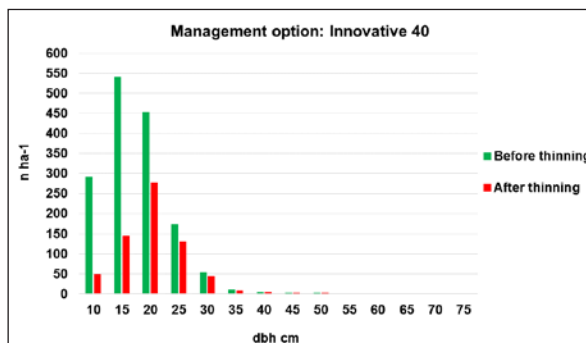
Scale of application	Specific knowledge	Costs	Interaction with other indicators
Stand	2 (inventory technician)	2	Carbon stock, Basal Area, Growing stock

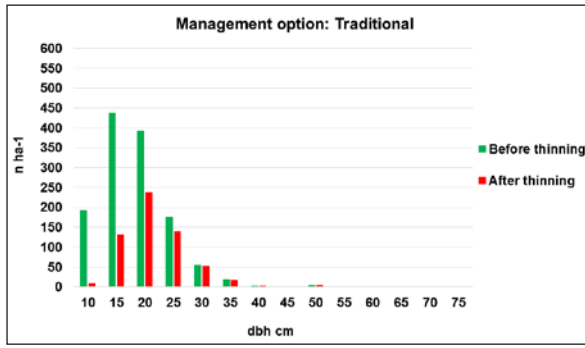
### Results from ManFor C.BD.

#### Cansiglio

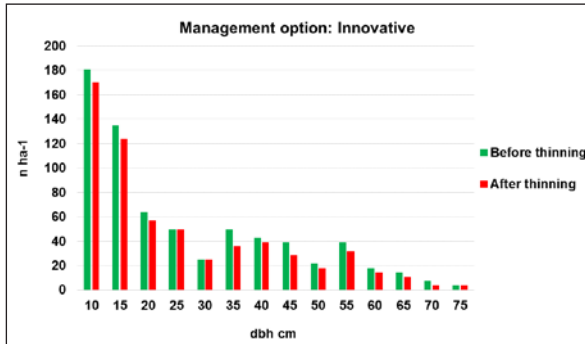


#### Chiarano

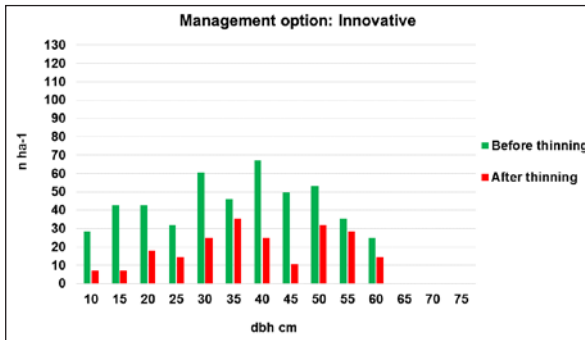
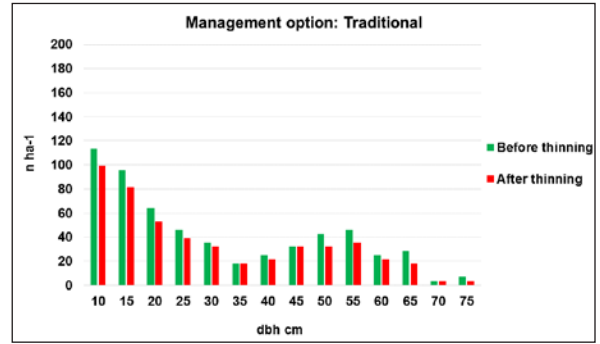




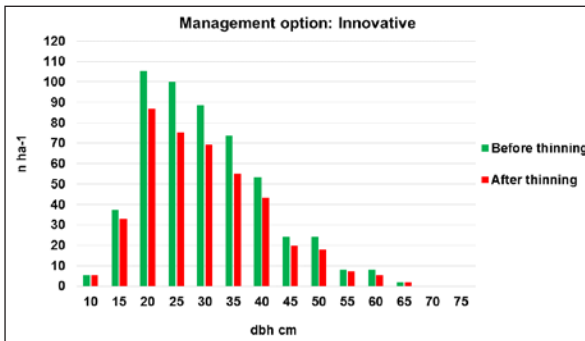
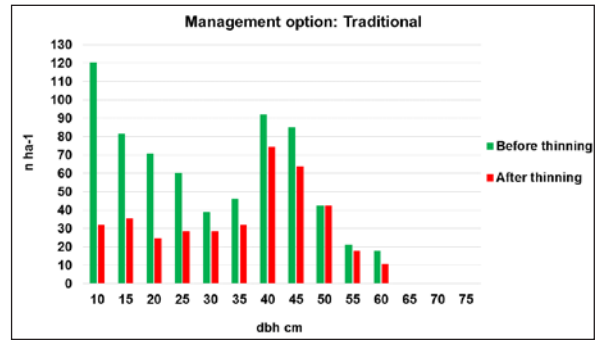
Lorenzago 1



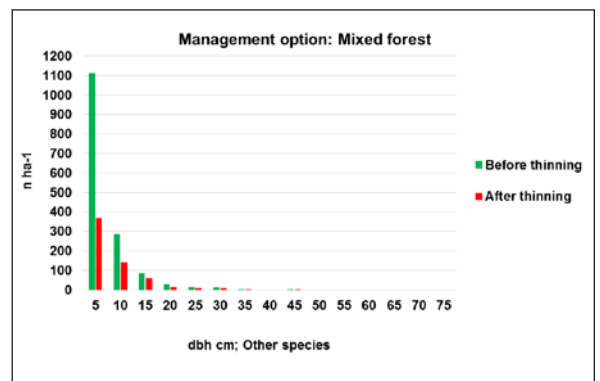
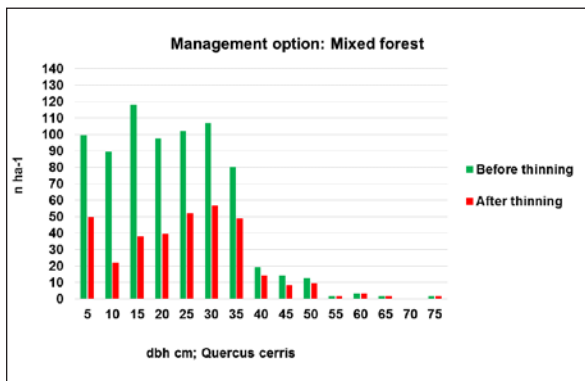
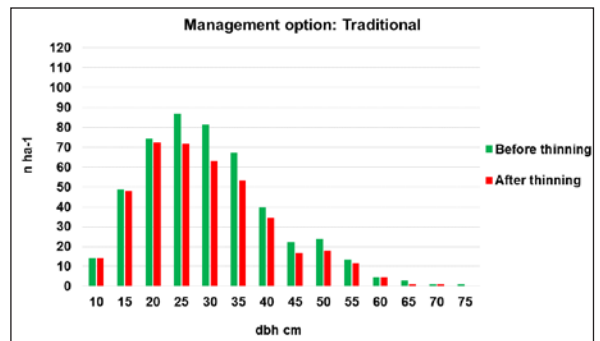
Lorenzago 2

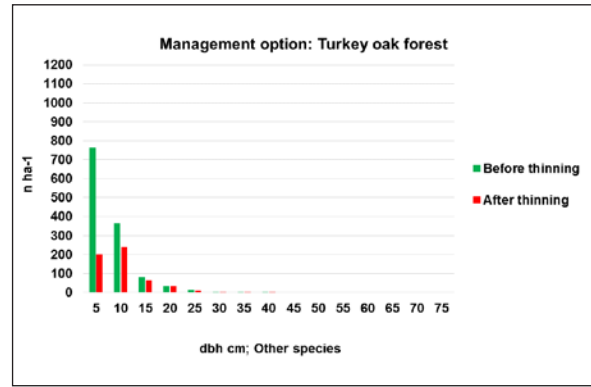
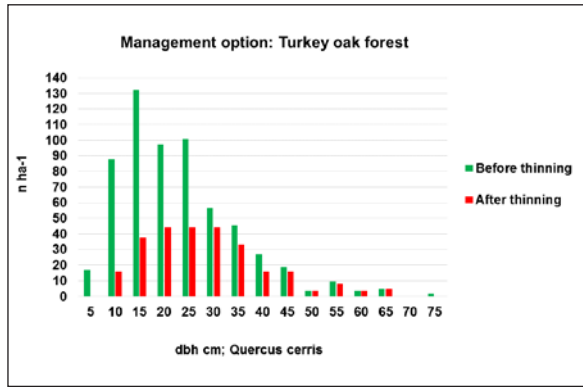


Mongiana

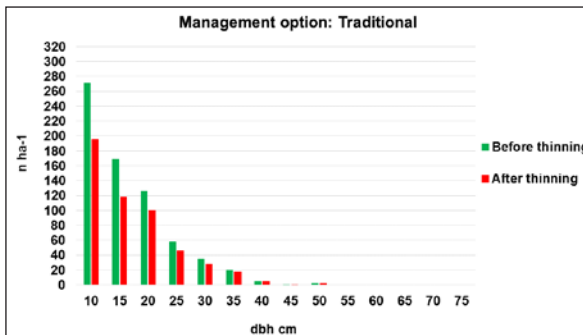
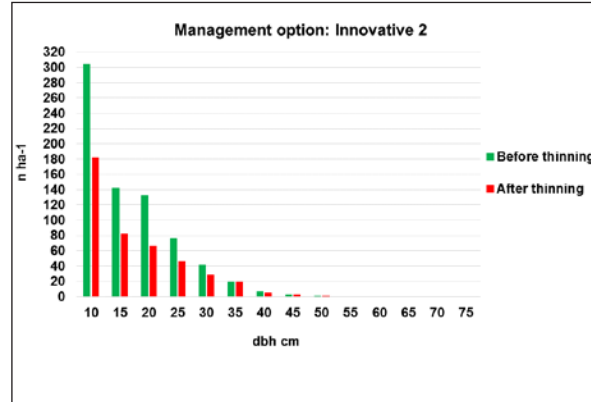
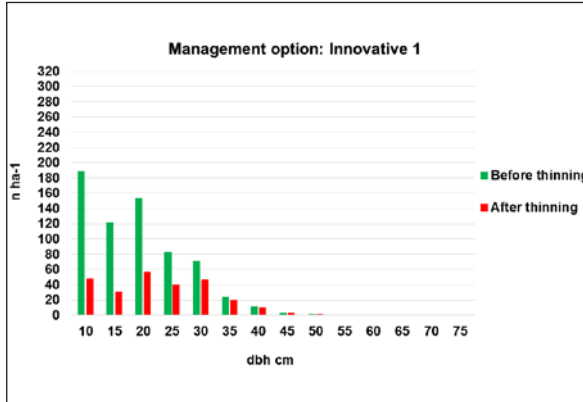


Pennataro

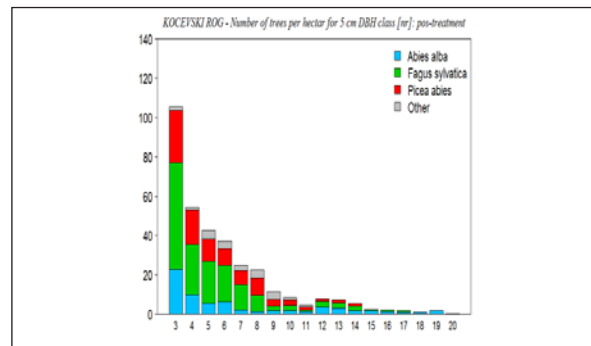
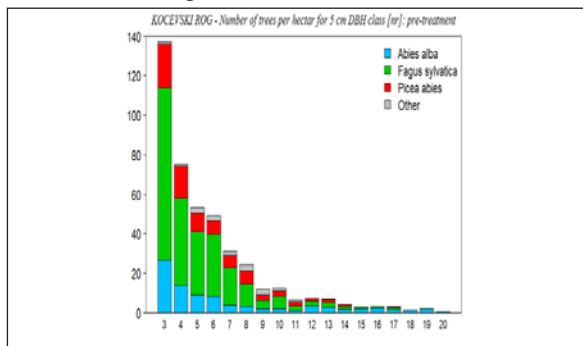




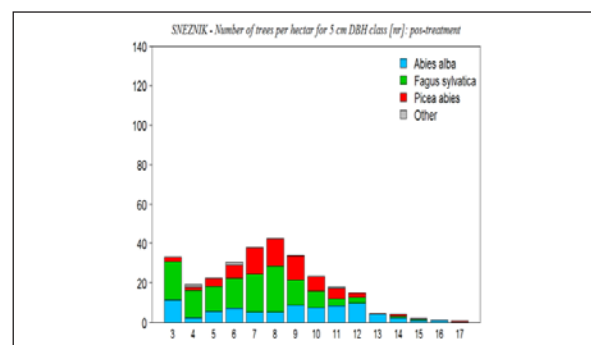
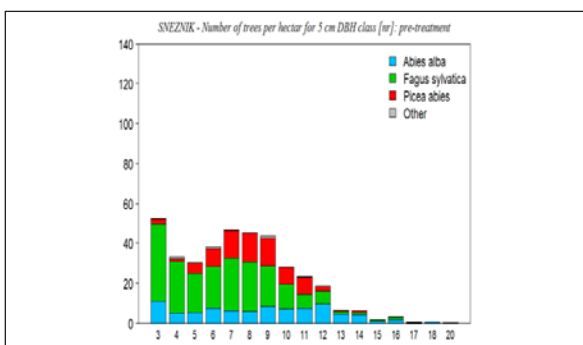
Tarvisio



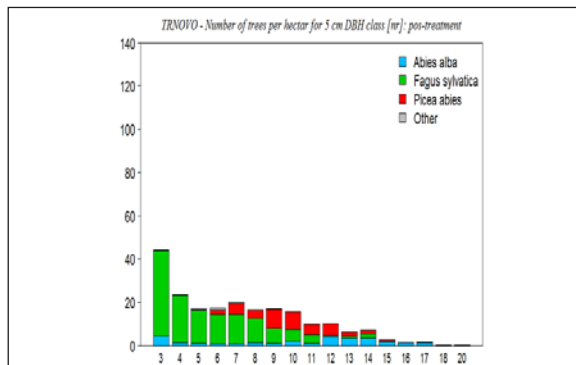
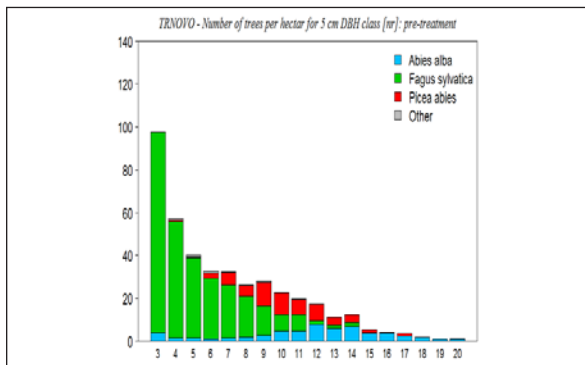
Kočevski Rog\*



Snežnik\*



**Trnovo\***



\*In Slovenian sites, diametric classes of 5 cm were reported on x axis and frequencies (number of trees ha<sup>-1</sup>) on y axis.

**Forest carbon stock – 1.4**

The Criterion 1 includes the “Carbon stock and carbon stock changes in forest biomass, forest soils and in harvested wood products” (FOREST EUROPE 2015).

**Full text** Carbon stock of biomass, deadwood, litter and soil on forest.

**Rationale** Carbon sequestration in forest ecosystems contributes to a reduction in the concentration of greenhouse gases in the atmosphere. Carbon accumulates in forest ecosystems through absorption of atmospheric CO<sub>2</sub> and its assimilation into biomass (above and below ground). Then carbon migrates from biomass in litter (leaves) or in deadwood, and from these components to soil. Carbon is retained for different periods in the forest biomass (above-below ground biomass), litter, deadwood and soils (MCPFE, 2007). European forests are a large reserve of carbon with 53 gigatonnes of carbon sequestered in forest biomass and deadwood. They continue to be a significant carbon sink, as evidenced by their increase in carbon stocks of 2 billion tonnes since 1990. Knowledge on the status and trends of carbon stocks in forest litter and soil remains limited (MCPFE,2007). This indicator can be useful to evaluate effects of different silviculture treatments on the five carbon pools.

**Methods**

Branches, stems and roots biomass can be assessed using allometric equations or other models, then measuring carbon concentration (or using the 0.5 coefficient) biomass carbon pool is estimated. Litter carbon pool is estimated collecting samples

from forest using a frame and measuring carbon concentration. Soil carbon pool is estimated using specific field sampling then in laboratory bulk density and carbon concentration is measured. Deadwood is assessed in plots, assigning each debris to a decay class (that differ for density and carbon content).

**Measurement units**

Status: MgC ha<sup>-1</sup>

Changes: MgC ha<sup>-1</sup>per yr.

**Measurement time**

Before [Y]

After [Y]

**Feasibility**

Scale of application	Specific knowledge	Costs	Interaction with other indicators
Stand	2 (inventory and laboratory technician)	3	Growing stock, Basal Area, Soil respiration, C/N

## Results from ManFor C.BD.\*

Indicator name	Site	Below ground biomass BEFORE	Above ground biomass BEFORE	Woody Debris BEFORE	Litter BEFORE	Soil BEFORE	Total BEFORE	Below ground biomass AFTER	Above ground biomass AFTER	Woody Debris AFTER	Litter AFTER	Soil AFTER	Total AFTER
Carbon Stock	Cansiglio Innovative	50.44	149.94	2.80	7.85	58.91	269.94	50.44	90.72	8.83	7.25	47.17	204.41
Carbon Stock	Cansiglio Traditional	46.30	141.18	5.08	7.99	52.75	253.29	46.30	100.97	8.92	7.40	45.77	209.36
Carbon Stock	Chiarano Traditional	27.78	118.91	3.39	4.60	100.06	254.74	27.78	79.39	4.85	3.00	108.61	223.63
Carbon Stock	Chiarano I80	27.60	131.84	3.03	5.06	106.42	273.95	27.60	88.68	7.24	2.88	116.32	242.72
Carbon Stock	Chiarano I40	27.13	130.26	4.23	5.28	97.32	264.22	27.13	74.95	7.21	1.75	113.36	224.40
Carbon Stock	Mongiana Innovative	48.16	149.37	1.68	4.61	172.22	376.04	48.16	119.49	8.13	3.97	161.05	340.80
Carbon Stock	Mongiana Traditional	42.31	135.48	1.53	5.21	188.81	373.34	42.31	111.38	8.64	5.36	180.74	348.44
Carbon Stock	Kočevski Rog 100	24.09	118.63	2.31	4.39	140.56	289.99	24.09	0.00	44.20	4.18	130.15	202.62
Carbon Stock	Kočevski Rog 50	21.51	106.59	7.35	4.15	173.17	312.77	21.51	53.30	26.09	4.10	168.95	273.95
Carbon Stock	Snežnik 100	36.69	179.77	8.44	6.92	123.29	355.11	36.69	0.00	72.10	6.59	114.15	229.53
Carbon Stock	Snežnik 50	35.42	173.24	3.35	3.47	121.74	337.22	35.42	86.62	34.05	3.43	118.77	278.30
Carbon Stock	Trnovo 100	33.77	165.74	3.47	8.21	197.63	408.82	33.77	0.00	62.10	7.82	182.99	286.69
Carbon Stock	Trnovo 50	33.94	167.35	2.75	5.17	224.00	433.20	33.94	83.67	32.27	5.10	218.53	373.52

\* In Italian Sites soil carbon pool was assessed 30 cm depth, In Slovenian sites 1 m (or bedrock) depth.

## Basal area

**Full text** Basal area is the area of a given section of land that is occupied by the cross-section of tree trunks and stems at the base.

**Rationale** The indicator is easy to measure and to calculate. The results depend only on the measured dbh of the tree. The indicator is already included into most of the forest management plans. With basal area it is possible to monitor the development of the stand. Through raw data it is possible to calculate the number of thick trees (potential habitat trees).

### Methods

Permanent plots to measure and compare the Basal area change in progress. Measurements have to be repeated every five years and before and after any silvicultural operations to determine their impact on the parameter. All living trees with dbh at least 7.5 cm were included.

## Measurement units

Status: m<sup>2</sup>

Changes: m<sup>2</sup> per yr.

Status: m<sup>2</sup> ha<sup>-1</sup>

Changes: m<sup>2</sup> ha<sup>-1</sup> per yr.

## Measurement time

Before [Y]

After [Y]

## Feasibility

Scale of application	Specific knowledge	Costs	Interaction with other indicators
Stand	2 (inventory technician)	2	Carbon stock, Growing stock

## Results from ManFor C.BD.

Indicator name	Site	Before	After
Basal area (m <sup>2</sup> ha <sup>-1</sup> )	Cansiglio Innovative	41.9	26.6
Basal area (m <sup>2</sup> ha <sup>-1</sup> )	Cansiglio Traditional	39.6	29.8
Basal area (m <sup>2</sup> ha <sup>-1</sup> )	Chiarano Traditional	36.7	23.1
Basal area (m <sup>2</sup> ha <sup>-1</sup> )	Chiarano I80	40.4	24.8
Basal area (m <sup>2</sup> ha <sup>-1</sup> )	Chiarano I40	40.2	23.0
Basal area (m <sup>2</sup> ha <sup>-1</sup> )	Lorenzago Area 1 Innovative	53.3	43.1
Basal area (m <sup>2</sup> ha <sup>-1</sup> )	Lorenzago Area 1 Traditional	58.8	46.4
Basal area (m <sup>2</sup> ha <sup>-1</sup> )	Lorenzago Area 2 Innovative	54.6	28.1
Basal area (m <sup>2</sup> ha <sup>-1</sup> )	Lorenzago Area 2 Traditional	58.0	43.2
Basal area (m <sup>2</sup> ha <sup>-1</sup> )	Mongiana Innovative	41.6	32.6
Basal area (m <sup>2</sup> ha <sup>-1</sup> )	Mongiana Traditional	38.7	31.4
Basal area (m <sup>2</sup> ha <sup>-1</sup> )	Pennataro Mixed forest	38.6	24.9
Basal area (m <sup>2</sup> ha <sup>-1</sup> )	Pennataro Turkey oak forest	43.7	25.3
Basal area (m <sup>2</sup> ha <sup>-1</sup> )	Tarvisio Innovative 1	47.7	25.8
Basal area (m <sup>2</sup> ha <sup>-1</sup> )	Tarvisio Innovative 2	37.9	24.7
Basal area (m <sup>2</sup> ha <sup>-1</sup> )	Tarvisio Traditional	35.7	28.5
Basal area (m <sup>2</sup> ha <sup>-1</sup> )	Vallombrosa Innovative	56.9	36.7
Basal area (m <sup>2</sup> ha <sup>-1</sup> )	Vallombrosa Traditional	54.3	53.2
Basal area (m <sup>2</sup> ha <sup>-1</sup> )	Kočevski Rog 100	30.9	0
Basal area (m <sup>2</sup> ha <sup>-1</sup> )	Kočevski Rog 50	31.1	17.9
Basal area (m <sup>2</sup> ha <sup>-1</sup> )	Snežnik 100	41.0	0
Basal area (m <sup>2</sup> ha <sup>-1</sup> )	Snežnik 50	45.5	25.7
Basal area (m <sup>2</sup> ha <sup>-1</sup> )	Trnovo 100	43.8	0
Basal area (m <sup>2</sup> ha <sup>-1</sup> )	Trnovo 50	45.5	19.5

## Prompt response of stem growth

### Full text Response of tree diameter increment to forest management

**Rationale** Tree growth can be useful indicator of processes that occur in the natural environment (Fritts 1976, Harley and Grissino-Mayer 2012). Since the growth rate of a tree is sensitive to both natural and human-induced events, conditions during a

given year will be either favourable or unfavourable for tree growth, resulting in a variation in tree ring widths (TRW) from year to year throughout the life of a tree. This pattern of wide and narrow growth rings can serve as an indicator for monitoring environmental processes. Tree diameter increment is connected with gross primary production, which could be influenced by stand structure, competition, etc. This indicator can be useful to evaluate effects of different silvicultural treatments on the carbon cycling.

### Methods

Comparing the radial growth Before and After silvicultural treatments allow us to evaluate the effect of applied forest management measures. Using woody cores enable us to compare the mean standardized growth of the trees 5 years before the silvicultural treatments and the years after the cutting, when the growth area is released. An easy way to standardize the growth is to divide each annual tree ring width by the mean of the tree ring width of the considered period.

### Instruments:

Incremental hammer

Core borers

Tree ring widths measurers (TSAP, Software for Image Analysis)

### Measurement units

Ratio between before and after treatment growth

### Feasibility

Scale of application	Specific knowledge	Costs	Interaction with other indicators
Tree level, Stand	2	2-4 (depending to TRW measurers)	Soil efflux, Basal area, Carbon stock,

## Results from ManFor C.BD.

Indicator name	Site	Before	After
Differences in growing stock	Trnovo, Kočevski Rog, Snežnik	YES	YES
Differences in growing stock	Cansiglio Innovative	0.95	1.59
Differences in growing stock	Cansiglio Control	0.91	0.59
Differences in growing stock	Cansiglio Traditional	1.07	0.94
Differences in growing stock	Chiarano Traditional	0.98	1.18
Differences in growing stock	Chiarano I80	0.83	1.67
Differences in growing stock	Chiarano I40	0.94	1.47
Differences in growing stock	Mongiana Innovative	0.80	1.39
Differences in growing stock	Mongiana Control	1.05	0.95
Differences in growing stock	Mongiana Traditional	0.89	0.96

## Soil efflux

**Full text** CO<sub>2</sub> efflux from forests soils.

**Rationale** CO<sub>2</sub> efflux out of the soil is the primary function of soil respiration; it is a significant component of the total atmospheric carbon cycle.

Significant disturbances related with aboveground biomass could increase the soil CO<sub>2</sub> efflux. This indicator can be useful to evaluate effects of different silviculture treatments on the carbon cycling (Eler et al. 2013).

### Methods

Different chambers techniques

Soil temperature and soil water profiles

### Measurement units

Status: tones of C /ha

Flux: tones of C /ha/yr.

**Measurement time** Diurnal [day]. Growing season [months/period]

Before [Y]

After [Y]

### Feasibility

Scale of application	Specific knowledge	Costs	Interaction with other indicators
Stand	5	5	Differences in growing stock

## Results from ManFor C.BD.\*

Indicator name	Site	Before	Growing season (Jun-Oct 2014)
Soil respiration (µmol CO <sub>2</sub> m <sup>2</sup> /sec)	Trnovo (beech stand with 100% logged growing stock)		2.1
Soil respiration (µmol CO <sub>2</sub> m <sup>2</sup> /sec)	Trnovo (control beech stand)		2.3
Soil respiration (µmol CO <sub>2</sub> m <sup>2</sup> /sec)	Chiarano Innovative 80		3.44
Soil respiration (µmol CO <sub>2</sub> m <sup>2</sup> /sec)	Chiarano Innovative 40		2.82
Soil respiration (µmol CO <sub>2</sub> m <sup>2</sup> /sec)	Chiarano Control		4.34
Soil respiration (µmol CO <sub>2</sub> m <sup>2</sup> /sec)	Mongiana Innovative		2.69
Soil respiration (µmol CO <sub>2</sub> m <sup>2</sup> /sec)	Mongiana Traditional		2.39
Soil respiration (µmol CO <sub>2</sub> m <sup>2</sup> /sec)	Mongiana Control		2.24

\*Slovenian data include also night measures; in all the sites there was a control plot to avoid to measurements before treatments.

The indicator proved to be suitable to describe the phenomena, due to its continuous period of measurement.

## Land use

**Full text** Main land uses classes in the land.

**Rationale** Land use is the type of activity being carried out on a unit of land. In GPG-LULUCF this term is used for the broad land-use categories, important for greenhouse gas (GHG) inventory

Scale of application	Specific knowledge	Costs	Interaction with other indicators
Landscape <sup>2</sup> /Regional	5	2	All Biodiversity indicators, Carbon stock

## Results from ManFor C.BD.

Indicator name	Site	Before	After
Land use	Kočevski Rog	Forest: 95 %, Settlements: 1%,Other land: 4%	
Land use	Snežnik	Forest: 80 %, Settlements: 2%,Other land: 18 %	
Land use	Trnovo	Forest: 83 %, Settlements: 2%,Other land: 15 %	
Land use	Cansiglio	Forest: 76 %, Settlements: 1%,Other land: 60 %	
Land use	Chiarano	Forest: 35 %, Settlements: 20%,Other land: 60 %	

## Rotation length

**Full text** Increased rotation lengths

**Rationale** Rotation length is together with site index a major determinant of Carbon stock both in the standing crop and in the forest soil. Carbon sequestration, i.e. annual NPP, is vice versa depending

reporting: Forest, Grassland, Cropland, Wetlands, Settlements and Other Land. It is recognized that these land categories are a mixture of land cover (e.g. Forest, Grassland, Wetlands) and land use (e.g., Cropland Settlements) classes (IPCC 2003).

Information about land area is needed to estimate carbon stocks and emissions and removals of greenhouse gases associated with Land Use, Land-Use Change and Forestry (LULUCF) activities. The categories are broad enough to classify all land areas in most countries and to accommodate differences in national classification system (IPCC 2003).

## Methods

In practice, countries use methods including annual census, periodic surveys and remote sensing to obtain area data (IPCC 2003). For Slovenian sites of the ManForCBD project, were used vector layers of the Agricultural land use map (scale 1:5,000) (Ministry of Agriculture, Forestry and Food) from 2012, reclassified in 25 national land use classes to 6 main LULUCF categories.

For Italian sites the Corine Land Cover maps (scale 1:100,000) from 2006 were used.

## Measurement units

Status: Percentage (area of land use category/ total area\*100)

## Measurement time

Before [Y]

After [N] (longer time period is necessary)

## Feasibility

on silvicultural management and the permanence time of the forest stand. It allows avoiding overstocking in the juvenile phase, creating and maintaining the condition for the full expression of individual growth rate and pattern (i.e. a sufficient available growing space) both at stemwood and branchwood level, the latter including the well-balanced crown expansion and the related rooting system growth. Where both an increased lifespan (as compared to traditional rotations) and consistent silvicultural practices are foreseen and applied in forest management, the goal of a high carbon stock and of a sustained sequestration ability may be reached. The issue may be well-addressed to all forests where different, complementary purposes to wood production, are being pursued as in most of cases today. The rationale may be summarized as “working with high

<sup>2</sup> Landscape of Italian and Slovenian sites refers to a squared area of 100 km<sup>2</sup> around the forest management units.



growing stocks”. Furthermore to increase rotation length promotes a more differentiated and complex structure and creates new microhabitats and related ecological niches.

#### Methods

We measure the rise in rotation length at stand level, the level to which we apply silvicultural treatments.

#### Measurement units

Status: year

Changes: year

#### Measurement time

Before [Y]

After [Y]

#### Feasibility

Scale of application	Specific knowledge	Costs	Interaction with other indicators
Stand, Compartment	2 (inventory technician)	2	Carbon stock, Basal Area, Diameter distribution, Novel practices

### Results from ManFor C.BD.

Indicator name	Site	Before	After
Rotation length	Cansiglio	90-100 years	140 years
Rotation length	Vallombrosa	120 years	160 years

### References

- Eler K., Plestenjak G., Ferlan M., Čater M., Simončič P., Vodnik D. 2013 - *Soil respiration of karst grasslands subjected to woody-plant encroachment*. European Journal of Soil Science 64 (2): 210-218
- Fritts H. C. 1976 - *Tree rings and climate*. Academic Press Inc. (London) Ltd., London.
- Harley G. L., Grissino-Mayer H. D. 2012 - *Tree Rings as Environmental Indicators* in: The Berkshire Encyclopedia of sustainability: measurements, indicators and research methods for sustainability: 359-361.
- IPPC 2003 - *Good Practice Guidance for Land Use, Land-Use Change and Forestry*. The Intergovernmental Panel on Climate Change (IPCC). 632 p.

## Assessing indicators of forest ecosystem health

Bertolotto P.<sup>1</sup>, Calienno L.<sup>2</sup>, Conforti M.<sup>3</sup>, D'Andrea E.<sup>1</sup>, Lo Monaco A.<sup>2</sup>, Magnani E.<sup>1</sup>, Marinšek A.<sup>4</sup>, Micali M.<sup>1</sup>, Picchio R.<sup>2</sup>, Sicuriello F.<sup>1</sup>, Spina R.<sup>2</sup>, Venanzi R.<sup>2</sup>

Received 16/03/2016- Accepted 06/04/2016 - Published online 19/07/2016

### C/N Ratio in soil

**Full text** The C/N ratio (C:N) or carbon-to-nitrogen ratio is a ratio of the mass of carbon to the mass of nitrogen in a substance.

**Rationale** All organic matter is made up of substantial amounts of carbon (C) combined with lesser amounts of nitrogen (N). The balance of these two elements in an organism is called the carbon-to-nitrogen ratio (C/N ratio). Forest management affects soil C and N storage, due to the variation of microclimatic characteristics and input of new organic matter. The general trends found by Johnson and Curtis (2001) indicate that high C/N ratio of residues are incorporated into soils over the short-term, with soil C re-equilibrating to lower levels and C/N ratios becoming more similar to background as time passes. Saw-log forest removal tend to increase the amount of carbon and nitrogen in the soil in the short term. This process is due to the rapid incorporation of small size carbon material into the soil, which allow microorganisms to decompose the carbon molecules and release the excess of nutrients to the soil. The abundance of carbon is taken by microbes which at the same time helps the

immobilization of nitrogen in the soil. Bacteria play a very important role in the decomposition process. Bacteria quickly break down organic matter and most efficiently when their substratum source has a C:N ratio of about 25:1. This means that each part of bacteria substratum should contain, ideally, 25 times as much carbon as nitrogen. If C/N ratios are higher, decomposition will be slow.

**Possible pitfalls** This indicator was evaluated in a short period (two years), therefore it can be utilized only in the first years after the harvesting.

#### Methods

ISO 10694 (C), ISO 13878 (N);

Principle: dry combustion of sample (weights around 0.2 g) at temperature of 1350 °C, followed by IR and thermal conductance analysis of burned gases (CO<sub>2</sub> and N<sub>2</sub>).

**Measurement units** No units. C/N is an index.

**Measurement time** Soil samples should be collected in autumn, after growing season. C and N from soil samples can be measured anytime in a laboratory.

Before [Y]

After [Y]

#### Feasibility

Scale of application	Specific knowledge	Costs	Interaction with other indicators
Stand	3	3	Deadwood

### Results from ManFor C.BD.

Indicator name	Site	Before	After
C/N ratio	Trnovo, Snežnik, Kočevski Rog (logged 50 % of growing stock)	32	41
C/N ratio	Trnovo, Snežnik, Kočevski Rog (logged 100 % of growing stock)	30	38
C/N ratio	Cansiglio Innovative	19	22
C/N ratio	Cansiglio Control	21	21
C/N ratio	Cansiglio Traditional	20	21
C/N ratio	Chiarano Traditional	18	21
C/N ratio	Chiarano Innovative 80	19	21
C/N ratio	Chiarano Innovative 40	19	20
C/N ratio	Mongiana Innovative	17	17
C/N ratio	Mongiana Control	18	18
C/N ratio	Mongiana Traditional	17	18

The indicator is well describing the phenomena of increasing C/N ratio in the case of Dinaric fir-beech forests, where high logging intensities were applied. On the base of average C/N ratio, it demonstrates increasing of C/N values towards an unfavourable ratio between C and N for the organic matter decomposition.

### Humus form

**Full text** Sequence and "morpho-functional"

<sup>1</sup> CNR-IBAF, National Research Council of Italy, Institute for Agro-environmental and Forest Biology, Monterotondo (RM), Italy

<sup>2</sup> DAFNE - Department of Agriculture, Forests, Nature and Energy, Università della Tuscia, Italy

<sup>3</sup> CNR-ISAFOM, National Research Council of Italy, Institute for Agriculture and Forest Mediterranean Systems, Rende (CS), Italy.

<sup>4</sup> Department of Forest Ecology, Slovenian Forestry Institute, Ljubljana, Slovenia

features of organic (OL, OF, OH, H) and underlying organo-mineral horizons (A, AE, Aa) of soil.

**Rationale** The humus form is the part of the topsoil that is strongly influenced by organic matter and coincides with the sequence of organic (OL, OF, OH, H) and underlying organo-mineral horizons (A, AE, Aa) (Zanella et al. 2011a, Zanella et al. 2011b). Humus forms are influenced by biotic (litter amount and quality, soil-dwelling microbial and animal communities) and abiotic factors (climate, bedrock, soil type) according to a variety of key processes (Ponge 2003, Ponge et al. 2014, Andreetta et al. 2015). More recently, humus forms have been found to be significant indicators of soil organic carbon (SOC) storage (Andreetta et al. 2011, Bonifacio et al. 2011, De Nicola et al. 2014, De Vos et al. 2015), also in correlation with stand age and management of forest (Hedde et al. 2008, Faggian et al. 2012)

### Systematics

Systematics of humus form follows the most recent "morpho-functional" classification (Zanella et al. 2011a, Zanella et al. 2011b) based on biological, ecological and pedological features of organic and organo-mineral horizons observed in the field. This systematics consists in a complete set of identification keys based on diagnostic horizons and environmental factors. It can be applied to every kind of soil (never water saturated and saturated – submerged soils) the upper part of which (topsoil) is not permanently disturbed by human activity.

In the 2013 (Jabiol et al. 2013) this systematics has been extended and modified, without any change in diagnostic horizons, in order to embrace a wide array of humus forms at worldwide level and it has been proposed for inclusion in the World Reference Base for Soil Resources (IUSS 2006).

### Humus form ecology

Humus forms play a key central role in the functional biodiversity of terrestrial ecosystems. They are the stable, visible result of most animal and microbial life in the soil and, in a feedback process, they condition the development of terrestrial plant, animal and microbial communities (Ponge 2003, Ponge et al. 2013).

MULL, MODER and MOR, are the main "humus form system" (Zanella 2014) characterized by the same ecological determinants (biotic, abiotic or mixed), correspond to a scale of decreasing nutrient availability, biological diversity and activity and increasing colder conditions. Animals, microbes and plants are involved in positive (building forces) and negative (stabilizing forces) feed-back relationships most of them taking place in the humus profile (Ponge et al. 2010). AMPHI and TANGEL,

insert more recently in the classification (Zanella et al. 2009), correspond respectively to a strongly seasonal and extremely high mountain climatic condition upon calcareous bedrock.

MULL is characterized by an intense mixing of organic matter with mineral matter with rapid turnover ( $\leq 3$  years) and high activity of edaphic fauna especially of anecic earthworms. These forms develop on temperatures not limiting the biological activity and non-acid substrates, usually carbonate bedrocks and easily degradable litter (C/N  $< 30$ ). Both the mineralization and the humification are quick and organic horizons are generally limited to short and thick OL and OF horizons. Organic matter is decomposed in 1 or 2 years and SOC is mainly stored in the "Clay-Humic Complexes" within the A horizon.

MODER is characterized by a less rapid transformation of litter by meso and macrofauna arthropods, (springtails, isopods, Diptera etc.) and fungi, resulting in the accumulation of organic humus. These forms develop on low temperatures, from soil carbonates or acidified or with a easily biodegradable litter unfavorable to the life of anecic and endogeous earthworms. Moder is characterized by slow (2-7 years) decomposition and carbon is stored in both horizons organic (humic components) than in those organo-mineral.

MOR is characterized by slow transformation and accumulation of undecayed plant debris, with a sharp transition to the mineral soil. These forms develop on low temperatures, usually on silicate rocks or without easily biodegradable litter. The decomposition of litter occurs primarily to mushroom (often mycorrhizal) and the edaphic fauna activities is very poor. Mor is characterized by very slow ( $> 7$  years) decomposition and SOC is stored in both horizons organic (humic components) than in those organo-mineral.

AMPHI ("twin humus") develop on calcareous substrates and it shows both characters of Mull (biomacro-structured organo-mineral horizon) and Moder (accumulated organic humus), due to periodically milder (warmer and humid soil-climate conditions in strongly seasonal Alpine and Mediterranean environments. SOC is stored both in organic horizons (humic components) and in "Clay-Humic Complexes" within the A horizon.

TANGEL expresses particular characters at high elevation and on hard calcareous rocks with slow litter turnover due to low temperature, summer drought or excess of carbonates. For the most of the year faunal activities and decomposition of organic matter are strongly limited by mountain

climate and temperature, continental distribution of rainfall, higher in summer. SOC is stored in organic horizons (humic components).

### Methods

The experimental design was planned in three phases:

1. macroscopic description of humus form profile in the field;
2. samples collection for each horizon and storage at 4°C;
3. laboratory analysis: estimation of organic

carbon ISO 10694, total nitrogen ISO 13878 and pH of A horizon ISO 10390;

4. determination of humus form.

**Measurement units** No units. Humus form is a quality indicator.

### Measurement time

Humus samples should be collected in autumn, after growing season. C, N and pH from soil samples can be measured anytime in a laboratory.

Before [Y]

After [Y]

### Feasibility

Scale of application	Specific knowledge	Costs	Interaction with other indicators
Stand	3	3	Deadwood, Soil C/N

### Results from ManFor C.BD.

The experimental design involved Cansiglio, Chiarano and Mongiana sites and it provided 27 samples of humus within each site (9 for each treatment), collected before and repeated after the implementation of the silvicultural treatments. Overall 162 profiles of humus were detected for a total of 477 analyzed samples. A wide range of humus forms has been found in the two samplings. All humus forms found in the three sites are "Terroform" that is never submerged and / or saturated in water, except for a few days a year. In Cansiglio and Chiarano sites, where the bedrock is limestone with pH of A horizon sub-acid to neutral ranging from 5.5 to 6.7, humus forms has been classified as MULL or AMPHI. In Mongiana site instead, bedrock is silicate and the organic-mineral horizon (A, AE, E) gives a reaction from strongly acid to acidic, with a pH ranging from 3.8 to 5.1, humus forms has been classified as MODER or MOR (Fig.1).

The effect of treatments has involved most OL and OF horizons with a trend from less active forms to more active ones. The opening of the canopy, which changes the amount of water and solar energy that reaches the soil and the different intake of litter, can lead to a change of micro-climatic conditions. In particular it has detected a change of the horizon thickness OF, diagnostic feature for humus forms determination.

In Cansiglio and Chiarano sites where predominate AMPHI and MULL humus systems has detected a decrease horizon OF probably because of increased activation of earthworms anecici responsible for the decomposition of litter and incorporation of organic matter within the A horizon.

In Mongiana site, where MODER and MOR were predominant, because of the acidic conditions not suitable for earthworms, we observed an increase of OF. This can be explained by the activation of the decomposer fauna of the soil (i.e. arthropodos).

Indicator name	Site	Time	EUMULL	MESOMULL	OLIGOMULL	DYSMULL	LEPTOAMPHI	EUMACROAMPHI	HEMIMODER	EUMODER	DYSMODER	HEMIMOR	HUMIMOR
Humus form Innovative	Cansiglio	Before				7	1	1					
		After			5	2			2				
Humus form Control	Cansiglio	Before				3							
		After	1			3	1		4				
Humus form Traditional	Cansiglio	Before			1	2							
		After		2	5	1			6				
Humus form Traditional	Chiarano	Before		2	3	2	1						
		After	2		3	4			1				
Humus form l80	Chiarano	Before	2		2	4				1			
		After	1	2	1	4	1						
Humus form l40	Chiarano	Before	2	2		5							
		After	3	3	3	3							
Humus form Innovative	Mongiana	Before							8				
		After							7	2			
Humus form Control	Mongiana	Before							4	4	1		
		After							5	2	2		
Humus form Traditional	Mongiana	Before							6		1		2
		After							4	1	3		1

**Table 1-** Number of humus forms collected before and after for each silvicultural treatment.

## GHG emissions - 2.1

The Criterion 2 (Maintenance of Forest Ecosystem Health and Vitality) includes the “Deposition and concentration of air pollutants on forest and other wooded land” among its indicators (FOREST EUROPE 2015).

**Full text** Deposition of air pollutants on forest and other wooded land, classified by N, S and base cations.

**Rationale** This indicator is one of the basic figures of forest operation planning and it is useful for various purposes. GHG emissions should be assessed. Planning, design and execution of forest operation in silvicultural treatments shall take into consideration also the potential impacts due to air pollutions.

Furthermore, this indicator is mainly linked to indicator 5.1, 5.2 (MCPFE 2003).

## Methods

Yard pollutant emissions due to the extraction operations were determined as described in Vusic et al. (2013). Emissions generated from the fuel were calculated as the sum of emissions produced by fuel combustion (Efc) and emissions produced during the fuel production, transport, and distribution (Efp). The emissions related to lubricant consumption were calculated as the sum of the emissions produced by both the production processes (Eop) and the reprocessing of used oils for the purposes of combustion (Eor). The values were referred to CO<sub>2</sub>eq.

### Measurement units

Status: g

Changes: g per m<sup>3</sup>

### Measurement time

During [Y]

Before [N]

After [N]

### Feasibility

Scale of application	Specific knowledge	Costs	Interaction with other indicators
Single yard or typology	2 (inventory technician)	2	5.1-5.2

## Results from ManFor C.BD.

Indicator name	Site	Value
CO <sub>2</sub> eq (g m <sup>-3</sup> )	Cansiglio Traditional	54000
CO <sub>2</sub> eq (g m <sup>-3</sup> )	Cansiglio Innovative 1	51000
CO <sub>2</sub> eq (g m <sup>-3</sup> )	Chiarano Traditional	13500
CO <sub>2</sub> eq (g m <sup>-3</sup> )	Chiarano Innovative 1	12900
CO <sub>2</sub> eq (g m <sup>-3</sup> )	Chiarano Innovative 2	13100
CO <sub>2</sub> eq (g m <sup>-3</sup> )	Mongiana Traditional	75000
CO <sub>2</sub> eq (g m <sup>-3</sup> )	Mongiana Innovative 1	78000
CO <sub>2</sub> eq (g m <sup>-3</sup> )	Tarvisio Traditional	98100
CO <sub>2</sub> eq (g m <sup>-3</sup> )	Tarvisio Innovative 1	94800
CO <sub>2</sub> eq (g m <sup>-3</sup> )	Tarvisio Innovative 2	99100

## Tree wounds - 2.4

The Criterion 2 (Maintenance of Forest Ecosystem Health and Vitality) includes the “Forest and other wooded land with damage, classified by primary damaging agent (abiotic, biotic and human induced)” among its indicators (FOREST EUROPE 2015).

**Full text** Forest and other wooded land with damage, classified by primary damaging agent (abiotic, biotic and human induced) and by forest type.

**Rationale** This indicator is one of the basic figures of after harvesting evaluation and useful for various purposes. An important aspect to be considered in forest operation planning is the impacts

on the environment, especially on residual trees. A range of 0–30% of damaged trees due to forest operations may be considered tolerable. Furthermore, this indicator is mainly linked to indicator 1.2, 1.4.

## Methods

Above ground damage was determined by visually inspecting all standing trees. Once a wound was detected, the following data were recorded: tree diameter at breast height (DBH); hierarchical and geographical positions of the tree within the stand; location, size, and depth of the wound. These parameters were translated into numerical classes. Wound size and depth classes were multiplied each other to obtain a synthetic damage severity index. Wounds with an index larger than 6 were considered severe, and capable of affecting tree growth, quality and survival.

### Measurement units

Status: %

Changes: % per ha

### Measurement time

Before [N]

After [Y]

### Feasibility

Scale of application	Specific knowledge	Costs	Interaction with other indicators
Single yard or typology of silvicultural operation	2 (inventory technician)	2	1.2-1.4

## Results ManFor C.BD.

Indicator name	Site	Value
Trees wound (%)	Cansiglio Traditional	0 %
Trees wound (%)	Cansiglio Innovative	0 %
Trees wound (%)	Chiarano Traditional	44 %
Trees wound (%)	Chiarano Innovative 40	50 %
Trees wound (%)	Mongiana Traditional	38 %
Trees wound (%)	Mongiana Innovative	20 %
Trees wound (%)	Tarvisio Traditional	6 %
Trees wound (%)	Tarvisio Innovative 1	2 %
Trees wound (%)	Tarvisio Innovative 2	0 %
Trees wound (%)	Chiarano Innovative 80	56 %

## QBS-ar variation

### Full text Variation of Soil Biological Quality.

**Rationale** An important aspect to be considered in forest operation planning is the impact on the environment, especially on soil during forest operations (compaction, rutting, soil mixing and displacement). This indicator is one of the basic

Scale of application	Specific knowledge	Costs	Interaction with other indicators
Single yard or typology	2 (inventory technician)	2	---

## Results from ManFor C.BD.

Indicator name	Site	Value
QBS-ar variation (%)	Cansiglio Traditional	65 %
QBS-ar variation (%)	Cansiglio Innovative	40 %
QBS-ar variation (%)	Chiarano Traditional	72 %
QBS-ar variation (%)	Chiarano Innovative 40	33 %
QBS-ar variation (%)	Chiarano Innovative 80	53 %
QBS-ar variation (%)	Mongiana Traditional	57 %
QBS-ar variation (%)	Mongiana Innovative	49 %
QBS-ar variation (%)	Tarvisio Traditional	72 %
QBS-ar variation (%)	Tarvisio Innovative 1	33 %
QBS-ar variation (%)	Tarvisio Innovative 2	53 %

## Other potential indicators related to forest ecosystem health

In forest Ecosystem, dynamics are quite slow and the lifespan of the project ManFor C.BD. did not allow to follow them. Other useful indicators will be presented here, but without testing them to avoid the creation of misleading data.

### Recruitment

**Full text** Recruitment of forest habitat type

Scale of application	Specific knowledge	Costs	Interaction with other indicators
Stand	2	2	Regeneration

### Regeneration

**Full text** Regeneration of forest habitat type (FHT) dominant species.

**Rationale** The regeneration may be defined as the process of stand renewal by means of self-sown seeds, root suckers (adventitious roots), coppicing or artificially-sown seeds. The result of regeneration is an established young growth with the height ranging between  $0 \text{ m} < h < 1.3 \text{ m}$ .

figures of after harvesting evaluation and useful for various purposes.

### Methods

For the microarthropods extraction and QBS-ar index application, three soil cores  $100 \text{ cm}^2$  and  $10 \text{ cm}$  deep were sampled in each soil typology. Microarthropods were extracted using a Berlese-Tullgren funnel; the specimens were collected in a preserving solution and identified to different taxonomic levels (class for Myriapoda and order for Insecta, Chelicerata and Crustacea) using a stereo microscope. Soil quality was estimated with the QBS-ar index (Parisi et al. 2005, Blasi et al. 2013).

### Measurement units

Status: %

Changes: % per ha

### Measurement time

Before [Y]

After [Y]

### Feasibility

(FHT) dominant species (Lexerød and Eid, 2005).

**Rationale** The recruitment is defined as the share of dominant and co-dominant tree species with diameter at breast height  $\geq X \text{ cm}$ .

Recruitment (addressed by Klopčič and Bončina 2011, Nagel et al. 2014 and many others) is well investigated and explained in the ecosystem disturbance studies while the biodiversity studies mostly neglect it. However, because one of the items of the conservation status definition (the conservation status of its typical species is also favorable) directly addresses the viability of the tree-species composition of a FHT, the indicator is relevant. The context of the conservation status of FHT also should be understood as sustainable development of FHT. In this context, recruitment is the indicator of the possibility of a FHT to survive in the long run.

### Methods

Counting tree species individuals with certain dimensions on the permanent sample plots.

### Feasibility

Successful regeneration is the precondition of sustainable forest habitat type development. A sufficient number of saplings and small trees is also an indicator of good environmental conditions (local climate, wildlife carrying capacity).

### Methods

Counting tree species saplings and small trees ( $h < 1.3 \text{ m}$ ) on the permanent sample plots.

## Feasibility

Scale of application	Specific knowledge	Costs	Interaction with other indicators
Stand	2	3	Regeneration

### Herbivories damage on regeneration

**Full text** Herbivory may be defined as the process whereby the animal eats or browses palatable tree species such as white fir, maple sp., etc.

**Rationale** Herbivory/browsing is the process

that undermines successful regeneration of forest stands.

### Methods

Counting damaged small trees (completely or partly browsed tops) on the permanent sample plots.

### Feasibility

Scale of application	Specific knowledge	Costs	Interaction with other indicators
Stand	2	3	Wildlife carrying capacity, Regeneration

## References

- Andreetta A., Cecchini G., Bonifacio E., Comolli R., Vingiani S., Carnicelli S. 2016 - *Tree or soil? Factors influencing humus form differentiation in Italian forests*. *Geoderma* 264: 195-204.
- Andreetta A., Ciampalini R., Moretti P., Vingiani S., Poggio G., Matteucci G., Tescari F., Carnicelli S. 2011 - *Forest humus forms as potential indicators of soil carbon storage in Mediterranean environments*. *Biol. Fertil. Soils* 47: 31-40.
- Bonifacio E., Falsone G., Petrillo M., 2011 - *Humus forms, organic matter stocks and carbon fractions in forest soils of northwestern Italy*. *Biol. Fertil. Soils* 47: 555-566.
- Brêthes A., Brun J.J., Jabiol B., Ponge J.F., Toutain F. 1995 - *Classification of forest humus forms: a French proposal*. *Ann Sci For*, 52: 535-546. <http://dx.doi.org/10.1051/forest:19950602> Chauvat.
- De Nicola C., Zanella A., Testi A., Fanelli G., Pignatti S. 2014 - *Humus forms in a Mediterranean area (Castelporziano Reserve, Rome, Italy): Classification, functioning and organic carbon storage*. *Geoderma* 235-236: 90-99.
- De Vos B., Cools N., Ilvesniemi H., Vesterdal L., Vanguelova E., Carnicelli S. 2015 - *Bench-mark values for forest soil carbon stocks in Europe: results from a large scale forest soil survey*. *Geoderma* 251-152: 33-46.
- Faggian V., Bini C., Zilioli D. M. 2012 - *Carbon stock evaluation from topsoil of forest stands in NE Italy*. *International journal of phytoremediation* 14(4): 415-428.
- Hedde M., Aubert M., Decaëns T., Bureau F. 2008 - *Dynamics of soil carbon in a beechwood chronosequence forest*. *Forest Ecology and Management* 255(1): 193-202.
- IUSS, ISRIC, FAO 2006 - *World reference base for soil resources - a framework for international classification, correlation and communication*. *World Soil Resources Report*. 103 p.
- Jabiol B., Zanella A., Ponge J. F., Sartori G., Englisch M., Van Delft B., Le Bayon, R. C. (2013). *A proposal for including humus forms in the World Reference Base for Soil Resources (WRB-FAO)*. *Geoderma* 192: 286-294.
- Johnson D.W., Curtis P.S. 2001 - *Effects of forest management on soil C and N storage: meta analysis*. *Forest Ecology and Management* 140: 227-238.
- Klopčič M., Boncina A. 2011 - *Stand dynamics of silver fir (Abies alba Mill.) - European beech (Fagus sylvatica L.) forests during the past century: a decline of silver fir?* *Forestry* 84: 259-271.
- Lexerød N., Eid T. 2005 - *Recruitment models for Norway spruce, Scots pine, birch and other broadleaves in young growth forests in Norway*. *Silva Fenn.* 39: 391-406.
- Nagel T.A., Diaci J., Jerina K., Kobal M., Rozenbergar D. 2014 - *Simultaneous influence of canopy decline and deer herbivory on regeneration in a conifer-broadleaf forest*. *Can. J. For. Res.* 45: 266-275.
- Ponge J. F., Zanella A., Sartori G., Jabiol B. 2010 - *Terrestrial humus forms: ecological relevance and classification*. DOI: 10.13140/RG.2.1.3713.5521, HAL, Id:hal-00521337 version 1.
- Ponge J.F. 2003 - *Humus forms in terrestrial ecosystems: A framework to biodiversity*. *Soil Biol. Biochem.* 35: 935-945.
- Ponge J.F. 2013 - *Plant-soil feedbacks mediated by humus forms: A review*. *Soil Biol. Biochem.* 57: 1048-1060.
- Ponge J.F., Sartori G., Garlato A., Ungaro F., Zanella A., Jabiol B., Obber S. 2014 - *The impact of parent material, climate, soil type and vegetation on Venetian forest humus forms: A direct gradient approach*. *Geoderma* 226-227: 290-299.
- Vusič D., Šušnjar M., Marchi E., Spina R., Zečić T., Picchio R. 2013 - *Skidding operations in thinning and shelterwood cut of mixed stands - Work productivity, energy inputs and emissions*. *Ecological Engineering* 61: 216-223.
- Zanella A. 2015 - *Novità sulle forme di humus*. In: Atti del II Congresso Internazionale di Selvicoltura. Progettare il futuro per il settore forestale, Firenze, 26-29 novembre 2014. Firenze: Accademia Italiana di Scienze Forestali. Vol. 1:81-90. ISBN 978-88-87553-21-5. <http://dx.doi.org/10.4129/2cis-az-nov>
- Zanella A., Jabiol B., Ponge J. F., Sartori G., De Waal R., Van Delft B., Englisch, M. 2009 - *Toward a European humus forms reference base*. *Studi Trentini di Scienze Naturali* 85: 145-151.
- Zanella A., Jabiol B., Ponge J.F., Sartori G., De Waal R., Van Delft B., Englisch M. 2011a - *A European morpho-functional classification of humus forms*. *Geoderma* 164: 138-145.
- Zanella A., Jabiol B., Ponge J.F., Sartori G., de Waal R., Van Delft B., Graefe U., Cools N., Katzensteiner K., Hager H., Englisch M., Brêthes A., Broll G., Gobat J.M., Brun J.J., Milbert G., Kolb E., Wolf U., Frizzera L., Galvan P., Koli R., Baritz R., Kemmers R., Vacca A., Serra G., Banas D., Garlato A., Chersich S., Klimo E., Langohr R. 2011b - *European Humus Forms Reference Base*.

# Assessing indicators of forest productive functions

D'Andrea E.<sup>1</sup>, Di Salvatore U.<sup>2</sup>, Ferretti F.<sup>2</sup>, Fabbio G.<sup>2</sup>

Received 16/03/2016- Accepted 06/04/2016 - Published online 19/07/2016

## Roundwood – 3.2

The Criterion 3 (Maintenance and Encouragement of Productive Functions of Forests (Wood and Non-Wood) includes the “Quantity and market value of roundwood” (FOREST EUROPE 2015).

**Full text** Value and quantity of marketed roundwood.

**Rationale** Marketed roundwood includes all wood removed from the forest with or without bark, including wood removed in its round form, or split, roughly squared or in other form and sold by the forest owner. Value added processing steps is not included. This indicator assesses the role that forest products play in the sequestration, cycling, or emission of carbon. Long term storage of carbon in products and landfills delays or reduces emissions. Use of wood products can also reduce emissions if they substitute products with higher carbon emission processes. As forest biomass is harvested, carbon is shifted from forest ecosystems to forest products held in products and landfills. The rate of accumulation of carbon in products can be influ-

enced by the mix of products and uses. In addition, marketed roundwood is a direct contribution to the income of the forest owner. This indicator is mainly linked to indicator 3.3 and 3.4.

### Methods

We calculated separately potential and real roundwood, because they give different information. The first can be used to evaluate the potential value of each silvicultural treatment. The second one is the real result considering the wood market and operators ability.

Roundwood volume can be estimated using a simple assortment table, which returns the different woody assortment in function of diameter. Real assortment can be assessed after treatments trough direct observation.

### Measurement units

Status: percentage of the different assortments.

### Measurement time

Before [N]

After [Y]

### Feasibility

Scale of application	Specific knowledge	Costs	Interaction with other indicators
Stand	1	1	Basal area, Carbon stock, Prompt response of stem growth

## Results from ManFor C.BD. Potential roundwood

Indicator name	Site	Saw Log (high value)	Log (middle value)	Fuel wood (low value)
Roundwood (%)	Cansiglio Innovative	42.19%	27.61%	30.20%
Roundwood (%)	Cansiglio Traditional	39.61%	29.78%	30.61%
Roundwood (%)	Chiarano Traditional	0.15%	38.96%	60.88%
Roundwood (%)	Chiarano I80	3.02%	40.55%	56.43%
Roundwood (%)	Chiarano I40	3.81%	44.38%	51.81%
Roundwood (%)	Lorenzago Area 1 Innovative	79.66%	0.42%	19.92%
Roundwood (%)	Lorenzago Area 1 Traditional	80.00%	0.00%	20.00%
Roundwood (%)	Lorenzago Area 2 Innovative	74.26%	7.18%	26.39%
Roundwood (%)	Lorenzago Area 2 Traditional	57.97%	27.53%	55.70%
Roundwood (%)	Mongiana Innovative	44.39%	25.83%	29.79%
Roundwood (%)	Mongiana Traditional	19.77%	45.28%	34.00%

<sup>1</sup> CNR-IBAF, National Research Council of Italy, Institute for Agro-environmental and Forest Biology, Monterotondo (RM), Italy

<sup>2</sup> Consiglio per la Ricerca in Agricoltura e l'Analisi dell'Economia Agraria, Forestry Research Centre (CREA-SEL), Arezzo, Italy



## Real roundwood

Site	Structural timber	Roundwood %		Pallet parquet	Wood biomass	Fuelwood
		Sawlog	Log			
Cansiglio Total	-	-	-	11.7	-	88.3
Vallombrosa Chiarano	not available					
Innovative 40	-	-	-	-	-	100
Innovative 80	-	-	-	-	-	100
Traditional	-	-	-	-	-	100
Mongiana Innovative	-	56.1	24.6	-	-	19.3
Traditional	-	47.0	27.7	-	-	25.3
Bosco Pennataro Turkey oak forest	-	-	-	-	-	100
Mixed forest	-	-	-	-	-	100
Lorenzago Area 1 Innovative	88.4	-	-	11.6	-	-
Traditional	85.1	-	-	14.9	-	-
Lorenzago Area 2 Innovative	99.8	-	-	0.2	-	-
Tarvisio Total	-	79.6	-	-	18.6	1.8

# Assessing indicators of forest vegetation diversity, stand structure and tree canopy arrangement

Becagli C.<sup>1</sup>, Bertini G.<sup>1</sup>, Cantiani P.<sup>1</sup>, Chiavetta U.<sup>1</sup>, Di Salvatore U.<sup>1,3</sup>, Fabbio G.<sup>1</sup>, Ferretti F.<sup>1</sup>, Kutnar L.<sup>2</sup>, Skudnik M.<sup>4</sup>

Received 16/03/2016- Accepted 06/04/2016 - Published online 19/07/2016

## Diversity of tree species – 4.1 (Slovenia)

The Criterion 4 (Maintenance, Conservation and Appropriate Enhancement of Biological Diversity in Forest Ecosystems) includes the “Area of forest and other wooded land, classified by number of tree species occurring” among its indicators (FOREST EUROPE 2015).

**Full text** Area of forest and other wooded land, classified by number of tree species occurring and by forest type.

**Rationale** The tree species composition is an indicator used by the Ministerial Conference for the Protection of Forests in Europe (Forest Europe) and is, therefore, comparable throughout Europe. However, the comparisons of tree species composition only make sense, if the corresponding ecological, economic and social conditions are also taken into consideration. These preconditions change from region to region and also over time.

## Methods

The assessment of tree species is performed in permanent sampling areas (comparable between statuses in different periods).

The cover of tree species can be evaluated by different scales (e.g. Braun-Blanquet, Barkman, Londo) transferable to %.

The cover of tree species can be estimated in separate vertical layers (e.g. upper-tree layer, lower-tree layer).

## Measurement units

Status: Number per hectare (or surface in m<sup>2</sup>)/

Cover (in %) per hectare (or surface in m<sup>2</sup>).

Changes: Number per hectare (or surface in m<sup>2</sup>)

/Cover (in %) per hectare (or surface in m<sup>2</sup>)

## Measurement time

Before [Y]

After [Y]

## Feasibility

Scale of application	Specific knowledge	Costs	Interaction with other indicators
Plot or stand level	3	2	Other indicators of plant/biodiversity and 4.3 Naturalness

## Results from ManFor C.BD. (Slovenia)

Indicator name	Site	Before	After
Diversity of tree species (Mean number of tree layer species)	8-Kočevski Rog; 9-Snežnik; 10-Trnovo	5.8 species per 400m <sup>2</sup> plot (min: 3 species; max: 10 species)	6.2 species per 400m <sup>2</sup> plot (min: 4 species; max: 10 species)
Tree species composition (Mean cover of main tree species)	8-Kočevski Rog; 9-Snežnik; 10-Trnovo	Upper tree layer: <i>Fagus sylvatica</i> : 38.9% <i>Abies alba</i> : 14.5% <i>Picea abies</i> :10.1%	Upper tree layer: <i>Fagus sylvatica</i> : 18.1% <i>Abies alba</i> : 5.3% <i>Picea abies</i> : 5.2%
Tree species composition (Mean cover of main tree species)	8-Kočevski Rog; 9-Snežnik; 10-Trnovo	Lower tree layer: <i>Fagus sylvatica</i> : 29.2% <i>Abies alba</i> : 3.5% <i>Picea abies</i> : 1.6%	Lower tree layer: <i>Fagus sylvatica</i> : 14.0% <i>Abies alba</i> : 1.0% <i>Picea abies</i> :0.8%

The mean cover of the main tree species was measured in 27 plots in 3 Slovenian sites (8-Kočevski Rog; 9-Snežnik; 10-Trnovo) for three silvicultural

measures (control without logging, logging 50 % and 100 % of growing stock on 0.4 ha) before and two years after the logging.

<sup>1</sup> Consiglio per la Ricerca in Agricoltura e l'Analisi dell'Economia Agraria, Forestry Research Centre (CREA-SEL), Arezzo, Italy

<sup>2</sup> Department of Forest Ecology, Slovenian Forestry Institute, Ljubljana, Slovenia

<sup>3</sup> EcoGeoFor, Dipartimento di Bioscienze e Territorio, Università degli Studi del Molise, Pesche (IS), Italy

<sup>4</sup> Department of Forest and Landscape Planning and Monitoring, Slovenian Forestry Institute, Ljubljana, Slovenia

Mean cover for the 3 Slovenian sites (n=9)	CONTROL		LOGGING 50% GS		LOGGING 100% GS	
	Before	After	Before	After	Before	After
<b>UPPER TREE LAYER</b>						
<i>Fagus sylvatica</i> (%)	39.9	33.9	30.4	20.4	46.4	0.0
<i>Abies alba</i> (%)	9.0	8.5	21.2	7.4	13.3	0.0
<i>Picea abies</i> (%)	13.4	10.6	13.2	5.1	3.6	0.0
<b>LOWER TREE LAYER</b>						
<i>Fagus sylvatica</i> (%)	25.6	26.7	33.1	8.6	29.0	6.8
<i>Abies alba</i> (%)	2.8	1.7	3.0	1.4	4.6	0.0
<i>Picea abies</i> (%)	1.9	1.9	2.4	0.4	0.5	0.0

### Tree species composition - 4.1 (Italy)

**Full text** Stand classified by number of tree species occurring.

**Rationale** Forest biodiversity and dynamics depend considerably on the composition of tree species. Multispecies forest and other wooded land are usually richer in biodiversity than monospecific forest and other wooded land. However, it has to be considered that some natural forest ecosystems have only one or two tree species, e.g. natural sub-alpine spruce stands.

### Methods

Permanent plots were established to quantify the number of different tree species. Measurements were repeated before and after any silvicultural operations to determine their impact on the parameter.

#### Measurement units

Status: Number of trees.

Changes: The same as status.

Measurement time

Before [Y]

After [Y]

#### Feasibility

Scale of application	Specific knowledge	Costs	Interaction with other indicators
Plot or stand level	3	2	Other indicators of plant/biodiversity and 4.3 Naturalness

### Results from ManForC.BD.

Indicator name	Site	Before	After
Number of tree species	Cansiglio Innovative	1	1
Number of tree species	Cansiglio Traditional	1	1
Number of tree species	Chiarano Traditional	1	1
Number of tree species	Chiarano Innovative 80	1	1
Number of tree species	Chiarano Innovative 40	1	1
Number of tree species	Lorenzago Area 1 Innovative	3	3
Number of tree species	Lorenzago Area 1 Traditional	4	3
Number of tree species	Lorenzago Area 2 Innovative	4	3
Number of tree species	Lorenzago Area 2 Traditional	4	4
Number of tree species	Mongiana Innovative	1	1
Number of tree species	Mongiana Traditional	1	1
Number of tree species	Pennataro Mixed forest	14	13
Number of tree species	Pennataro Turkey oak forest	13	12
Number of tree species	Tarvisio Innovative 1	6	5
Number of tree species	Tarvisio Innovative 2	4	4
Number of tree species	Tarvisio Traditional	5	4
Number of tree species	Vallombrosa Innovative	1	1
Number of tree species	Vallombrosa Traditional	1	1

### Naturalness – 4.3 (Slovenia)

The Criterion 4 (Maintenance, Conservation and Appropriate Enhancement of Biological Diversity in Forest Ecosystems) includes the “Area of forest and other wooded land by class of naturalness” among its indicators (FOREST EUROPE 2015).

**Full text** Describe the Area of forest and other wooded land, classified by “undisturbed by man”, by “semi-natural” or by “plantations”.

**Rationale** Indicator Naturalness is associated with the tree species composition (also with understory species). The concept of naturalness has been proposed and used for describing the

ecological value of forest ecosystems, evaluating management efforts to conserve biodiversity, and identifying natural, old-growth forests for purposes of establishing protected areas. The necessity for harmonized reporting motivated an investigation of variables that can be used to quantify and assess forest naturalness. National forest inventories (NFIs) could be sources of the most comprehensive and extensive data available (e.g. as reference values) for assessing naturalness in particular study sites.

### Methods

The assessment of tree species compositions is performed in permanent sampling areas (comparable between statuses in different periods).

Tree species composition, in a certain stratum, is compared with reference values (e.g. forest type, habitat type, forest community).

Mathematical calculation of the deviation from the model (natural) state.

#### Measurement units

Status: % of undisturbed area comparing to the reference values

Changes: % of undisturbed area comparing to the reference values

#### Measurement time

Before[Y]

After [Y]

#### Feasibility

Scale of application	Specific knowledge	Costs	Interaction with other indicators
Plot, Stand or Landscape	4	2	Other indicators of plant/biodiversity 4.1 Tree species composition/Diversity of tree species

This indicator has not been tested by the project.

## Plant species richness (Slovenia)

**Full text** Number of vascular plant species - all seed-bearing plants (the gymnosperms and angiosperms) and the pteridophytes (including the ferns, lycophytes, and horsetails) - in forest and other wooded land, classified by number of vascular plant species occurring.

**Rationale** Plant species richness is commonly used to evaluate the biodiversity status of forests, and it is comparable throughout Europe. Plant species richness is simply the number of vascular plant species present in a sample, community, or taxonomic group. Species richness is one component of the concept of species diversity, which also incorporates evenness, that is, the relative abundance of species.

Species diversity is one component of the broader concept of biodiversity.

### Methods

Assessment of vascular plant species in a permanent sampling area (comparable between statuses in different periods).

Counting the number of different vascular plant species.

The number of vascular plant species can be estimated for each separate vertical layer (e.g. herb, shrub layer).

### Measurement units

Status: Number per hectare (or surface in m<sup>2</sup>).

Changes: Number per hectare (or surface in m<sup>2</sup>).

### Measurement time

Before[Y]

After [Y]

### Feasibility

Scale of application	Specific knowledge	Costs	Interaction with other indicators
Plot or Stand	5	3	Other indicators of plant/biodiversity 4.1 Tree species composition/Diversity of tree species 4.3 Naturalness

## Results from ManFor C.BD.

Indicator name	Site/treatment	Before (before implementation of silvicultural measures in 2012)	After (after implementation of silvicultural measures in 2014)
Plant species richness (total number of vascular species)	8-Kočevski Rog; 9-Snežnik; 10-Trnovo	151 species	250 species
Plant species richness (mean, minimum and maximum number of vascular species)	8-Kočevski Rog; 9-Snežnik; 10-Trnovo	48.8 species per 400m <sup>2</sup> plot (min: 29 species; max: 68 species)	70.4 species per 400m <sup>2</sup> plot (min: 41 species; max: 106 species)
Plant species richness (mean, minimum and maximum number of herb species*)	8-Kočevski Rog; 9-Snežnik; 10-Trnovo	37.2 species per 400 m <sup>2</sup> plot (min: 21 species; max: 51 species)	57.0 species per 400 m <sup>2</sup> plot (min: 33 species; max: 87 species)

\* Herb species – including all non-woody (non-ligneous) plants (also without mosses and lichens)

Indicator name	Site	Before (mean species number per plot)	After (mean species number per plot)
Plant species richness	Kočevski Rog	47.4	65.9
Plant species richness	Snežnik	55.8	78.1
Plant species richness	Trnovo	43.1	67.3

Indicator name	Treatment	Before (mean species number per plot)	After (mean species number per plot)
Plant species richness	Control	50.7	50.6
Plant species richness	50% logging	49.2	73.3
Plant species richness	100% logging	46.4	87.4

## Vertical vegetation structure (Slovenia)

**Full text** Number and cover of vertical vegetation layers (tree, shrub, herb and moss layer).

**Rationale** The vertical vegetation structure indicators is used for assessment of current status and development of forest stands. This indicator is used for evaluation of biodiversity status of forests. In general, more developed vertical structure with

more layers is favourable for biodiversity in broader sense.

### Methods

The visual estimation of the percentage cover of each vertical vegetation layer (moss, herb, shrub, and tree layer) may be performed according to the ICP-Forests protocol (Canullo et al. 2011). The definitions of vertical vegetation layers are following:

- moss layer (i.e. bryophytes and lichens),
- herb layer (all non-ligneous, and ligneous, including eventual seedling and browsed trees under 0.5 m height)
- shrub layer (only ligneous and all climbers of a height between 0.5 m and 5 m),
- tree layer (only ligneous and all climbers with a height over 5 m).

Besides the cover of vegetation layers, share of bare soil and of surface rock could be estimated.

### Measurement units

Status: Number of vertical vegetation layer per plot/site; cover of vertical vegetation layer (in %).

Changes: Number of vertical vegetation layer per plot/site; Cover of vertical vegetation layer (in %).

### Measurement time

Before[Y]

After [Y]

### Feasibility

Scale of application	Specific knowledge	Costs	Interaction with other indicators
Plot or Stand	3	2	Other indicators of plant/biodiversity 4.1 Tree species composition/Diversity of tree species and indicator 4.3 Naturalness and Plant species richness indicator.

## Results from ManForC.BD.

Indicator name	Site/treatment	Before	After
Vertical vegetation structure (mean cover of layers)	8-Kočevski Rog; 9-Snežnik; 10-Trnovo	Tree layer cover: 95.4% Shrub layer cover: 7.1% Herb layer cover: 27.5% Moss layer cover: 24.9%	Tree layer cover: 48.0% Shrub layer cover: 7.3% Herb layer cover: 47.5% Moss layer cover: 22.9%

Indicator name	Site	Before (mean herb-layer cover (in %) per plot)	After (mean herb-layer cover (in %) per plot)
Vertical vegetation structure	Kočevski Rog	23.6	40.6
Vertical vegetation structure	Snežnik	21.7	38.9
Vertical vegetation structure	Trnovo	37.2	63.1

Indicator name	Treatment	Before (mean herb-layer cover (in %) per plot)	After (mean herb-layer cover (in %) per plot)
Vertical vegetation structure	Control	25.0	23.3
Vertical vegetation structure	50% logging	33.3	51.1
Vertical vegetation structure	100% logging	24.1	68.1

## Plant diversity indexes (Slovenia)

**Full text** Plant species diversity and evenness.

**Rationale** A plant diversity index is a measure that reflects how many different plant species occur in a forest type (or stand or plot), and simultaneously takes into account how evenly plant species are distributed within this forest type (or stand or plot). The value of a plant diversity index increases both when the number of types increases and when evenness increases. For a given number of species, the value of a plant diversity index is maximized when all species are equally abundant.

### Methods

The Shannon index or Shannon's diversity index is calculated as follows:

$$H' = -\sum_{i=1}^R p_i \ln p_i$$

The Simpson index is calculated as follows:

$$\lambda = \frac{1}{\sum_{i=1}^R p_i^2}$$

where  $p_i$  is a relative cover of species  $i$  in a record.

### Measurement units

Status: Values of Shannon/Simpson index.

Changes: Values of Shannon/Simpson index.

### Measurement time

Before[Y]

After [Y]

## Feasibility

Scale of application	Specific knowledge	Costs	Interaction with other indicators
Plot or Stand level	4	3	Other indicators of plant/biodiversity 4.1 Tree species composition/Diversity of tree species 4.3 Naturalness and Plant species richness indicator/Vertical vegetation structure)

## Results from ManForC.BD.

Indicator name	Site/treatment	Before	After
Plant diversity indexes (mean values of diversity indexes)	8-Kočevski Rog; 9-Snežnik; 10-Trnovo	Shannon index: 2.413 Simpson index: 0.801	Shannon index: 3.074 Simpson index: 0.881
Plant diversity indexes (mean values of Simpson index)	(control plots without logging, plots with logging 50% of GS, plots with logging 100% of GS)	Control: 0.811 50% logging: 0.812 100% logging: 0.782	Control: 0.822 50% logging: 0.896 100% logging: 0.926

Indicator name	Site	Before (mean value of Shannon index per plot)	After (mean value of Shannon index per plot)
Plant diversity indexes	Kočevski Rog	2.53	3.01
Plant diversity indexes	Snežnik	2.40	3.30
Plant diversity indexes	Trnovo	2.31	2.91

## Stand structural complexity

**Full text** Indexing changes towards the structural, compositional and functional diversity at the stand scale.

**Rationale** A large share of cultivated forests over Europe present a diffuse uniformity of stand structures and of a nearly monospecific composition, either because of the autoecology of component tree species (e.g. beech forests) or due to former choices of removing less valuable (in terms of timber) or less productive species. Current trend of forest management is aimed at improving the overall stand complexity to meet the manifold goals addressed over the same forest or forest patch, i.e. the stand level. Efforts are therefore made to mimic a more “natural” physiognomy through the use of consistent silvicultural practices, designed to maintain the affordable cost of interventions and to

improve as well the three components of diversity i.e. the structural, compositional and functional types at the operative or stand level.

### Methods

Permanent plots to measure and compare the change in progress with a series of suited indexes descriptive of types of diversity. Measurements have to be repeated before and after any silvicultural operations to determine their impact on the parameters concerning structural, compositional and functional diversity.

### Measurement units

Status: Value of descriptive indexes

Changes: The same as for status

### Measurement time

Before [Y]

After [Y]

### Feasibility

Scale of application	Specific knowledge	Costs	Interaction with other indicators
Stand	2 (inventory technician)	2	Carbon stock, Basal Area, Diameter distribution

## Results from ManForC.BD.

Aggregation Index [CE] (Clark and Evans 1954)

Indicator name	Site	Before	After
CE	Cansiglio Innovative	1.22	1.38
CE	Cansiglio Traditional	1.24	1.34
CE	Chiarano Traditional	1.19	1.29
CE	Chiarano I80	1.19	1.29
CE	Chiarano I40	1.11	1.23
CE	Lorenzago Area 1 Innovative	0.90	0.86
CE	Lorenzago Area 1 Traditional	1.00	0.99
CE	Lorenzago Area 2 Innovative	1.03	0.80
CE	Lorenzago Area 2 Traditional	1.03	0.94
CE	Mongiana Innovative	1.14	1.21
CE	Mongiana Traditional	1.16	1.21
CE	Pennataro Mixed forest	0.97	1.13
CE	Pennataro Turkey oak forest	1.05	1.15
CE	Tarvisio Innovative1	0.94	1.07
CE	Tarvisio Innovative2	0.92	1.05
CE	Tarvisio Traditional	0.95	0.95
CE	Vallombrosa Innovative	1.32	1.41
CE	Vallombrosa Traditional	1.31	1.32

Height - Differentiation [TH] (Pommerening 2002)

Indicator name	Site	Before	After
TH	Cansiglio Innovative	0.07	0.07
TH	Cansiglio Traditional	0.06	0.06
TH	Chiarano Traditional	0.13	0.08
TH	Chiarano I80	0.14	0.12
TH	Chiarano I40	0.14	0.11
TH	Lorenzago Area 1 Innovative	0.46	0.46
TH	Lorenzago Area 1 Traditional	0.43	0.43
TH	Lorenzago Area 2 Innovative	0.27	0.25
TH	Lorenzago Area 2 Traditional	0.46	0.25
TH	Mongiana Innovative	0.11	0.11
TH	Mongiana Traditional	0.12	0.13
TH	Pennataro Mixed forest	0.29	0.30
TH	Pennataro Turkey oak forest	0.31	0.32
TH	Tarvisio Innovative1	0.24	0.28
TH	Tarvisio Innovative2	0.21	0.20
TH	Tarvisio Traditional	0.22	0.21
TH	Vallombrosa Innovative	0.12	0.14
TH	Vallombrosa Traditional	0.12	0.12

DHB - Differentiation [TH] (Pommerening 2002)

Indicator name	Site	Before	After
TD	Cansiglio Innovative	0.19	0.19
TD	Cansiglio Traditional	0.19	0.18
TD	Chiarano Traditional	0.25	0.18
TD	Chiarano I80	0.27	0.24
TD	Chiarano I40	0.26	0.23
TD	Lorenzago Area 1 Innovative	0.41	0.47
TD	Lorenzago Area 1 Traditional	0.44	0.44
TD	Lorenzago Area 2 Innovative	0.36	0.32
TD	Lorenzago Area 2 Traditional	0.50	0.35
TD	Mongiana Innovative	0.24	0.25
TD	Mongiana Traditional	0.25	0.25
TD	Pennataro Mixed forest	0.40	0.42
TD	Pennataro Turkey oak forest	0.41	0.43
TD	Tarvisio Innovative1	0.32	0.32
TD	Tarvisio Innovative2	0.30	0.32
TD	Tarvisio Traditional	0.30	0.31
TD	Vallombrosa Innovative	0.25	0.28
TD	Vallombrosa Traditional	0.22	0.23

Height diversity based on variance [STVIhtot] (Staudhammer and LeMay 2011)

Indicator name	Site	Before	After
STVIhtot	Cansiglio Innovative	0.05	0.04
STVIhtot	Cansiglio Traditional	0.06	0.07
STVIhtot	Chiarano Traditional	0.05	0.02
STVIhtot	Chiarano I80	0.06	0.04
STVIhtot	Chiarano I40	0.06	0.04
STVIhtot	Lorenzago Area 1 Innovative	0.99	0.99
STVIhtot	Lorenzago Area 1 Traditional	1.00	1.00
STVIhtot	Lorenzago Area 2 Innovative	0.62	0.55
STVIhtot	Lorenzago Area 2 Traditional	1.00	0.60
STVIhtot	Mongiana Innovative	0.10	0.11
STVIhtot	Mongiana Traditional	0.14	0.15
STVIhtot	Pennataro Mixed forest	0.63	0.63
STVIhtot	Pennataro Turkey oak forest	0.56	0.51
STVIhtot	Tarvisio Innovative1	0.27	0.15
STVIhtot	Tarvisio Innovative2	0.24	0.20
STVIhtot	Tarvisio Traditional	0.29	0.23
STVIhtot	Vallombrosa Innovative	0.12	0.14
STVIhtot	Vallombrosa Traditional	0.10	0.10

Diameter diversity based on variance [STVIDbh] (Staudhammer and LeMay 2011)

Indicator name	Site	Before	After
STVIDbh	Cansiglio Innovative	0.31	0.27
STVIDbh	Cansiglio Traditional	0.28	0.26
STVIDbh	Chiarano Traditional	0.20	0.17
STVIDbh	Chiarano I80	0.22	0.18
STVIDbh	Chiarano I40	0.20	0.13
STVIDbh	Lorenzago Area 1 Innovative	1.00	1.00
STVIDbh	Lorenzago Area 1 Traditional	1.00	1.00
STVIDbh	Lorenzago Area 2 Innovative	0.67	0.60
STVIDbh	Lorenzago Area 2 Traditional	1.00	0.60
STVIDbh	Mongiana Innovative	0.46	0.49
STVIDbh	Mongiana Traditional	0.50	0.49
STVIDbh	Pennataro Mixed forest	0.88	0.83
STVIDbh	Pennataro Turkey oak forest	0.77	0.75
STVIDbh	Tarvisio Innovative1	0.37	0.33
STVIDbh	Tarvisio Innovative2	0.36	0.36
STVIDbh	Tarvisio Traditional	0.42	0.41
STVIDbh	Vallombrosa Innovative	0.42	0.46
STVIDbh	Vallombrosa Traditional	0.29	0.29

BAL modified [BALMOD] (Schröder and Gadow 1999)

Indicator name	Site	Before	After
BALMOD	Cansiglio Innovative	0.66	0.46
BALMOD	Cansiglio Traditional	0.67	0.53
BALMOD	Chiarano Traditional	0.59	0.33
BALMOD	Chiarano I80	0.63	0.40
BALMOD	Chiarano I40	0.68	0.39
BALMOD	Lorenzago Area 1 Innovative	3.46	3.22
BALMOD	Lorenzago Area 1 Traditional	3.44	3.02
BALMOD	Lorenzago Area 2 Innovative	2.18	1.32
BALMOD	Lorenzago Area 2 Traditional	2.97	1.80
BALMOD	Mongiana Innovative	0.93	0.84
BALMOD	Mongiana Traditional	0.95	0.86
BALMOD	Pennataro Mixed forest	1.39	1.00
BALMOD	Pennataro Turkey oak forest	1.28	0.83
BALMOD	Tarvisio Innovative1	1.04	0.55
BALMOD	Tarvisio Innovative2	1.02	0.74
BALMOD	Tarvisio Traditional	1.07	0.88
BALMOD	Vallombrosa Innovative	0.77	0.62
BALMOD	Vallombrosa Traditional	0.77	0.77

Haegy [Hg] (Haegy 1974)

Indicator name	Site	Before	After
Hg	Cansiglio Innovative	0.77	0.34
Hg	Cansiglio Traditional	0.79	0.47
Hg	Chiarano Traditional	1.77	0.66
Hg	Chiarano I80	1.67	0.64
Hg	Chiarano I40	2.27	0.63
Hg	Lorenzago Area 1 Innovative	1.56	1.09
Hg	Lorenzago Area 1 Traditional	1.60	1.39
Hg	Lorenzago Area 2 Innovative	1.82	0.82
Hg	Lorenzago Area 2 Traditional	1.21	1.31
Hg	Mongiana Innovative	1.22	0.84
Hg	Mongiana Traditional	1.19	0.90
Hg	Pennataro Mixed forest	2.12	0.82
Hg	Pennataro Turkey oak forest	1.98	0.72
Hg	Tarvisio Innovative1	3.14	1.05
Hg	Tarvisio Innovative2	3.24	1.68
Hg	Tarvisio Traditional	2.81	2.16
Hg	Vallombrosa Innovative	1.29	0.72
Hg	Vallombrosa Traditional	1.45	1.40

Haegy modified [Hg mod] (Pretzsch 2010)

Indicator name	Site	Before	After
Hg mod	Cansiglio Innovative	0.97	0.47
Hg mod	Cansiglio Traditional	0.95	0.59
Hg mod	Chiarano Traditional	1.88	0.79
Hg mod	Chiarano I80	1.91	0.78
Hg mod	Chiarano I40	2.29	0.81
Hg mod	Lorenzago Area 1 Innovative	2.37	1.91
Hg mod	Lorenzago Area 1 Traditional	2.19	1.80
Hg mod	Lorenzago Area 2 Innovative	2.00	0.97
Hg mod	Lorenzago Area 2 Traditional	1.65	1.23
Hg mod	Mongiana Innovative	1.25	0.96
Hg mod	Mongiana Traditional	1.24	0.89
Hg mod	Pennataro Mixed forest	2.11	0.92
Hg mod	Pennataro Turkey oak forest	1.99	0.76
Hg mod	Tarvisio Innovative1	2.84	1.04
Hg mod	Tarvisio Innovative2	2.70	1.40
Hg mod	Tarvisio Traditional	2.57	1.85
Hg mod	Vallombrosa Innovative	1.34	0.70
Hg mod	Vallombrosa Traditional	1.39	1.33

Site	SH	SI	EV	Aggr.	Ming	SizDiff
Kočevski Rog 100% Before	2.52	0.91	1.36	0.6	0.26	0.52
Kočevski Rog 100% After	0	0	0	0	0	0
Kočevski Rog 50% Before	2.53	0.91	1.38	0.61	0.41	0.51
Kočevski Rog 50% After	2.39	0.9	1.67	0.62	0.41	0.51
Kočevski Rog 0% Before	2.65	0.92	1.1	0.6	0.63	0.52
Kočevski Rog 0% After	2.65	0.92	1.1	0.6	0.63	0.52
Snežnik 100% Before	2.31	0.88	1.58	0.58	0.35	0.51
Snežnik 100% After	0	0	0	0	0	0
Snežnik 50% Before	2.27	0.88	1.63	0.56	0.32	0.5
Snežnik 50% After	2.01	0.84	1.43	0.57	0.22	0.52
Snežnik 0% Before	2.32	0.88	1.22	0.57	0.48	0.52
Snežnik 0% After	2.32	0.88	1.22	0.57	0.48	0.52

SH: Shannon Index of diversity (Shannon, 1948);  
 SI: Simpson Index of diversity (Simpson 1949);  
 EV: Evenness (Lloyd and Ghelardi 1964);

Aggr: Aggregation (Hui et al.1998);  
 Ming: Species mingling (Füldner1995);  
 SizDiff: Size differentiation (Hui et al.1998)

## Gaps texture (Italy)

**Full text** Gaps size and spatial distributive pattern.

**Rationale** Gaps in canopy cover determine the amount of light, heat and precipitation reaching directly the forest floor.

Their size and distributive pattern affect inner microclimate, the establishment of vascular flora and tree spp. regeneration. Heat and water enhance the biological activity in the rooting layer and the rate of soil processes. Carbon stocking in the soil is also affected, it depending on soil properties, bedrock and local site-climate conditions as well.

Different species require a different amount and distribution of gaps in accordance with their auto-ecology.

## Methods

Permanent sampling area where to measure: number of gaps, total gaps area, area and perimeter of each gap, perimeter/area ratio, average surface, average perimeter.

Measurements have to be repeated before and after any silvicultural operations, to estimate their impact on canopy properties and on gap texture in the case.

### Measurement units

Status: number, m<sup>2</sup>, m

Changes: number, m<sup>2</sup>, m

### Measurement time

Before [Y]

After [Y]

### Feasibility

Scale of application	Specific knowledge	Costs	Interaction with other indicators
Stand	2 (inventory technician)	2	Carbon stock, Basal Area, Stand structural complexity

## Results from ManForC.BD.

Indicator name	Site	Crown cover %		Crown overlapping %	
		Before	After	Before	After
Gaps texture	Cansiglio Innovative	90.2	67.0	115.3	73.9
Gaps texture	Cansiglio Traditional	79.1	64.0	93.0	71.5
Gaps texture	Chiarano Traditional	78.6	49.3	99.5	52.8
Gaps texture	Chiarano I80	79.8	58.4	102.4	66.8
Gaps texture	Chiarano I40	80.6	59.7	107.8	71.5
Gaps texture	Mongiana Innovative	66.4	56.1	75.8	62.0
Gaps texture	Mongiana Traditional	65.4	54.9	77.0	61.7
Gaps texture	Tarvisio Innovative1	61.2	43.9	81.0	49.7
Gaps texture	Tarvisio Innovative2	64.4	46.6	83.5	53.6
Gaps texture	Tarvisio Traditional	56.1	46.9	71.2	57.4

## Novel silvicultural and management practices (Italy)

**Full text** Novel silvicultural practices: from mass to selective tending.

**Rationale** Many forest customarily devoted to timber production are nowadays managed according to manifold goals, i.e. wood production but also other non wood productions, biodiversity,

recreation, amenity and scenic value. Traditional rotations are in the meantime becoming longer and canonical silvicultural practices applied in the past, in full accordance with the former management models, may be adapted to the new scenarios and to multiple management goals. Into even-aged forests it basically means to move from a mass tending of standing crop to the selective tending of a number of



final crop trees, to ensure their “health and vitality” up to the farther regeneration time. This approach is economically more feasible because: aimed at spatially concentrating intermediate fellings all around selected trees; operates also in the co-dominant and dominant layers and this results in the higher exploited woody mass; breaks the uniformity of the stand structure usually one-storied and is the basis to build up a more differentiated and complex structure over the following permanence time; promotes the even residual specific diversity preserving other species at tree level; creates new habitats and related ecological niches. As for uneven-aged forests, the formal shift is basically from the single-tree to the small-group harvesting, promoting more easily enforceable technical operations and preserving as well patchy unevenness at the stand scale.

## Methods

Permanent sampling plots to measure and compare the changes in terms of harvested wood and of the indexes of tree size range and relative frequencies, biomass allocation per layer, stand structure evenness and specific diversity. Measurements have to be repeated before and after any silvicultural operations to determine their impact on stand texture.

### Measurement units

Status: Number of trees (tree density), allocation of number of trees per layer; relative tree size distributive patterns: basal area per layer and diameter distribution per layer.

Changes: The same as for status.

### Measurement time

Before [Y]

After [Y]

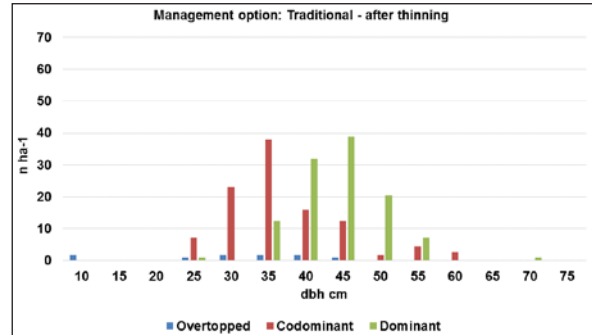
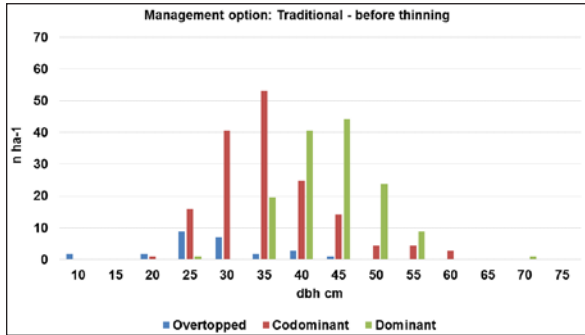
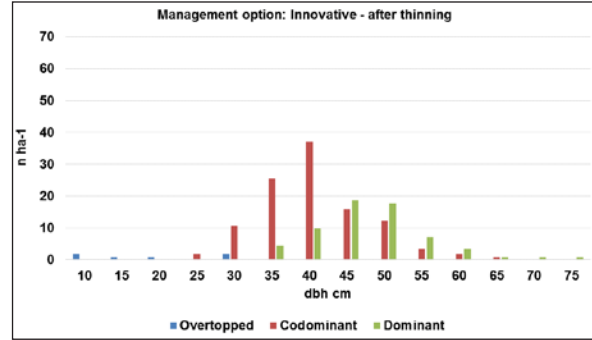
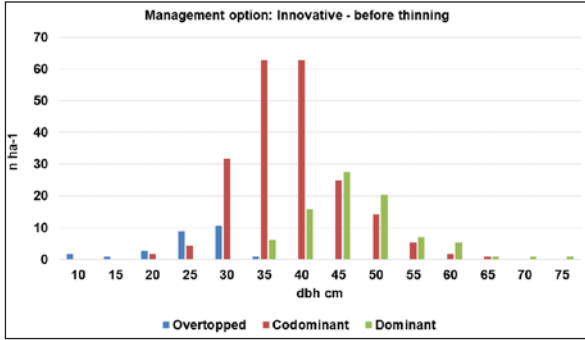
### Feasibility

Scale of application	Specific knowledge	Costs	Interaction with other indicators
Stand	2 (inventory technician)	2	Carbon stock, Basal Area, Diameter distribution

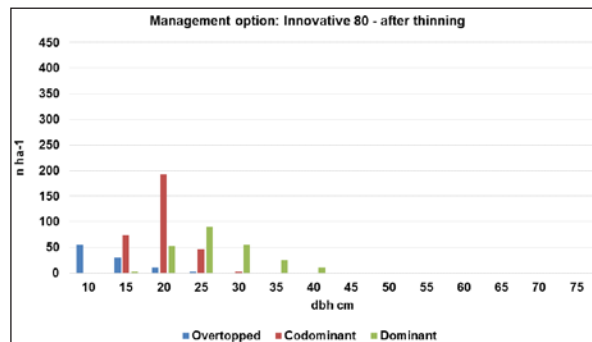
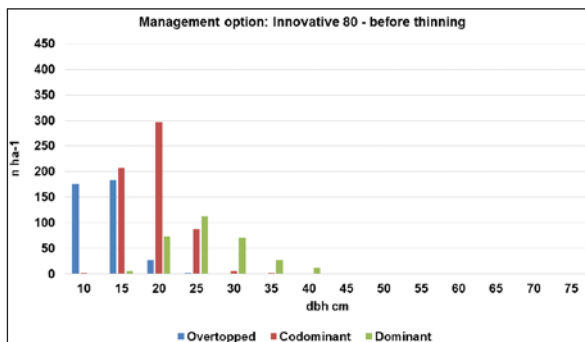
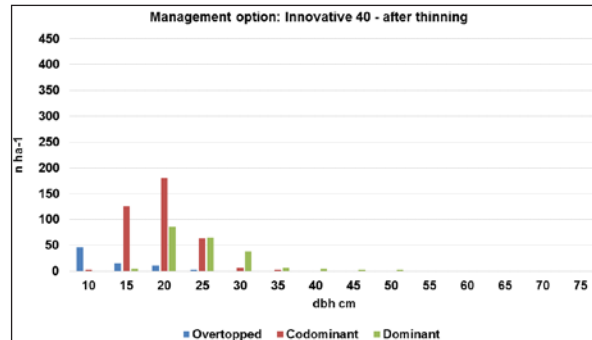
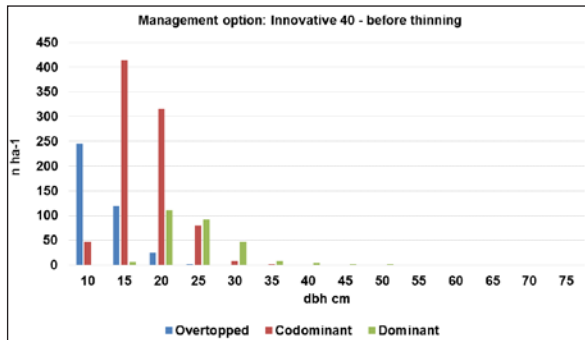
## Results from ManForC.BD.

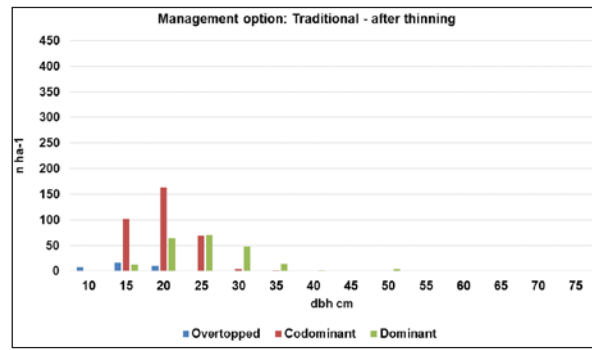
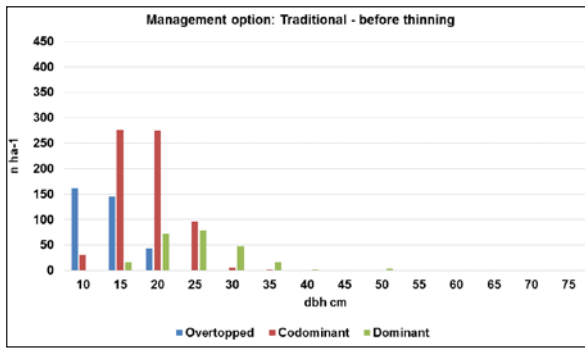
Indicator name	Site	Layer	Before	After	Indicator name	Site	Layer	Before	After
Tree density per layer (n ha <sup>-1</sup> )	Cansiglio Innovative	Dominant	85	64	Basal area per layer (m <sup>2</sup> ha <sup>-1</sup> )	Cansiglio Innovative	Dominant	15.1	11.7
		Codominant	210	110			Codominant	25.3	14.6
		Overtopped	26	5			Overtopped	1.6	1.7
Tree density per layer (n ha <sup>-1</sup> )	Cansiglio Traditional	Dominant	139	112	Basal area per layer (m <sup>2</sup> ha <sup>-1</sup> )	Cansiglio Traditional	Dominant	21.0	17.3
		Codominant	161	105			Codominant	17.0	11.9
		Overtopped	25	9			Overtopped	1.6	1.7
Tree density per layer (n ha <sup>-1</sup> )	Chiarano Traditiona	Dominant	241	218	Basal area per layer (m <sup>2</sup> ha <sup>-1</sup> )	Chiarano Traditional	Dominant	12.5	11.6
		Codominant	686	341			Codominant	19.0	10.9
		Overtopped	350	36			Overtopped	5.1	0.6
Tree density per layer (n ha <sup>-1</sup> )	Chiarano Innovative 80	Dominant	303	234	Basal area per layer (m <sup>2</sup> ha <sup>-1</sup> )	Chiarano Innovative 80	Dominant	17.0	13.5
		Codominant	603	314			Codominant	18.0	9.9
		Overtopped	391	96			Overtopped	5.4	1.4
Tree density per layer (n ha <sup>-1</sup> )	Chiarano Innovative 40	Dominant	272	207	Basal area per layer (m <sup>2</sup> ha <sup>-1</sup> )	Chiarano Innovative 40	Dominant	13.6	10.6
		Codominant	866	379			Codominant	21.8	11.4
		Overtopped	391	73			Overtopped	4.8	1.0
Tree density per layer (n ha <sup>-1</sup> )	Lorenzago Area 1 Innovative	Dominant	131	103	Basal area per layer (m <sup>2</sup> ha <sup>-1</sup> )	Lorenzago Area 1 Innovative	Dominant	30.6	23.7
		Codominant	110	95			Codominant	12.6	11.0
		Overtopped	446	400			Overtopped	10.0	8.5
Tree density per layer (n ha <sup>-1</sup> )	Lorenzago Area 1 Traditional	Dominant	120	95	Basal area per layer (m <sup>2</sup> ha <sup>-1</sup> )	Lorenzago Area 1 Traditional	Dominant	31.1	24.3
		Codominant	88	67			Codominant	15.7	11.2
		Overtopped	371	325			Overtopped	12.0	10.9
Tree density per layer (n ha <sup>-1</sup> )	Lorenzago Area 2 Innovative	Dominant	131	81	Basal area per layer (m <sup>2</sup> ha <sup>-1</sup> )	Lorenzago Area 2 Innovative	Dominant	25.0	16.2
		Codominant	180	74			Codominant	11.9	8.6
		Overtopped	170	60			Overtopped	6.7	3.3
Tree density per layer (n ha <sup>-1</sup> )	Lorenzago Area 2 Traditional	Dominant	95	81	Basal area per layer (m <sup>2</sup> ha <sup>-1</sup> )	Lorenzago Area 2 Traditional	Dominant	16.8	14.7
		Codominant	255	191			Codominant	33.2	25.0
		Overtopped	325	117			Overtopped	8.0	3.5
Tree density per layer (n ha <sup>-1</sup> )	Mongiana Innovative	Dominant	302	234	Basal area per layer (m <sup>2</sup> ha <sup>-1</sup> )	Mongiana Innovative	Dominant	30.0	23.5
		Codominant	150	118			Codominant	9.0	6.9
		Overtopped	75	66			Overtopped	2.6	2.2
Tree density per layer (n ha <sup>-1</sup> )	Mongiana Traditional	Dominant	219	184	Basal area per layer (m <sup>2</sup> ha <sup>-1</sup> )	Mongiana Traditional	Dominant	25.5	21.1
		Codominant	157	126			Codominant	10.3	7.6
		Overtopped	103	98			Overtopped	3.0	2.8
Tree density per layer (n ha <sup>-1</sup> )	Pennataro Mixed forest	Dominant	254	184	Basal area per layer (m <sup>2</sup> ha <sup>-1</sup> )	Pennataro Mixed forest	Dominant	23.8	16.8
		Codominant	145	91			Codominant	5.9	3.8
		Overtopped	1285	542			Overtopped	8.9	4.4
Tree density per layer (n ha <sup>-1</sup> )	Pennataro Turkey oak forest	Dominant	310	171	Basal area per layer (m <sup>2</sup> ha <sup>-1</sup> )	Pennataro Turkey oak forest	Dominant	24.6	15.9
		Codominant	192	96			Codominant	9.1	4.8
		Overtopped	1779	676			Overtopped	9.9	4.5
Tree density per layer (n ha <sup>-1</sup> )	Tarvisio Innovative 1	Dominant	357	226	Basal area per layer (m <sup>2</sup> ha <sup>-1</sup> )	Tarvisio Innovative 1	Dominant	21.2	16.5
		Codominant	645	241			Codominant	19.3	7.6
		Overtopped	500	124			Overtopped	7.3	1.8
Tree density per layer (n ha <sup>-1</sup> )	Tarvisio Innovative 2	Dominant	234	170	Basal area per layer (m <sup>2</sup> ha <sup>-1</sup> )	Tarvisio Innovative 2	Dominant	13.5	11.5
		Codominant	984	590			Codominant	21.8	12.2
		Overtopped	295	144			Overtopped	2.7	1.1
Tree density per layer (n ha <sup>-1</sup> )	Tarvisio Traditional	Dominant	213	188	Basal area per layer (m <sup>2</sup> ha <sup>-1</sup> )	Tarvisio Traditional	Dominant	14.0	12.6
		Codominant	841	640			Codominant	18.0	13.6
		Overtopped	383	245			Overtopped	3.7	2.3
Tree density per layer (n ha <sup>-1</sup> )	Vallombrosa Innovative	Dominant	242	157	Basal area per layer (m <sup>2</sup> ha <sup>-1</sup> )	Vallombrosa Innovative	Dominant	34.9	23.9
		Codominant	178	88			Codominant	17.5	9.3
		Overtopped	88	71			Overtopped	4.6	3.4
Tree density per layer (n ha <sup>-1</sup> )	Vallombrosa Traditional	Dominant	266	261	Basal area per layer (m <sup>2</sup> ha <sup>-1</sup> )	Vallombrosa Traditional	Dominant	30.9	30.3
		Codominant	215	211			Codominant	18.8	18.4
		Overtopped	107	101			Overtopped	4.6	4.4

### Cansiglio

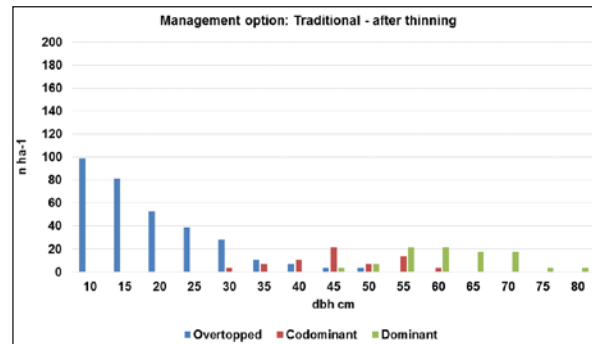
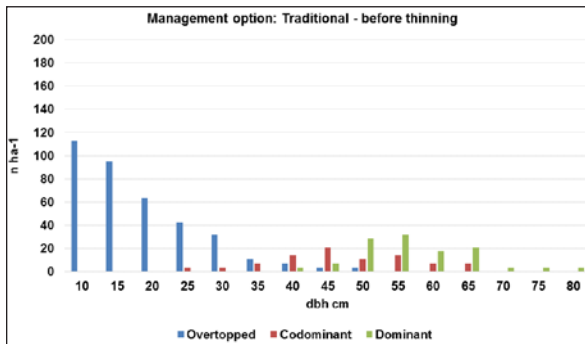
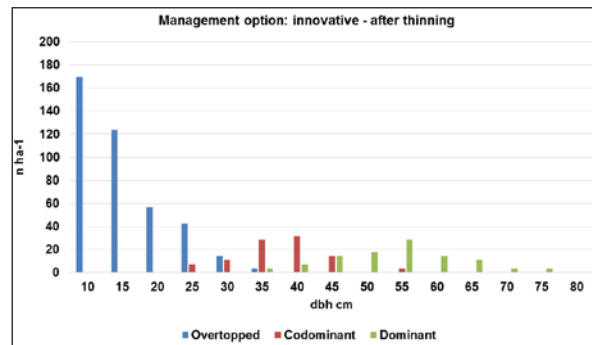
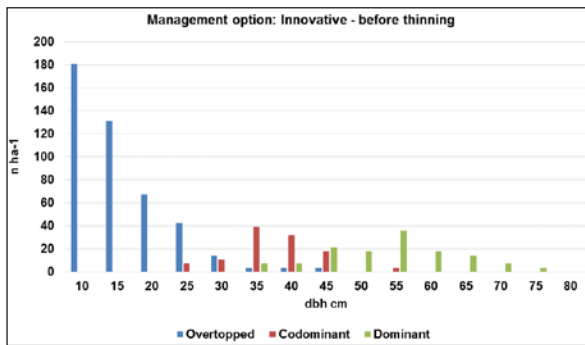


### Chiarano

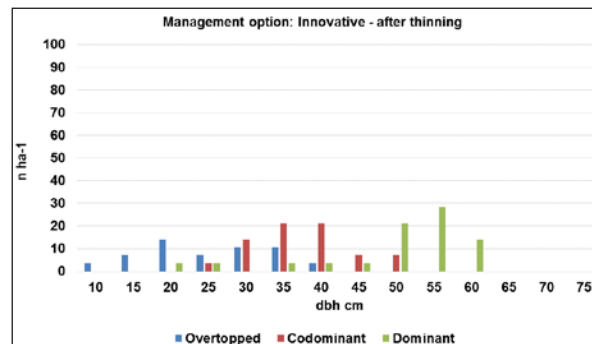
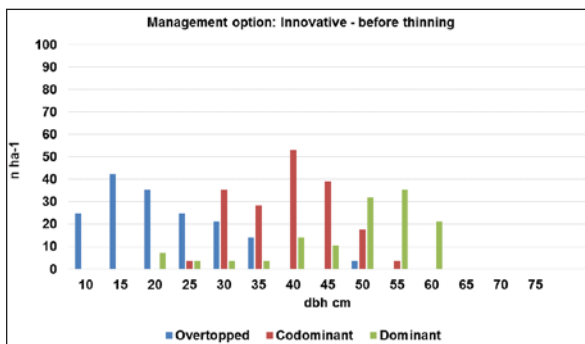


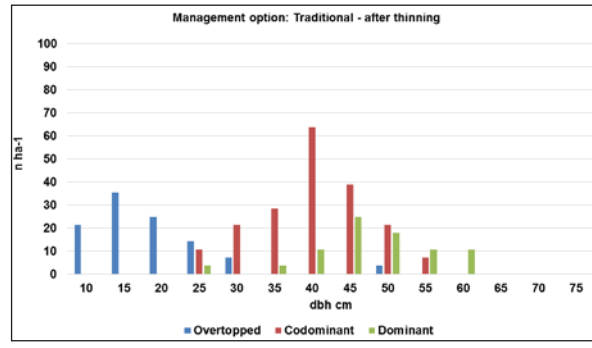
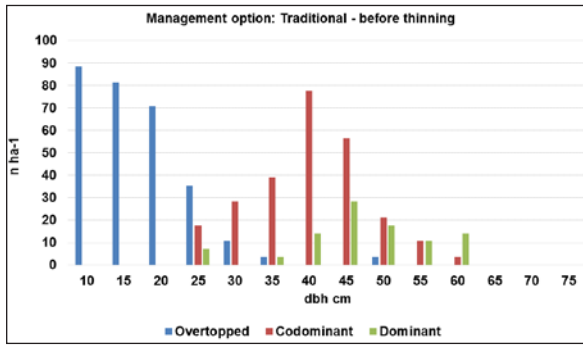


Lorenzago 1

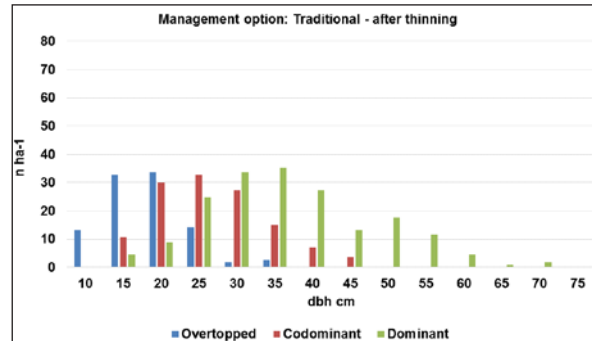
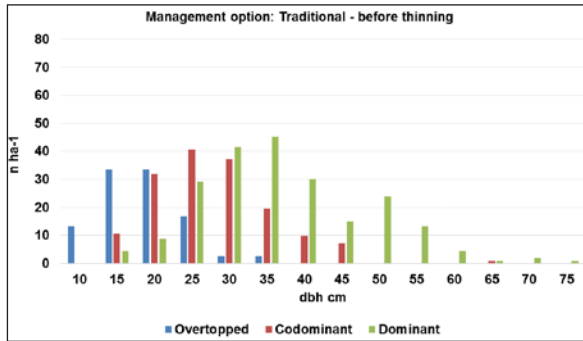
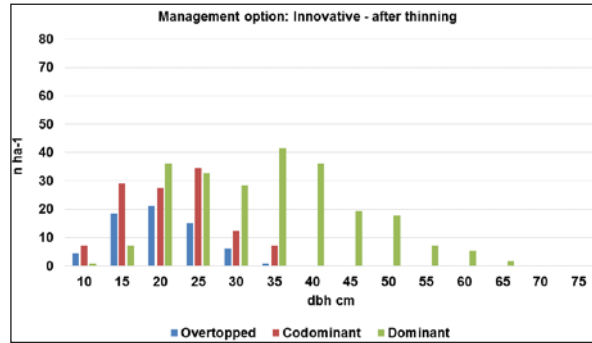
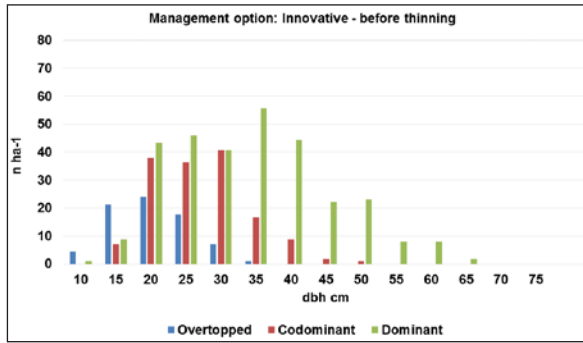


Lorenzago 2

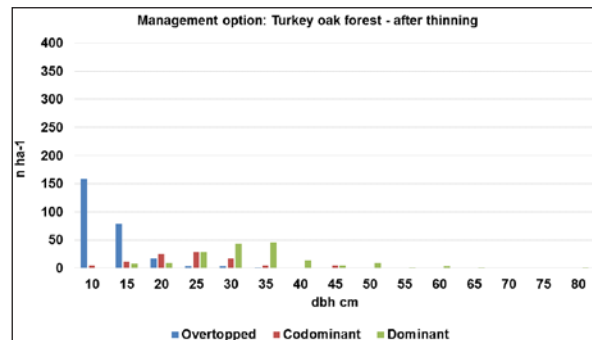
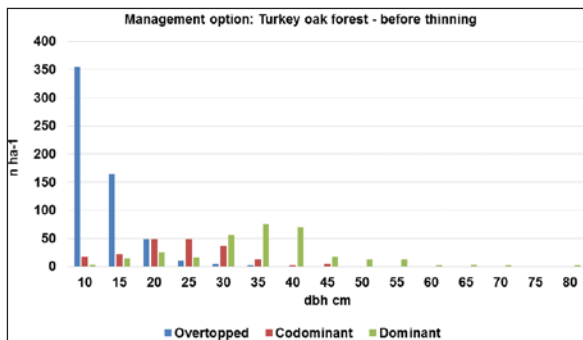


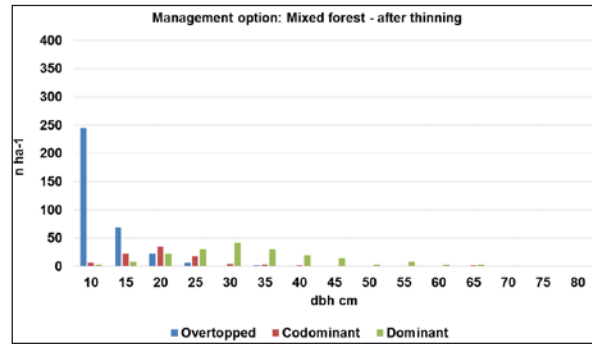
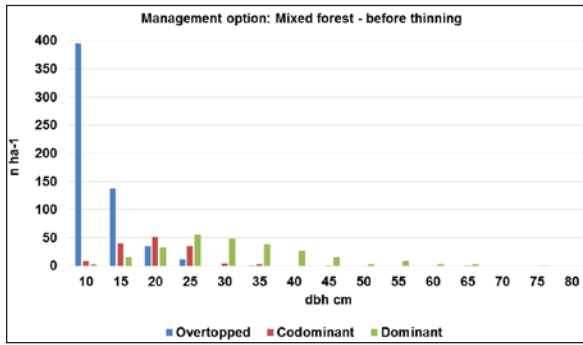


Mongiana

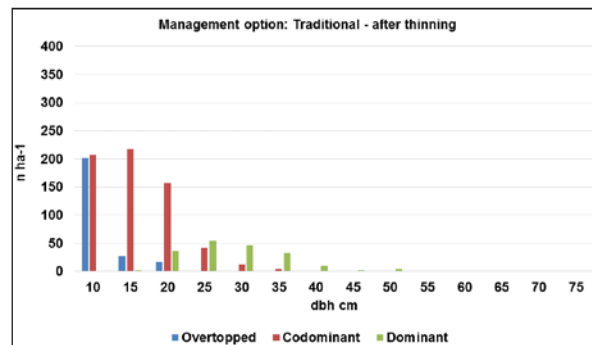
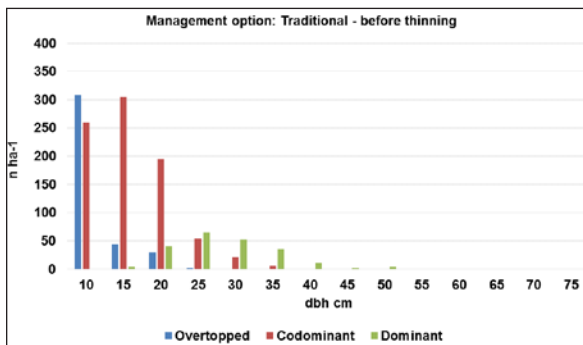
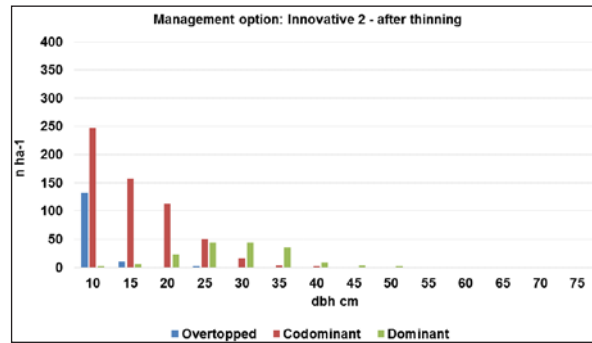
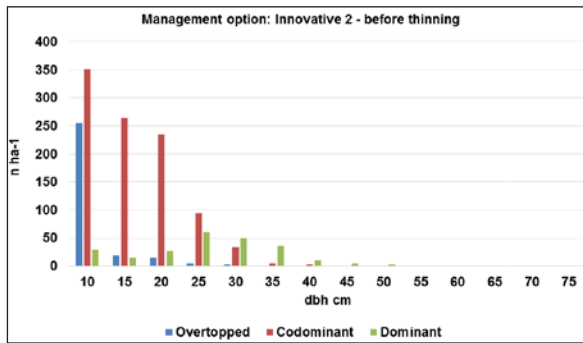
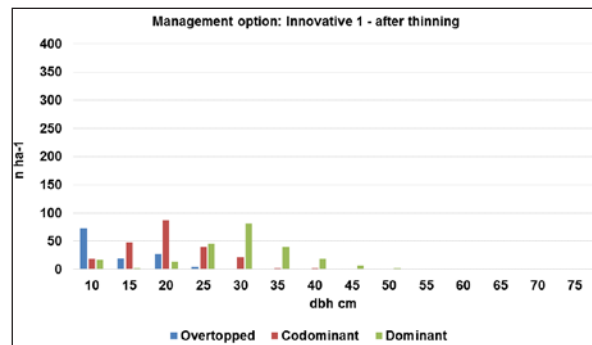
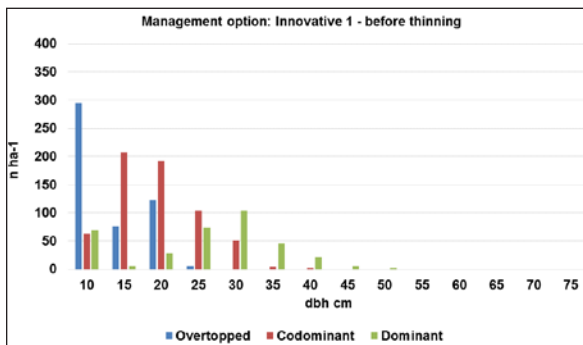


Pennataro

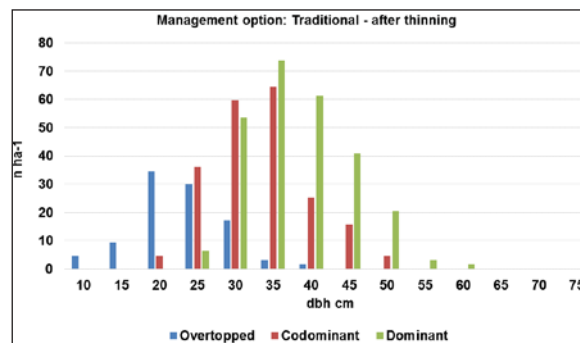
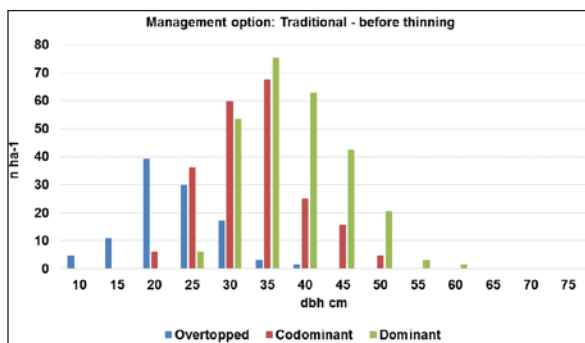
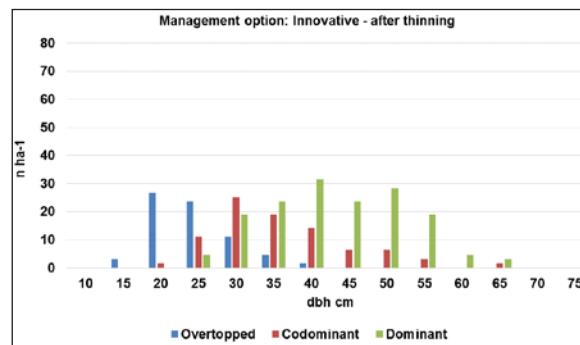
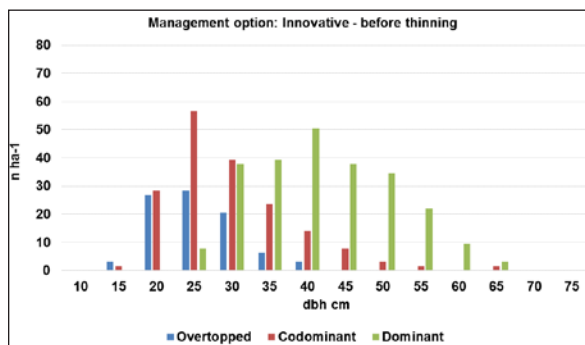




Tarvisio



## Vallombrosa



## Other potential indicators related to vegetation diversity

**Horizontal structure indicators** - share of different forest types within area: number and share of vegetation syntaxa (e.g. association, geographic variance, sub-association, facies); number and share of habitat types (e.g. Natura 2000 habitat types, PHYSIS habitat type, EUNIS habitat type, etc).

**Life forms** - based on the place of the plant's growth-point (bud) during seasons with adverse conditions: structure of Raunkiaer's life forms (e.g. share of Phanerophyte, Chamaephytes, Hemicryptophyte, Geophytes, Therophyte) (Raunkiaer 1934).

**Plant functional traits** - functional traits of species as indicator of species' persistence and recovery following habitat change or disturbance: Grime's CSR strategies (share of Competitor species (C; adapted to low stress and low levels of disturbance), Stress-tolerator species (S; adapted to high stress and low levels of disturbance), and Ruderal species (R; adapted to low stress and high levels of disturbance) (Grime 1977); LEDA trait based functional traits (e.g. Mean canopy height, Age of first flowering, Seed mass) (Kleyer et al. 2008); BIOLFLOR trait based functional traits (e.g. Vegetative propagation and dispersal, Leaf persistence, Pollen vector) (Klotz et al. 2002) etc.

**Plant species indicators** - presence/absence and status of key plant species or group of species: number, vitality and abundance of characteristic species (e.g. for association, geographic variance

habitat type); number, vitality and abundance of environmental sensitive species (e.g. shade tolerant species, cold site species, dry tolerant species, nutrient indicator species), etc.

## References

- AA. VV. Forest Europe 2015 - *State of Europe's Forests 2015*. <http://www.foresteurope.org/docs/fullsoef2015.pdf>
- Canullo, R., Starlinger, F., Granke, O., Fischer, R., Aamlid, D., Neville P., 2011 - *Assessment of ground vegetation. Manual Part VII-SPI*. In: ICP Forests. Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests. UNECE ICP Forests Programme Co-ordinating Centre, Hamburg
- Clark P., Evans F. 1954 - *Distance to nearest neighbor as a measure of spatial relationships in populations*. Ecology 35: 445-453.
- Füldner K. 1995 - *Strukturbeschreibung von Buchen-Edellaubholz-Mischwäldern*. [Describing forest structures in mixed beech-ash-maple-sycamore stands.]. University of Göttingen.
- Grime J.P. 1977 - *Evidence for the existence of three primary strategies in plants and its relevance to ecological and evolutionary theory*. Am. Nat. 111: 1169-1194.
- Hegyí F. 1974 - *A simulation model for managing jack pine stands*. pp. 74-90 Proc. IUFRO Meeting, Royal College of Forestry, Stockholm, Sweden.
- Hui G.Y., Albert M., Von Gadow K. 1998 - *Das Umgebungsmaß als Parameter zur Nachbildung von Bestandesstrukturen*. [The diameter dominance as a parameter for simulating forest structure]. Forstwissenschaftliches Cent. 117:258-266.
- Kleyer M., Bekker R.M., Knevel I.C. et al. 2008 - *The LEDA traitbase: a database of life-history traits of the Northwest European flora*. J. Ecol. 96: 1266-1274.

- Klotz S., Kühn I., Durka W. 2002 - *BIOLFLOR—Eine Datenbank mit biologisch-ökologischen Merkmalen zur Flora von Deutschland*. Schr.reihe Veg.kd 38: 1-334.
- Lloyd M., Ghelardi R.J. 1964 - *A table for calculating the 'equitability' component of species diversity*. J. Anim. Ecol. 33:217-225.
- Pommerening A. 2002 - *Approaches to quantifying forest structures*. Forestry 75: 305-324.
- Pretzsch H. 2010 - *Forest dynamics, growth and yield*. Springer, Berlin.
- Raunkiaer C. 1934 - *The life forms of plants and statistical plant geography*; being the collected papers of C. Raunkiaer. Clarendon Press, Oxford.
- Schröder J., von Gadow K. 1999 - *Testing a new competition index for Maritime pine in northwestern Spain*. Can. J. For. Res. 29: 280-283.
- Shannon C.E. 1948 - *A mathematical theory of communication*. Bell Syst. Tech. J. 27:379-423.
- Simpson E.H. 1949 - *Measurement of diversity*. Nature 163:688-688.
- Staudhammer C.L., LeMay V.M. 2011 - *Introduction and evaluation of possible indices of stand structural diversity*. Can. J. For. Res. 31: 1105-1115.

## Assessing indicators of deadwood and microhabitats

Lombardi F.<sup>1</sup>, Mali B.<sup>2</sup>, Skudnik M.<sup>2</sup>

Received 16/03/2016 - Accepted 06/04/2016 - Published online 19/07/2016

### Deadwood – 4.5 (Italy)

The Criterion 4 (Maintenance, Conservation and Appropriate Enhancement of Biological Diversity in Forest Ecosystems) includes the “Volume of standing deadwood and of lying deadwood on forest and other wooded land” among its indicators (FOREST EUROPE 2015).

**Full text** Deadwood is a biodiversity indicator including all above and below ground detritus in forest, like stumps, snags, coarse woody debris, standing and dead downed trees.

**Rationale** The indicator is easy to measure and to calculate. The results depend on measured DBH, min/max diameter thresholds, length and height of standing and lying dead wood components.

#### Methods

In each site, an area of 30 ha was selected and 9

plots for each treatment (10 ha) were sampled, for a total of 27 circular plots of 13 m-radius. In each plot, snags, standing and dead downed trees with DBH  $\geq 5$  cm and height  $\geq 1,30$  m were included. Coarse woody debris was sampled if its minimum diameter was  $\geq 5$  cm and length  $\geq 100$  cm. Stumps threshold were: top diameter  $\geq 5$  cm and height  $\leq 130$  cm. Measurements have been repeated before and after the silvicultural operations to determine their impact on the parameter.

#### Measurement units

Status:  $m^3 ha^{-1}$

Changes:  $m^3 ha^{-1}$  - before/after silvicultural intervention.

#### Measurement time

Before [Y]

After [Y]

#### Feasibility

Scale of application	Specific knowledge	Costs	Interaction with other indicators
Stand	2 (inventory technician)	2	Saprophytic fauna, small mammals, birds, fungi, forest management, carbon sink

### Results from ManFor C.BD.

Indicator name	Site	Before	After
Deadwood ( $m^3 ha^{-1}$ )	Cansiglio Innovative	9.64	29.45
Deadwood ( $m^3 ha^{-1}$ )	Cansiglio Traditional	16.92	29.74
Deadwood ( $m^3 ha^{-1}$ )	Cansiglio Control	10.27	9.81
Deadwood ( $m^3 ha^{-1}$ )	Chiarano Traditional	11.78	16.16
Deadwood ( $m^3 ha^{-1}$ )	Chiarano Innovative 80	10.30	24.55
Deadwood ( $m^3 ha^{-1}$ )	Chiarano Innovative 40	14.38	24.49
Deadwood ( $m^3 ha^{-1}$ )	Lorenzago Traditional	76.50	NA
Deadwood ( $m^3 ha^{-1}$ )	Lorenzago Innovative 2	33.90	NA
Deadwood ( $m^3 ha^{-1}$ )	Lorenzago Innovative 1	90.00	NA
Deadwood ( $m^3 ha^{-1}$ )	Mongiana Innovative	5.61	30.18
Deadwood ( $m^3 ha^{-1}$ )	Mongiana Traditional	5.13	28.27
Deadwood ( $m^3 ha^{-1}$ )	Mongiana Control	5.47	11.76
Deadwood ( $m^3 ha^{-1}$ )	Pennataro Mixed forest	8.11	NA
Deadwood ( $m^3 ha^{-1}$ )	Pennataro Turkey oak forest	11.21	NA
Deadwood ( $m^3 ha^{-1}$ )	Tarvisio Innovative 1	72.50	NA
Deadwood ( $m^3 ha^{-1}$ )	Tarvisio Innovative 2	69.40	NA
Deadwood ( $m^3 ha^{-1}$ )	Tarvisio Traditional	74.00	NA
Deadwood ( $m^3 ha^{-1}$ )	Kočevski Rog 100	1.53	29.26
Deadwood ( $m^3 ha^{-1}$ )	Kočevski Rog 50	4.86	17.27
Deadwood ( $m^3 ha^{-1}$ )	Snežnik 100	5.59	47.73
Deadwood ( $m^3 ha^{-1}$ )	Snežnik 50	2.22	22.54
Deadwood ( $m^3 ha^{-1}$ )	Trnovo 100	2.30	41.11
Deadwood ( $m^3 ha^{-1}$ )	Trnovo 50	1.82	21.36

### Microhabitats

**Full text** The term “microhabitat” encompasses several structural features on single trees and small substrates used by numerous species, or groups of species, to grow, nest or forage. Microhabitats might be associated with decreasing tree vitality, which is commonly caused by a combination of fungi, viruses and bacteria. They are useful indicators of biodiversity, since they can describe the level of forest naturalness.

**Rationale** Microhabitats are easy to be censused and estimated in number per hectare. The results depend on the forest structure, tree height and diameters and deadwood amounts. The indicator is not included into most of the forest management plans. However, with microhabitats it is possible to monitor the level of naturalness of the forest stand.

<sup>1</sup> Dipartimento di Gestione dei Sistemi Agrari e Forestali, Università degli Studi Mediterranea di Reggio Calabria, Italy

<sup>2</sup> Department of Forest and Landscape Planning, Slovenian Forestry Institute, Ljubljana, Slovenia



The indicator is easy to measure and to calculate through a visual inspection of the whole trees and deadwood components occurring in the investigated forest stand.

### Methods

Permanent plots to measure and compare the occurrence of microhabitats change in progress. Measurements should be repeated every five-ten years, but also before and after any silvicultural intervention in order to determine their impact on this indicator.

In each plot surveyed, the microhabitat census consists in a visual inspection and a careful exami-

nation of the trunks (living trees) from the ground to the crown or the whole length of horizontal elements (deadwood). Usually, the sampling method is based on the identification of a set of 23 types of microhabitats.

### Measurement units

Status:  $N_{tot}/ha^{-1}$

Changes:  $N_{tot}/ha^{-1}$  before/after silvicultural intervention

### Measurement time

Before [Y]

After [Y]

### Feasibility

Scale of application	Specific knowledge	Costs	Interaction with other indicators
Stand	1 (inventory technician)	1	Saproxylic fauna, small mammals, birds, fungi, forest management, basal area, tree height

## Results from ManFor C.BD.

Indicator name	Site	Before	After
Microhabitats ( $N_{tot}/ha$ )	Cansiglio Innovative	100.5	113.1
	Cansiglio Traditional	136.1	161.2
	Cansiglio Control	108.9	182.2
	Chiarano Traditional	148.7	129.8
	Chiarano Innovative 80	289.0	121.4
	Chiarano Innovative 40	203.1	121.4
	Lorenzago Traditional	31.4	
	Lorenzago Innovative 2	69.2	
	Lorenzago Innovative 1	44.0	
	Mongiana Innovative	169.6	224.0
	Mongiana Traditional	236.6	224.0
	Mongiana Control	129.8	219.9
	Pennataro Mixed forest	196.3	
	Pennataro Turkey oak forest	216.7	
	Tarvisio Innovative 1	228.2	
	Tarvisio Innovative 2	134.0	
	Tarvisio Traditional	326.6	

## Assessing indicators of animal diversity

Badano D.<sup>1,2</sup>, Balestrieri R.<sup>1</sup>, Basile M.<sup>1</sup>, Birtele D.<sup>2</sup>, Cistrone L.<sup>1</sup>, Corezzola S.<sup>1,2</sup>, Costa A.<sup>1</sup>, de Groot M.<sup>3</sup>, Jurc M.<sup>4</sup>, Mason F.<sup>2</sup>, Meterc G.<sup>4</sup>, Posillico M.<sup>1,5</sup>, Romano A.<sup>1</sup>, Zapponi L.<sup>1,2</sup>

Received 16/03/2016 - Accepted 06/04/2016 - Published online 19/07/2016

### Threatened forest species - 4.8

The Criterion 4 (Maintenance, Conservation and Appropriate Enhancement of Biological Diversity in Forest Ecosystems) includes the “Number of threatened forest species, classified according to IUCN Red List categories in relation to total number of forest species” among its indicators (MCPFE, 2003). This indicator has been applied to all the taxa focus of the project.

### Threatened bat species (Italy)

**Full text** Number of threatened forest species of bats, classified according to IUCN Red List categories (Rondinini et al. 2013), in relation to total number of forest species.

**Rationale** Woodlands, and particularly those one with a high richness of decaying wood, provide both roosting and foraging habitats for tree-dwelling bats (Russo et al. 2004). Monitoring the number of threatened forest bat species can provide an indication of the quality of forest management. The number of threatened tree-dwelling bats recorded in a forest stand can be related to the overall forest bat species that can be found in the same area.

Following the “Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests”, two main issue can be tested:

- Number of forest associated bat species: this indicator provides information on the health of forest ecosystems through the number of strictly forest associated bat species. Knowledge of the number of forest associated bat species highlights the importance of certain forest types in meeting conservation objectives and in understanding the relationships

that different bat species have within forest ecosystems. The loss or addition of threatened bat species in a forest stand after logging, can easily provide valuable information about the overall quality of management of that forest.

- Number and status of forest associated and threatened bat species, classified in according to IUCN Red List and National Mammals Red List categories (Rondinini et al. 2013), in relation to total number of bat forest species: this indicator provides information on the number and status of tree-dwelling and threatened bat species recorded in a determined area. The presence of these species may require specific actions in forest management to ensure their survival. The number of threatened bat species and their status is an indicator of the health of forest ecosystem and can be related to the overall bat species recorded in the same area as well.

### Methods

Check list of bat species applying both acoustic surveys with bat detector and mist netting capture sessions; evaluation of threatened bat species (according to the risk rank reported in the IUCN Red List, the inclusion in the annexes II and IV of Habitat directive, and the risk rank reported in National Mammals Red List); evaluation of tree-dwelling (or strictly forest associated) threatened bat species.

### Measurement units

- Overall number of bat species.
- Conservation-dependent number of bat species.
- Conservation-dependent number of strictly forest associated (tree-dwelling) bat species.

### Measurement time

Before[Y]

After [Y]

<sup>1</sup> CNR-IBAF, National Research Council of Italy, Institute for Agro-environmental and Forest Biology, Monterotondo (RM), Italy

<sup>2</sup> CNBF National Centre for the Study and Conservation of Forest Biodiversity 'Bosco Fontana', Marmirolo (MN), Italy

<sup>3</sup> Department of Forest Protection, Slovenian Forestry Institute, Ljubljana, Slovenia

<sup>4</sup> Department of Forest Ecology, Slovenian Forestry Institute, Ljubljana, Slovenia

<sup>5</sup> Corpo Forestale dello Stato, Ufficio Territoriale Biodiversità di Castel di Sangro - Centro Ricerche Ambienti Montani, Castel di Sangro (AQ), Italy

## Feasibility

Scale of application	Specific knowledge	Costs	Interaction with other indicators
Stand/Compartment	5	2	

### Results from ManFor C.BD.

Indicator name	Site	Before	After
Threatened bat species	Mongiana	0.40	Trad. 0.17 – Innov. 0.42 – Ctrl. 0.42
Threatened bat species	Tarvisio	0.33	Trad. 0.38 – Innov. 10.13 – Innov. 20.25
Threatened bat species	Cansiglio	0.33	Trad. 0.18 – Innov. 0.18 – Ctrl. 0.27
Threatened bat species	Lorenzago	0.20	Trad. 0.43 – Innov. 0.00 – Ctrl. 0.14
Threatened bat species	Pennataro	0.43	NA
Threatened bat species	Vallombrosa	0.30	NA
Threatened bat species	Chiarano	0.33	Trad. 0.33 – Innov. 40 0.44 – Innov. 80 0.33 – Ctrl. 0.11

### Threatened bird species (Italy)

**Full text** Number of threatened species (based on IUCN National Red List, Peronace et al. 2012) and Bird Directive species (Annex I), in relation to total number of species.

**Rationale** The disappearance of rare and threatened species, if present before the treatments, may provide an initial warning of changes in vital forest

ecosystem functions. Such species are those with narrower ecological requirements and their disappearance can be linked to habitat impoverishment, in terms of availability and number of resources, like dead wood or cavity trees.

### Methods

Aural/visual point counts to assess the presence/abundance of each species (Blondel et al. 1981). For the present study, a point count was carried out in each experimental plot. An additional buffer, with an area comparable to the forest management unit (FMU), was included, and the same amount of point counts included in the FMU was performed in this area.

### Measurement units

- Number of threatened or Bird Directive species, expressed as % of the total number of species.
- Changes: Decrement or increment of the absolute value.

### Measurement time

Before [Y]

After [Y]

### Feasibility

Scale of application	Specific knowledge	Costs	Interaction with other indicators
Compartment	5	3	Bird insectivorous cavity nester guild

### Results from ManFor C.BD.

Considering species listed in the IUCN Red List (Peronace et al. 2012)

Indicator name	Site	Before	After
Threatened bird species (IUCN)	Cansiglio	3.5%	Trad. 3.5; Innov. 3.6%; Contr. 3.8% Buffer 3.6%
Threatened bird species (IUCN)	Chiarano	11.1%	Trad. 4.1%; Innov. 1 4.6%; Innov. 2 4.2 Buffer 4.3 %
Threatened bird species (IUCN)	Lorenzago	3.5%	Trad. 3.6%; Innov. 1 3.8%; Contr. 4 % Buffer 4%
Threatened bird species (IUCN)	Mongiana	0%	Trad. 4.3%; Innov. 4.1%; Contr. 4% Buffer 4.5 %
Threatened bird species (IUCN)	Pennataro	4.3 %	4.3%
Threatened bird species (IUCN)	Tarvisio	3.3 %	Trad. 3.6%; Innov. 1 3.2%; Innov. 2 3.3% Buffer 3.7%

Considering species listed in the Birds Directive (2009/147/EC)

Indicator name	Site	Before	After
Threatened bird species (BD)	Cansiglio	3.5 %	Trad. 0%; Innov. 0%; Contr. 0% Buffer 0%
Threatened bird species (BD)	Chiarano	3.7 %	Trad. 3.1%; Innov. 1 4.2%; Innov. 2 4.1 Buffer 4.2 %
Threatened bird species (BD)	Lorenzago	14.2 %	16% Trad. 10.6%; Innov. 1 13.8%; Contr. 14.4 % Buffer 16 %
Threatened bird species (BD)	Mongiana	4.3 %	Trad. 0%; Innov. 0%; Contr. 0% Buffer 0%
Threatened bird species (BD)	Pennataro	0%	NA
Threatened bird species (BD)	Tarvisio	6.6 %	Trad. 3.5%; Innov. 1 3.7%; Innov. 2 3.4% Buffer 3.2%

### Limits

The indicator is not particularly suited for the spatial scale used, because of the great movement capacity of birds. Indeed, it can be misleading to distinguish the bird community between plots so close, which, even though they differ in the treatment, are

part of the whole spatial extent exploited by most of the species. In such small plots, it is more likely that the whole forest management unit alteration influences the community more than single treatments influence single species.

## Threatened amphibian and reptile species (Italy)

**Full text** Number of threatened amphibian and reptile species considering the IUCN National Red List and the Habitats Directive.

**Rationale** The number of threatened species is calculated considering species included in one of the following category of threat: Vulnerable, Endangered, Critically Endangered, based on IUCN National Red List assessment (Rondinini et al. 2013). The number of species in Habitats Directive is calculated considering species both in annex II and IV following three criteria: (i) species mentioned explicitly in the Directive, (ii) species mentioned in the directive with another name for subsequent taxonomic changes, (iii) species formalized after the Habitat dir. are considered as the species in which they that were previously included (e.g. *Salamandrina perspicillata* is considered as part of *Salamandrina terdigitata*). Both "Threatened" and "Habitat" species are considered in relation to total number of species. If no species occurred in a given site, the index was inapplicable and we reports it as NA (Not Applicable). If at a given site, none of the

species is included neither in the Habitats dir. nor among the Threatened species, then this evidence is shown as 0%

The disappearance of rare and threatened species, if present before the treatments, may provide an initial warning of changes in vital forest ecosystem functions.

### Methods

VES (Visual Encounter Survey) of any life stage (eggs, larvae and adults) including scanning with binoculars, visual searches, blind dip nettings; ACS (Active cover searches); CS (Calling Survey, for anurans); aural/visual point counts to assess the presence/abundance of each species.

### Measurement units

- Number of threatened (IUCN criteria at national level) or amphibian and reptile species in Habitat directive, expressed as % of the total number of species.
- Changes: decrement or increment of the absolute value

### Measurement time

Before [Y]

After [Y]

### Feasibility

Scale of application	Specific knowledge	Costs	Interaction with other indicators
Stand	5	4	

## Results from ManFor C.BD.

Considering species listed in the IUCN Red List (Rondinini et al. 2013)

Indicator name	Site	Before	After
Threatened amphibian species (IUCN)	Cansiglio	0%	Trad.0% ; Innov.0% ; Contr. 0%
Threatened amphibian species (IUCN)	Chiarano	NA	NA
Threatened amphibian species (IUCN)	Lorenzago	0%	Trad. 0% ;Innov. 0% ; Contr. 0%
Threatened amphibian species (IUCN)	Mongiana	0%	Trad. 0% ;Innov. 0% ; Contr. 0%
Threatened amphibian species (IUCN)	Pennataro	33.3%	33.3%
Threatened amphibian species (IUCN)	Tarvisio	16.6%	Trad. 16.6% ; Innov.1 16.6% ; Innov.2. 16.6% Control 0%
Threatened amphibian species (IUCN)	Vallombrosa	NA	NA

Indicator name	Site	Before	After
Threatened reptile species (IUCN)	Cansiglio	NA	NA
Threatened reptile species (IUCN)	Chiarano	0%	Trad. 0% ; Innov.1 0% ; Innov.2 0% ; Contr. 0%
Threatened reptile species (IUCN)	Lorenzago	NA	NA
Threatened reptile species (IUCN)	Mongiana	0%	Trad. 0% ;Innov. 0% ; Contr. 0%
Threatened reptile species (IUCN)	Pennataro	0%	0%
Threatened reptile species (IUCN)	Tarvisio	0%	Trad. 0% ; Innov.1 0% ; Innov.2. 0% Control 0%
Threatened reptile species (IUCN)	Vallombrosa	NA	NA

Considering species listed in the Habitats Directive (92/43/EEC)

Indicator name	Site	Before	After
Threatened amphibian species (HD)	Cansiglio	0%	Trad.0% ; Innov.0% ; Contr. 0%
Threatened amphibian species (HD)	Chiarano	NA	NA
Threatened amphibian species (HD)	Lorenzago	50%	Trad. 50% ; Innov. 50% ; Contr. 50%
Threatened amphibian species (HD)	Mongiana	75%	Trad. 50% ;Innov. 75% ; Contr. 50%
Threatened amphibian species (HD)	Pennataro	66.6%	66.6%
Threatened amphibian species (HD)	Tarvisio	33.3%	Trad. 33.3% ; Innov.1 33.3% ; Innov.2. 33.3% Control 0%
Threatened amphibian species (HD)	Vallombrosa	NA	NA

Indicator name	Site	Before	After
Threatened reptile species (HD)	Cansiglio	NA	NA
Threatened reptile species (HD)	Chiarano	100%	Trad. 100%; Innov.1 0%; Innov.2. 0%
Threatened reptile species (HD)	Lorenzago	NA	NA
Threatened reptile species (HD)	Mongiana	0%	Trad. 0% ;Innov. 0%; Contr. 0%
Threatened reptile species (HD)	Pennataro	100%	100%
Threatened reptile species (HD)	Tarvisio	25%	Trad. 0%; Innov.1 25%; Innov.2. 25%; Control NA
Threatened reptile species (HD)	Vallombrosa	NA	NA

### Limits

The MCPFE approach (see “Rationale”) for amphibians and reptiles, in the context of ManFor C.BD., does not appear adequate to evaluate the sustainability of any forest management for several reasons:

- In European countries, the number of species is too low to draw any percentage that has real meaning.
- The previous point can have paradoxical consequences, as for example the fact that in a given sites none of the occurring species falls within the IUCN categories of Threat and in the annexes of Habitat Directive, and the results is that the index score is zero.
- Amphibians and reptiles have aggregate distributions in forest ecosystems: reptiles are associated in small areas that receive higher solar radiation, while amphibians are strictly associated to water bodies that are not uniformly distributed in the study area.
- Surface areas of different treatments are too small and herps should be evaluated at larger scale.
- Both amphibians and reptiles exhibit low vagility, and therefore only very intensive forest management (i.e. clearcutting) may cause appearance or disappearance of species in a short time.

Amphibians and Reptiles could be used in evaluating the sustainability of forest management but different methods have to be applied, for example: Body Condition Index, pattern of activities, reproductive success, density and demographic trends.

### Threatened beetle species (Italy)

**Full text** Number of threatened amphibian and reptile species considering the IUCN National Red List and the Habitats Directive.

**Rationale** Insects constitute a substantial and

functionally significant component of terrestrial biodiversity and are known to be valuable indicators of environmental conditions. In forested habitats, a key component of the fauna includes saproxylic organisms, which depend at least in one phase of their vital cycle on living, dead or decaying trees or on other saproxylic organisms. These specialized species, with restricted dispersal capacities and dependent on old-growth forest, are especially sensitive to forest management. According to the IUCN Red List categories, a species is listed as threatened if it falls in the critically endangered, endangered or vulnerable categories. The proportion of threatened forest species present in a site is considered an indicator of forest ecosystem threat. Recognizing that human activities and their effect drive the vast majority of threats to habitat and organisms, the amount of species threatened with extinction is a measure of human impact on the world’s biodiversity. This indicator can be useful to evaluate effects of different silviculture treatments on invertebrate biodiversity conservation.

### Methods

The specimens are collected with standardised surveys, using interception traps (e.g. window traps), during the adult activity season. The samples are sorted into taxonomic groups with a stereomicroscope, then they have to be identified at species level by relevant specialists. We consider indicator species all those listed as threatened by the European (Nieto and Alexander 2010) and Italian (Audisio et al. 2014) Red Lists of Saproxylic Beetles.

### Measurement units

- Number of threatened species, expressed as % of the total number of species.

### Measurement time

Before [Y]

After [Y]

### Feasibility

Scale of application	Specific knowledge	Costs	Interaction with other indicators
Stand	5	5	Deadwood

## Results from ManFor C.BD.

Indicator name	Site	Before	After
Threatened beetle species	Cansiglio	1.9%	Trad. 3.4%; Innov. 1.7%; Contr. 1.9%
Threatened beetle species	Chiarano	1.8%	Trad. 3.3%; Innov. 3.5%; Innov. 2.8%
Threatened beetle species	Lorenzago	NA	Trad. 3.1%; Innov. 4.0%; Contr. 2.4%
Threatened beetle species	Mongiana	2.1%	Trad. 2.9%; Innov. 1.0%; Contr. 2.3%
Threatened beetle species	Pennataro	0.0%	NA
Threatened beetle species	Tarvisio	NA	Trad. 3.6%; Innov. 1.5%; Innov. 5.9%
Threatened beetle species	Vallombrosa	4.8%	NA

The number of threatened species varied in the plots where the different silvicultural treatments were experimented, supporting the potential of this indicator. However, its main limit is that Red Lists rely on data often unavailable for invertebrate species, restricting the number of assessed species (Warren et al. 2007), and the criteria adopted for the assessment present several limits when applied to invertebrates (Cardoso et al. 2011).

### Threatened insect forest species (Slovenia)

**Full text** Number of threatened forest species, classified according to IUCN Red List categories in relation to total number of forest species.

**Rationale** In forested habitats, a key component of the fauna includes saproxylic organism. These specialized species, with restricted dispersal capacities and dependent on old-growth forest, are especially sensitive to forest management. According to the IUCN Red List categories, a species is listed

as threatened if it falls in the critically endangered, endangered or vulnerable categories. The proportion of threatened forest species present in a site is considered an indicator of forest ecosystem threat.

#### Methods

The specimens are collected with standardised surveys, using interception traps (e.g. window traps), during the adult activity season. The samples are sorted into taxonomic groups with a stereo-microscope, then they have to be identified at species level by relevant specialists. We consider indicator species all those listed as threatened by the European (Nieto and Alexander 2010), Italian (Audisio et al. 2014) and Slovenian (Anonymous 2002) Red Lists of Saproxylic Beetles.

#### Measurement units

- Number of threatened species, expressed as % of the total number of species.

#### Measurement time

Before [Y]

After [Y]

#### Feasibility

Scale of application	Specific knowledge	Costs	Interaction with other indicators
Stand	5	5	Deadwood

## Results from ManFor C.BD.

Indicator name	Site	Before	After
Percentage threatened saproxylic species	Kočevski Rog	0%: 0%	50%: 20%; 100%: 0%
Percentage threatened saproxylic species	Snežnik	0%: 0%	50%: 0%; 100%: 6%
Percentage threatened saproxylic species	Trnovo	0%: 0%	50%: 0%; 100%: 0%

For the Slovenian sites, only the longhorn beetles were taken into account. There were two red list species found: *Rosalia alpina* and *Prionus coriarius*. Each species was only found in one plot. Because of the low number of red list species, the percentage of red list saproxylic species was not able to describe the cutting intensity gradient in any of the sites.

### Guild related indicators

#### Bird insectivorous cavity nester guild (Italy)

**Full text** Presence/abundance of species of the insectivorous cavity nester guild in relation to other forest bird guilds. Species are identified as those that breed in cavity (Newton 1994) and base their diet mainly on (saproxylic) invertebrates.

**Rationale** The insectivorous cavity nester guild includes the species most sensitive to forest alteration, with regards to changes in deadwood amount and tree ageing. This is due to their ecological requirements in relation to the nesting site and food. Natural tree cavities are those formed by the fall of decayed or dead branches or excavated by woodpeckers. The former situation is typical of mature and old-growth forests, that are considered an unaltered habitat (Peace 1962). Woodpeckers presence, instead, is affected mainly by food availability and tree suitability for excavation (Newton 1994). Their presence increase the number of cavities, which in turn increase the number of secondary cavity nesters (i.e. those species that do not excavate their cavity). A decrement in this guild

may provide a warning of habitat homogenization, due to the disappearance of (saproxylic) insects and/or woodpeckers, as a consequence of forest alteration (Canterbury et al. 2000, King and DeGraaf 2000, Robles et al. 2011, Carrillo-Rubio et al. 2014, Balestrieri et al. 2015).

#### Methods

- Aural/visual point counts to assess the presence of each species (Blondel et al. 1981).

#### Measurement units

- Status: Number of species of the insectivorous cavity nester guild present.

- Changes: Appearance or disappearance of target species.

#### Measurement time

Before [Y]

After [Y]

#### Feasibility

Scale of application	Specific knowledge	Costs	Interaction with other indicators
Compartment	5	4	Species index

### Results from ManFor C.BD.

Indicator name	Site	Before	After
Bird insectivorous cavity nester guild	Cansiglio	35.7 %	Trad. 35.1%; Innov. 33.4%; Contr. 32.8.% Buffer 36.0%
Bird insectivorous cavity nester guild	Chiarano	48.1 %	Trad. 44.5%; Innov.1 46.4%; Innov.2 43.5% Buffer 47.5 %
Bird insectivorous cavity nester guild	Lorenzago	39.2 %	Trad. 36.4%; Innov.1 38.6%; Contr. 40.1 % Buffer 40.1 %
Bird insectivorous cavity nester guild	Mongiana	47.8 %	Trad. 43.6 %; Innov. 47.5 %; Contr. 46.0 Buffer 48.0 %
Bird insectivorous cavity nester guild	Pennataro	34.3 %	34.3 %
Bird insectivorous cavity nester guild	Tarvisio	40.0 %	Trad. 37.2 %; Innov.1 33.6 %; Innov.2 35.5.% Buffer 39.2 %

#### Forest birds (Slovenia)

**Full text** Number of forest bird species

**Rationale** Changes in the composition of forest bird community and reduction/disappearance of specialist or threatened species (according to their classification in IUCN or, better, country-wide red lists) may provide an early warning about substantial effects of forestry operations on losses of biological diversity. Threatened species, according to IUCN classification, are all species falling within vulnerable, endangered or critically endangered conservation status categories. The variation in the number of both bird species and of the proportion of rare species (over total forest bird species) following forest harvest could be considered an indication of the sustainability of logging with respect to biological diversity. Provided many silvicultural alternatives exist, this indicator could be considered to evaluate the effects of different treatments. As the effects of logging have also a temporal and not just spatial component, the proportion of threatened species and the number of bird species as a whole must be monitored annually to track changes in the index, hopefully related to variation in forest structure, which could be linked to the progressive natural restoration and regeneration of harvested parcels, or to more specific forest restoration interventions. Only forest bird species will be selected to build the index; moreover, depending on the forest surface to be considered, among forest bird species, only those with small territories and home ranges could be further selected when forest harvesting is scheduled for small plots (less than 30-50 hectares).

#### Methods

The passerine bird community has been investigated with the point count technique (RB). Surveys have been carried out twice per point from April to

the end of May/early June. The birds (species and if possible individuals) were counted (both aural and visual cues) within a buffer of 35 meter around the centre, to further minimise spatial dependency among points. A count took 10 minutes in which all species of passerine birds which occurred in the plot were recorded.

Surveys have been carried out in three forest areas in Slovenia: Kočevski Rog, Snežnik and Trnovo. For every forest area, nine plots have been selected as experimental ManFor C.BD. sites and three have been assigned to each treatment or have been regarded as control plots. Average surface of each plot was 0.04 hectares.

#### Measurement units

Number of forest species.

**Measurement time** A representative sampling should be carried out before and after treatments, in order to evaluate the effects on bird communities exactly in the same site where treatment will be applied. If resources exist, and if harvest planning allows for such an approach, before treatment measures should be repeated at least within two reproductive seasons (usually two years) before logging. This will buffer inter-annual variation in bird community. In our case sampling was not performed before treatment, but we evaluated bird community at the same time in un-harvested plots (which act as control plots) and within harvested plot. The treatment applied in the harvested plots simply foresaw the removal of 50% or 100% of trees. As control and treatment plots fall within the same kind of forest (in terms of species composition and structure) we are confident that our approach is similar or could be compared to a before and after sampling scheme.

Before[Y]

After [Y]

## Feasibility

Scale of application	Specific knowledge	Costs	Interaction with other indicators
Stand	2	2	Vertical vegetation structure, Plant species richness

## Results from ManFor C.BD.

Indicator name	Site	Control	Treatment plots (% harvested trees)	
			50%	100%
Number of forest bird species	KočevskiRog	9	9	4
Number of forest bird species	Snežnik	11	12	2
Number of forest bird species	Trnovo	14	10	5

May be because of the outstanding differences in the treatments applied to the plots in Slovenian sites, the total number of forest species showed a marked decrease with increasing thinning intensity across all sites, but for control vs. 50% harvest in Snežnik (site 9). There was only one non forest species found, so the pattern observed with the forest species reflects the pattern of the total forest species richness.

### *Amphibian guild index (Italy)*

**Full text** Presence/absence of the amphibians species that require highly humidity level and are not thermophilous species (i.e. forest guild)

**Rationale** Not all amphibians species have the same ecological requirements. Some species need high level of moisture while other taxa are more thermophilous and adapted to drier environmental condition. For amphibians strictly associated to forest environment (and related moist condition),

forest cutting may significantly alter the suitability of a given area. A decrement in this guild may provide a warning from habitat homogenization.

### Methods

VES (Visual Encounter Survey) of any life stage (eggs, larvae and adults) including scanning with binoculars, visual searches, blind dip nettings; ACS (Active cover searches); CS (Calling Survey, for anurans); aural/visual point counts to assess the presence/abundance of each species.

### Measurement units

- Status: presence/absence of number of amphibian species in forest guild on the total of amphibians species occurring in the site, expressed as percentage.

- Changes: disappearance or new occurrence of a given guild.

### Measurement time

Before[Y]

After [Y]

### Feasibility

Scale of application	Specific knowledge	Costs	Interaction with other indicators
Stand	5	3	Species index

## Results from ManFor C.BD.

Indicator name	Site	Before	After
Amphibian guild index	Cansiglio	Trad.0% ; Innov.0% ; Contr. 0%	Trad.0% ; Innov.0% ; Contr. 0%
Amphibian guild index	Chiarano	NA	NA
Amphibian guild index	Lorenzago	Trad. 50% ; Innov. 50% ; Contr. 50%	Trad. 50% ; Innov. 50% ; Contr. 50%
Amphibian guild index	Mongiana	Trad. 25% ; Innov. 25% ; Contr. 25%	Trad. 25% ; Innov. 25% ; Contr. 25%
Amphibian guild index	Pennataro	66.7%	66.7%
Amphibian guild index	Tarvisio	Trad. 20% ; Innov.1 25% ; Innov.2 25% ; Contr. NA	Trad. 20% ; Innov.1 25% ; Innov.2 25% ; Contr. NA
Amphibian guild index	Vallombrosa	NA	NA

### Limits

The main problem is that in Italy, as in other European countries, in a given small area (from unity to hundreds of hectares) only few species of amphibians occur. This represent the major limit of this approach

### *Hoverfly obligate forest species (Slovenia)*

**Full text** Number of threatened forest species

of saproxylic and obligate forest insects, classified according to Syrph the Net in relation to total number of hoverfly species.

**Rationale** Insects are a large component of the world's terrestrial biodiversity. Hymenoptera, beetles and flies are the largest taxonomic groups within the insects. Among flies hoverflies (Diptera: Syrphidae) are the most common and best known



group. Hoverflies occupy many different habitat types, have many different important traits and play important ecosystem services. These reasons and the large abundance overall make the hoverflies an important indicator of ecosystem changes. The largest part of the hoverfly species occur in forests. They are saproxylic, predate on aphids and hymenoptera and feed on plants and many are indicative of the age of the forest. Because they have many different ecological functions they are sensitive to forest management.

Syrph the Net is a database based on biological traits and habitats of hoverflies which is compiled on basis of scientific literature and professional experience for every hoverfly species in Europe. The macro habitat mature forest contains micro habitats like trunk cavities, rot holes, sap runs and loose bark in over mature trees. These microhabitats can change drastically in areas with intensive silvicultural practices and many of the species that use these structures are considered threatened or vulnerable. Therefore the proportion of forest species occurring in these types of micro habitats, present in a site is considered an indicator of forest ecosystem threat. On the other hand, open area species can be used as indicators when the openness of the canopy is large enough. These indicator can be used to evaluate effects of different silviculture treatments on invertebrate conservation.

## Methods

- Indicator species: we consider indicator species all those which are listed as saproxylic species, or are associated with micro habitats in over mature trees or are obligate forest species in Syrph the Net.

- Standard surveys: windows traps and transects

- Period: The window traps are set three times a year for one week and the transects are conducted three times a year.

- Trap position: one trap per plot.

Collected specimens are sorted under a stereomicroscope and determined at species level by expert entomologists.

- Measurements are compared between control and treatments in the same area, in order to evaluate the effects on the hoverfly communities.

## Measurement units

- Proportion of saproxylic hoverfly species compared to the total number of species per site.

- Proportion of obligate forest species compared to the total number of species per site; proportion of open area species compared to the total number of species per site.

## Measurement time

Before [Y]

After [Y]

## Feasibility

Scale of application	Specific knowledge	Costs	Interaction with other indicators
Stand	5	3	Vertical vegetation structure, Deadwood

## Results from ManFor C.BD.

Indicator name	Site	Before	After
Average proportion of saproxylic hoverfly species	Kočevski Rog	0.02	50%: 0.11; 100%: 0.08
Average proportion of saproxylic hoverfly species	Snežnik	0.03	50%: 0.10; 100%: 0.03
Average proportion of saproxylic hoverfly species	Trnovo	0.07	50%: 0.10; 100%: 0.03
Average proportion of obligate forest species	Kočevski Rog	0.42	50%: 0.11; 100%: 0.12
Average proportion of obligate forest species	Snežnik	0.39	50%: 0.40; 100%: 0.33
Average proportion of obligate forest species	Trnovo	0.40	50%: 0.43; 100%: 0.41
Average proportion of open area species	Kočevski Rog	0.25	50%: 0.09; 100%: 0.13
Average proportion of open area species	Snežnik	0.14	50%: 0.15; 100%: 0.27
Average proportion of open area species	Trnovo	0.08	50%: 0.08; 100%: 0.19

From this indicator only the proportion of **open land species** could be used as a possible indicator for intensity of logging. There was a higher proportion of open land species in 100% logging compared to other intensities of logging. The proportion of **saproxylic species** did not follow patterns as expected. There was a higher proportion of species in the 50% logged plots. Therefore, it seemed not to be a good indicator for logging intensity. Neither the proportion of **obligate forest species** did not seem to be a good indicator of logging intensity. The observed pattern did not follow logging intensity as expected: the higher number was recorded in 0% log-

ging and lower numbers in 100% logging. There were higher numbers of species in the 50% logged plots.

## Hoverflies diversity and ecology (Italy)

**Full text** Number of saproxylic, forest and open habitat species of hoverflies, in relation to total species number.

**Rationale** Hoverflies are considered reliable bio-indicators of forest conservation since larvae of saproxylic species tend to be very sensitive to stress and environmental changes. These larvae are highly bounded to microhabitat related to deadwood, such as holes and stumps, hence the presence in forests

of different typology of deadwood is fundamental for their conservation. The ecology of many species has been studied thoroughly, using standardized sampling methods, and the data has been gathered in a European database developed by Martin Speight (Speight, 2014).

### Methods

The specimens are collected with standardised surveys, using interception traps (Malaise traps), during the adult activity season. The samples are sorted with a stereo-microscope, Syrphidae specimens are identified at species level by relevant specialists.

### Measurement units

- Number of saproxylic hoverflies species, expressed as % of the total number of species.
- Number of obligate forest hoverflies species, expressed as % of the total number of species.
- Number of hoverflies species associated with open habitats, expressed as % of the total number of species.

### Measurement time

Before[Y]

After [Y]

### Feasibility

Scale of application	Specific knowledge	Costs	Interaction with other indicators
Stand	5	5	Deadwood, Stand structural complexity

## Results from ManFor C.BD.

Indicator name	Site	Before	After
Saproxylic hoverfly species	Cansiglio	4%	Trad. 7%; Innov. 11%; Contr. 7%
Forest hoverfly species	Cansiglio	25%	Trad. 23%; Innov. 39%; Contr. 18%
Open area hoverfly species	Cansiglio	9%	Trad. 4%; Innov. 9%; Contr. 2%
Saproxylic hoverfly species	Chiarano	0%	Trad. 0%; Innov. 0%; Contr. 6%
Forest hoverfly species	Chiarano	15%	Trad. 9%; Innov1. 6%; Innov2. 27%
Open area hoverfly species	Chiarano	9%	Trad. 6%; Innov1. 6%; Innov2. 15%
Saproxylic hoverfly species	Lorenzago	NA	Trad. 1%; Innov. 16%; Contr. 11%
Forest hoverfly species	Lorenzago	NA	Trad. 23%; Innov. 50%; Contr. 36%
Open area hoverfly species	Lorenzago	NA	Trad. 1%; Innov. 1%; Contr. 1%
Saproxylic hoverfly species	Mongiana	6%	Trad. 0%; Innov. 3%; Innov2. 0%
Forest hoverfly species	Mongiana	20%	Trad. 16%; Innov1. 15%; Innov2. 11%
Open area hoverfly species	Mongiana	8%	Trad. 8%; Innov1. 8%; Innov2. 9%
Saproxylic hoverfly species	Pennataro	0%	NA
Forest hoverfly species	Pennataro	25%	NA
Open area hoverfly species	Pennataro	0%	NA
Saproxylic hoverfly species	Tarvisio	NA	Trad. 1%; Innov1. 16%; Innov2. 11%
Forest hoverfly species	Tarvisio	NA	Trad. 23%; Innov1. 50%; Innov2. 36%
Open area hoverfly species	Tarvisio	NA	Trad. 0%; Innov1. 0%; Innov2. 0%
Saproxylic hoverfly species	Vallombrosa	13%	NA
Forest hoverfly species	Vallombrosa	40%	NA
Open area hoverfly species	Vallombrosa	6%	NA

The diversity of hoverflies showed a trend towards an increase in species number after treatment, probably due to the newly realized clearings that allowed the growth of a complex herbaceous layer on which hoverfly depend for pollen and nectar. The number of Syrphidae species varied according to the different applied silvicultural treatments, supporting the suitability of this indicator. After treatment, innovative plots were usually characterized by a more complex and diverse community than traditional plots, in particular for saproxylic and forest-dwelling species. The main limit of this indicator is probably the duration of the sampling effort: in some cases, a short time interval after treatment may be not adequate to verify the changes in hoverflies communities (as noted for site 4).

## Species activity indicators

### Bat activity index

**Full text** Number of bat passes per hour in a determined area.

**Rationale** Woodlands, and particularly those

with great amounts of decaying wood, provide both roosting and foraging habitats for tree-dwelling bats (Russo et al. 2004). Unsustainable forest management methods not considering the presence of bats can threaten forest bat species. Monitoring the overall bat activity in managed forests can provide an indicator about the quality of forest management. Bat activity index can be obtained recording the number of bat passes using a bat detector.

### Methods

Recording the overall number of bat passes in the study area. Calculating the bat activity index as the number of bat passes divided by the total sampling time. Check list of bat species applying both acoustic surveys with bat detectors and mist netting.

### Measurement units

- Bat activity index (overall number of bat passes per hour).
- Overall number of bat passes.

### Measurement time

Before[Y]

After [Y]

## Feasibility

Scale of application	Specific knowledge	Costs	Interaction with other indicators
Stand/ Compartment	5	2	

## Results from ManFor C.BD.

Indicator name	Site	Before	After
Bat activity index	Mongiana	4.02	Trad. 3.31 – Innov. 12.14 – Ctrl. 0.75
Bat activity index	Tarvisio	1.83	Trad. 10.69 – Innov.1 0.07 – Innov.2 0.54 – Ctrl. 0.01
Bat activity index	Cansiglio	2.53	Trad. 1.88 – Innov. 1.24 – Ctrl. 8.83
Bat activity index	Lorenzago	2.65	Trad. 6.56 – Innov. 0.44 – Ctrl. 2.25
Bat activity index	Pennataro	0.92	N.A.
Bat activity index	Vallombrosa	1.74	N.A.
Bat activity index	Chiarano	1.31	Trad. 0.60 – Innov.400.65 – Innov.80 4.67 – Ctrl. 0.08

In every investigated study area, we have observed an increasing of general bat activity, particularly within plots subjected to “innovative” silvicultural treatments.

## References

- Anonymous 2002 - *Pravilnik o uvrstitvi groženih rastlinskih in živalskih vrst v rdečiseznam* (Uradni list RS, št. 82/02 in 42/10).
- Audisio P., Baviera C., Carpaneto G.M., Biscaccianti A.B., Battistoni A., Teofili C., Rondinini C., 2014 - *Lista Rossa IUCN dei Coleotteri saproxilici Italiani*. Comitato Italiano IUCN e Ministero dell'Ambiente e della Tutela del Territorio e del Mare. 134 p.
- Balestrieri R., Basile M., Posillico M., Altea T., De Cinti B., Matteucci G. 2015 - *A guild-based approach to assessing the influence of beech forest structure on bird communities*. For. Ecol. Manage. 356: 216-223
- Blondel J., Ferry C., Frochot B. 1981 - *Point counts with unlimited distance*, in: Ralph, J.C., Scott, J.M. (Eds.), *Estimating Numbers of Terrestrial Birds*. Studies in Avian Biology, Asilomar, California, USA: 414-420.
- Canterbury G.E., Martin T.E., Petit D.R., Peti L.J., Bradford D.F. 2000 - *Bird communities and habitat as ecological indicators of forest condition in regional monitoring*. Conserv. Biol. 14: 544-558. doi:10.1046/j.1523-1739.2000.98235.x
- Cardoso P., Borges P.A., Triantis K.A., Ferrández M.A., Martín J.L. 2011 - *Adapting the IUCN Red List criteria for invertebrates*. Biol. Conserv. 144: 2432-2440. doi:10.1016/j.biocon.2011.06.020
- Carrillo-Rubio E., Kéry M., Morreale S.J., Sullivan P.J., Gardner B., Cooch E.G., Lassoie J.P. 2014 - *Use of multispecies occupancy models to evaluate the response of bird communities to forest degradation associated with logging*. Conserv. Biol. 28: 1034-44. doi:10.1111/cobi.12261
- King D.I., DeGraaf R.M. 2000 - *Bird species diversity and nesting success in mature, clearcut and shelterwood forest in northern New Hampshire, USA*. For. Ecol. Manage. 129: 227-235. doi:10.1016/S0378-1127(99)00167-X
- Lindenmayer D.B., Margules C.R., Botkin D.B. 2000 - *Indicators of biodiversity for ecologically sustainable forest management*. Conserv. Biol. 14: 941-950. doi:10.1046/j.1523-1739.2000.98533.x
- Newton I. 1994 - *The role of nest sites in limiting the numbers of hole-nesting birds: a review*. Biol. Conserv. 70, 265–276. doi:10.1016/0006-3207(94)90172-4
- Nieto A., Alexander K. 2010 - *European Red List of Saproxilic Beetles*. Publications Office of the European Union, Luxembourg. 45 p.
- Peace T.R. 1962 - *Pathology of trees and shrubs*. Clarendon Press, Oxford, UK.
- Peronace V., Cecere J., Gustin M., Rondinini C. 2012 - *Lista rossa 2011 degli uccelli nidificanti in Italia*. Avocetta 36 (1): 11-58.
- Robles H., Ciudad C., Matthysen E. 2011 - *Tree-cavity occurrence, cavity occupation and reproductive performance of secondary cavity-nesting birds in oak forests: the role of traditional management practices*. For. Ecol. Manage. 261: 1428-1435. doi:10.1016/j.foreco.2011.01.029
- Rondinini C., Battistoni A., Peronace V., Teofili C. 2013 - *Lista Rossa IUCN dei Vertebrati Italiani*. Comitato Italiano IUCN e Ministero dell'Ambiente e della Tutela del Territorio e del Mare, Roma.
- Russo D., Cistrone L., Jones G., Mazzoleni S. 2004 - *Roost selection by barbastelle bats (Barbastella barbastellus, Chiroptera: Vespertilionidae) in beech woodlands of central Italy: consequences for conservation*. Biological Conservation 117: 73-81.
- Speight M. 2014 - *Species accounts of European Syrphidae (Diptera)*. Syrph the Net, the database of European Syrphidae. Syrph the Net publications, Dublin.
- Warren M.S., Burn N., Brereton T., Fox R., Middlebrook I., Parsons M.S. 2007 - *What have red lists done for us? The values and limitations of protected species listing for invertebrates*. In: Stewart, A.J.A., New, T.R., Lewis, O.T. (Eds.), *Insect Conservation Biology: Proceedings of the Royal Entomological Society's 23rd Symposium*. CABI: 76-91.

## Applying indicators of vegetation diversity

Kutnar L.<sup>1</sup>, Marinšek A.<sup>1,2</sup>, Eler K.<sup>1,3</sup>

Received 16/03/2016 - Accepted 06/04/2016 - Published online 19/07/2016

For maintaining forest biodiversity, different sets of indicators might be used (e.g. CBD 1992, Larsson 2001, MCPFE 2002, MCPFE 2007, Marchetti 2004a, Cantarello and Newton 2006, Cantarello and Newton 2008, Sogaard et al. 2007, EEA 2014, Forest Europe 2015, Kovač et al. 2015). The MCPFE process played a crucial role in developing a set of criteria and indicators for sustainable forest management with taking into account different biodiversity aspects (Schuck and Rois 2004).

With respect to the loss of biodiversity and its components, which is an issue of global concern (e.g. CBD 1992, EEA 2007, Butchart et al. 2010, EEA 2012, IUCN 2015), tree species composition was recognised as one of the important MCPFE indicators of forest ecosystems (MCPFE 2002). Beside this, the common studied MCPFE indicators and significant elements of forest ecosystems are dead and living wood that play an important role as carbon storage in the context of removal of human-derived CO<sub>2</sub> emissions and reduction of the climate change effect (Fan et al. 1998, Hamilton et al. 2002, Nabuurs and Schelhaas 2002, Gutrich and Howarth 2007, Piškur and Krajnc 2007). Moreover, other multifunctional roles of dead wood in forest ecosystems have been recognised (Harmon et al. 1986, Franklin et al. 1987, Crites and Dale 1998, Bormann and Likens 1994, Peterken 1996, Kraigher et al. 2002, Kutnar et al. 2002).

Generally, the overall biodiversity of a forested area is dependent on the biodiversity of individual communities and the spatial heterogeneity of the area. In this respect, the measures can be targeted to either of these two levels. Spatial heterogeneity in forest can be significantly increased by gap formation and other similar silvicultural options. Variation in understory plant communities may be a useful tool in quantifying gap influence extent and may be a good indicator of overall response of biodiversity to forest management (Fahey and Puettmann 2008). Understory plant communities represent most of the vascular plant diversity in temperate forests, and the

species present there characterize a wide variety of growth forms and functional groups. Moreover, understory plants identify important sources of food and habitat for a large number of wildlife species (Felton et al. 2010), as well as they influence on nutrient cycling (Hart and Chen 2006). Species composition and structure of understory provide to maintain complex structure and indigenous floras within forest (Halpern and Spies 1995, Thomas et al. 1999). Functional group approach is likely to be useful in highlighting the mechanisms responsible for understory community response to forest management. The understory also provides important habitat for other taxa in forest ecosystems and may be a good indicator of biodiversity in general (Hayes et al. 1997).

Among indicators related to plant diversity the following were proposed by Brändli et al. (2007): i) Stand density and/or crown closure; ii) Degree of mixture (ratio deciduous/conifer trees) and iii) Degree of ground vegetation coverage.

Plant traits are used as ecologists' common language in order to make comparisons across regions and scales, pool data and maximize the utility of the data (Evan et al. 1999). An analysis of species traits is a useful tool to overcome the problems of describing effects across borders of regions and countries and to overcome differences in taxonomy (Lavorel et al. 1997). Also differences that are often difficult to detect because of differences in species composition, stand ages, soil conditions, and regional differences of species pools could be potentially revealed by analyses of species traits (Graae and Sunde 2000). Species traits may be very important as indicators of processes in forest ecosystems, as these often operate on long time-scales and are therefore difficult to record (Gitay and Noble 1997).

Species with different traits might respond in dissimilar ways to habitat modification, with local changes in diversity structure and composition as consequence of habitat alteration (Keddy 1992, La-

<sup>1</sup> Department of Forest Ecology, Slovenian Forestry Institute, Ljubljana, Slovenia

<sup>2</sup> Higher Vocational College for Forestry and Hunting, Postojna, Slovenia

<sup>3</sup> Department of Agronomy, Biotechnical Faculty, University of Ljubljana, Ljubljana, Slovenia

vorel and Garnier 2002, Hewitt et al. 2005). Therefore functional traits of species can be used as indicator of species' persistence and recovery following habitat change or disturbance (e.g. forest management). Even though introduced long ago (Raunkiaer 1934, Grime 1977, Noble and Slatyer 1980, Box 1981, 1996), the concept of plant functional traits has received new attention as one possible framework for predicting ecosystem response to human-induced changes at a global scale.

Another trait-based approach is possible for assessment of impacts of forest management practices on the adaptive capacity of ecosystems. The relationship between overstorey trees and understorey vegetation for species grouped by traits that reflect food availability for wildlife, for instances production of flowers, fleshy fruit, and palatable leaves, was studied in different silviculture options (Neill and Puettmann 2013).

### Test sites and experimental design in Slovenia

Plant diversity indicators were tested in three sites within Dinaric fir-beech forests in Slovenia; Kočevski Rog (KR), Snežnik (S) and Trnovo (T) (Kutnar et al. 2015). These forests thrive in high altitude karst areas with diverse soil and climate conditions, which are highly favourable for the growth of forests as there is plenty of rainfall and high air humidity. Such forests grow at an altitude of 700 to 1200 m a.s.l. in a diverse land configuration. The forests stands in all three study sites are dominated by European beech (*Fagus sylvatica*), European silver fir (*Abies alba*) and Norway spruce (*Picea abies*). Other tree species, found mostly in the understorey layers, include sycamore maple (*Acer pseudoplatanus*), wych elm (*Ulmus glabra*), common ash (*Fraxinus excelsior*), rowan (*Sorbus aucuparia*), small-leaved and large-leaved lindens (*Tilia cordata*, *T. platyphyllos*), manna ash (*Fraxinus ornus*), whitebeam (*Sorbus aria*), Norway and Bosnian maples (*Acer platanoides*, *A. obtusatum*), and common aspen (*Populus tremula*).

An area of karst depressions (sinkholes) was preselected at each test site. Among all preselected sinkholes, nine were randomly selected for each test site, and circular plots of 0.4 ha were established at the bottom of these sinkholes (27 plots in total). At the beginning of the silvicultural experiment, the forests stands in the selected sinkholes were relatively dense.

To test the effects of forest management, three different silvicultural measures were implemented in the selected plots in 2012. In one third of all plots (3 per site), all trees (100% of the growing stock) in

the 0.4 ha area were cut. In one third of all plots, 50% of the growing stock was cut. In these plots, a single-tree selection silvicultural system was used to identify the candidate trees with desirable properties (e.g. healthy, stable, desirable species, straight stem, regeneration potential). The tree species composition of the candidate trees followed the current management goals according to the forest management plans. The selected candidate trees were promoted by removal of their competitors with less desirable properties. The diameters at breast height of the cut trees were at least 10 centimetres. Immediately after tree logging in two thirds of the plots, the logs and thick branches were removed from the logging sites and skidded to a landing. No logging was conducted in one third of the plots, and these plots were selected as the control plots (Kutnar et al. 2015).

### Methods of vegetation assessment and indicators

The plant species diversity was assessed before and two years after the silvicultural measures (control without logging, logging 50 % and 100 % of growing stock on 0.4 ha). We studied the plant species diversity in the central part of the 0.4 ha plots at the bottom of the sinkholes. In the centre of the plots where different silvicultural measures were implemented, 27 circular vegetation plots measuring 400 m<sup>2</sup> in size were established. The central points of the vegetation plots were at the lowest point of the sinkholes. In the vegetation plots, the cover estimation of different vertical vegetation-layers and plant species diversity were assessed according to the modified ICP-Forests protocol (Canullo et al. 2011).

All vascular plant species were recorded separately in three vertical layers (herb, shrub, and tree layer). A separate record was compiled for each species in the different vertical layers. The ocular estimation of plant species cover was conducted using a modified Barkman's method (Barkman et al. 1964). Nomenclature of species names followed Mala Flora Slovenije (Martinčič et al. 2007) and Flora Europaea (Tutin et al. 1964-1980, Tutin et al. 1993).

Vegetation layer cover and diversity measures were assessed at plot and site levels before and two years after the silvicultural interventions. After implementation of the silvicultural measures, different vegetation related indicators (indexes) were tested by ANOVA (significant differences between means by comparing variances).

The following measures of diversity were calculated:

1. Species richness (N) as the number of species within a given plot;

2. Shannon diversity index is a measure that describes the structural composition of communities and it is calculated as follows:

$$H' = - \sum_{i=1}^R p_i \ln p_i$$

3. Simpson index is calculated as follows:

$$\lambda = \sum_{i=1}^R p_i^2$$

where  $p_i$  is the relative cover of the  $i$ -th species in a record, and  $R$  is the number of records in the data set considered.

Differences among treatments in herb cover, number of species and Shannon index were tested using linear mixed-effects models, using sampling plots as a random factor and silvicultural measures, location and sampling periods as fixed factors. Prior to the analysis, Levene's test was applied to each variable to check for variance homogeneity among treatments. After the overall model was tested,

planned contrasts were applied to test for the differences between combinations of silvicultural measures and sampling periods (6 levels). All tests were conducted using the software package R with  $\alpha = 0.05$  (Kutnar et al. 2015).

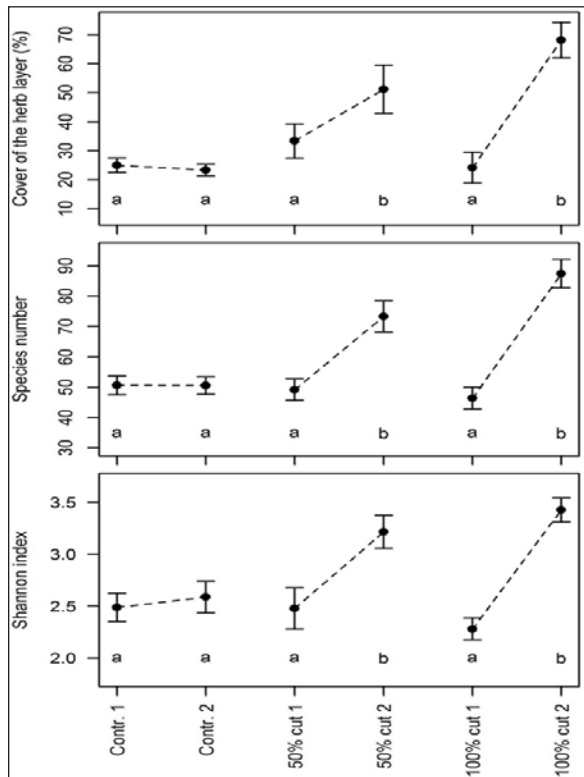
Plant functional traits according to Grime (1977) were analysed. Grime advocates three strategies that have evolved in response to combinations of stress and disturbance intensity: (1) competitor species (adapted to low stress and low levels of disturbance), (2) ruderal species (adapted to low stress and high levels of disturbance), and (3) stress-tolerator species (adapted to high stress and low levels of disturbance).

### Indicators of forest management

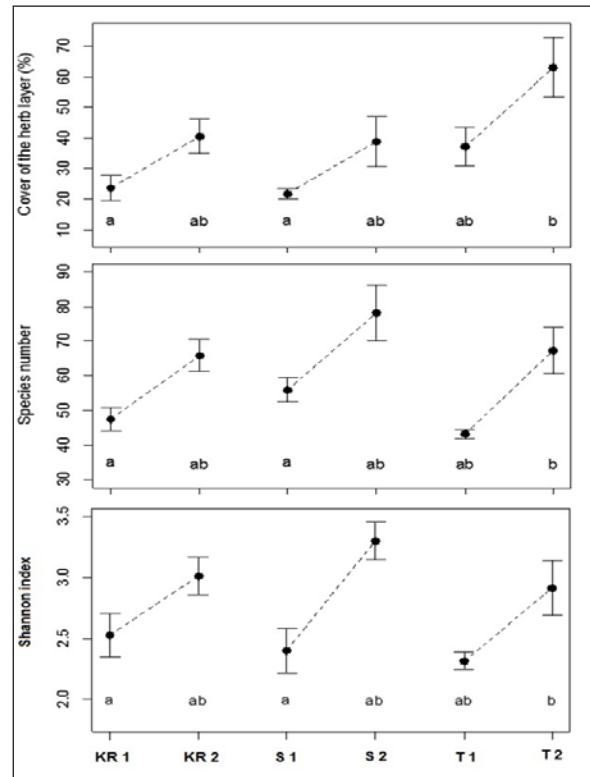
In Table 1, the parameters related to site conditions, stand characteristics and species diversity are shown. Using forest management measures (treatments) as a grouping factor, ANOVA were performed to test differences among the mean values of parameters related to site conditions, stand characteristics and species diversity. The parameters pointed out as significant may be established as the indicators of forest management treatment.

**Table 1** - Test of the potential plant diversity indicators; responds to the three silvicultural measures (control without logging, logging 50 % and 100 % of growing stock on 0.4 ha) is tested by ANOVA. Legend: \*\*\* =  $p < 0.001$ ; \*\* =  $0.001 < p < 0.010$ ; \* =  $0.010 < p < 0.050$

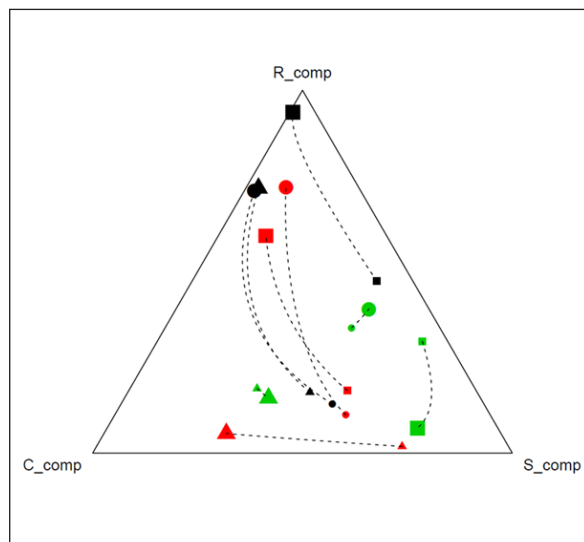
PLANT BIODIVERSITY INDICATOR/INDEX		F	p	Signif.
VEGETATION LAYER COVER	COVER ALL LAYERS (%)	6.22	0.0002	***
	COVER GROUND LAYER (without tree) (%)	9.31	0.0000	***
	BARE SOIL (%)	9.15	0.0000	***
	COVER TREE LAYER (%)	51.37	0.0000	***
	COVER SHRUB LAYER (%)	1.28	0.2867	ns
	COVER HERB LAYER (%)	11.11	0.0000	***
	COVER MOSS LAYER (%)	2.39	0.0516	ns
DOMINANT TREE SPECIES COVER	<i>Fagus sylvatica</i> - UPPER TREE LAYER (%)	3.12	0.0162	*
	<i>Fagus sylvatica</i> - LOWER TREE LAYER (%)	3.40	0.0104	*
	<i>Fagus sylvatica</i> - SHRUB LAYER (%)	1.82	0.1270	ns
	<i>Fagus sylvatica</i> - HERB LAYER (%)	0.97	0.4439	ns
	<i>Abies alba</i> - UPPER TREE LAYER (%)	1.31	0.2772	ns
	<i>Abies alba</i> - LOWER TREE LAYER (%)	0.84	0.5271	ns
	<i>Abies alba</i> - SHRUB LAYER (%)	0.30	0.9101	ns
	<i>Abies alba</i> - HERB LAYER (%)	0.94	0.4637	ns
	<i>Picea abies</i> - UPPER TREE LAYER (%)	1.13	0.3567	ns
	<i>Picea abies</i> - LOWER TREE LAYER (%)	1.52	0.2027	ns
SPECIES RICHNESS	<i>Picea abies</i> - SHRUB TREE LAYER (%)	0.85	0.5186	ns
	<i>Picea abies</i> - HERB LAYER (%)	1.09	0.3782	ns
	NUMBER OF SPECIES OCCURRENCE IN ALL LAYERS	11.86	0.0000	***
	NUMBER OF ALL VASCULAR PLANT SPECIES	18.43	0.0000	***
	NUMBER OF TREE LAYER SPECIES	0.94	0.4640	ns
	NUMBER OF SHRUB LAYER SPECIES	1.10	0.3723	ns
BIODIVERSITY INDEX	NUMBER OF HERB LAYER SPECIES	27.97	0.0000	***
	EVENNESS index	6.46	0.0001	***
	SHANNON index H	9.71	0.0000	***
	SIMPSON index D'	4.00	0.0041	**



**Figure 1** - Comparison of selected indicators; mean cover of the herb layer, the vascular species number and the Shannon index for three silvicultural measures before (1) and two years after the logging (2) in the study plots at three test sites in Slovenia (Kutnar et al. 2015). The error bars represent standard errors of the mean. The letters denote homogeneous groups of treatments at a 0.05 significance level – means with the same letter are not significantly different from each other.



**Figure 2** - Comparison of selected indicators; mean cover of the herb layer, the vascular species number and the Shannon index for three test sites (Kočevski Rog - KR, Snežnik - S and Trnovo - T). A comparison between the states before (1) and after (2) logging is presented. The error bars represent standard errors of the mean. The letters denote homogeneous groups of treatments at a 0.05 significance level – means with the same letter are not significantly different from each other.



**Figure 3** - Shifts in CSR strategies by Grime (1977) between two sampling periods (small symbols – before implementation of forest management measures, large symbols – after implementation of forest management measures) for three locations (square – Trnovo, circle – Kočevski Rog, triangle – Snežnik) and three intensities of forest management (green – control, red – logging of 50% growing stock, black – logging of 100% of growing stock). Before the implementation of silvicultural measures, the studied Dinaric fir-beech forest were dominated mostly by plants of CS to CSR strategies. The tendency of plants to SR strategy were observed on plots of Kočevski Rog-control (green circle) and Trnovo-100% (black square). Plants on these plots were at the middle level of stress and disturbance. On average, plant species from plots of Trnovo-control (green square) were adapted to even higher level of stress. Before the implementation of silvicultural measures, Snežnik-50% (red triangle) plots were dominated by stress-tolerator species. In forest understory plants of these plots, stress was likely to be manifested in low availability of light under a closed canopy.

On plots where silvicultural measures (logging 50% and 100% of growing stock) were implemented the notable drift to R plant strategy were documented. The high intensity disturbance in these forests is mainly related to rigorous forest management actions which significantly changed the forest stand conditions.

Even on the control plots where no logging was conducted the small changes of plant strategies were recognised. Due to position of Trnovo study area which is close to the border between the Dinaric and Sub-Mediterranean region the changes might be more expressed under influence of local climate with higher summer temperatures and longer periods of droughts.

## References

- Barkman J.J., Doing H., Segal S. 1964 - *Kritische Bemerkungen und Vorschläge zur quantitativen Vegetationsanalyse*. Acta Botanica Neerlandica 13: 394-419.
- Bormann F.H., Likens G.E. 1994 - *Pattern and process in a forested ecosystem*. Springer-Verlag, New York, USA.
- Box E.O. 1981 - *Macroclimate and plant forms: an introduction to predictive modeling in phytogeography*. Junk, The Hague.
- Box E.O. 1996 - *Plant functional types and climate at the global scale*. J. Veg. Sci. 7: 309-320.
- Brändli U.B., Bühler C., Zangger A. 2007 - *Waldindikatoren zur Artenvielfalt – Erkenntnisniveau LFI und BDM Schweiz*. Schweiz. Z Forstwes 158 (8): 243-254.
- Butchart S.H.M., Walpole M., Collen B., van Strien A., Scharlemann J.P.W., Almond R.E.A., Baillie J.E.M., Bomhard B., Brown C., Bruno J., Carpenter K.E., Carr G.M., Chanson J., Chenery A.M., Csirke J., Davidson N.C., Dentener F., Foster M., Galli A., Galloway J.N., Genovesi P., Gregory R.D., Hockings M., Kapos V., Lamarque J.-F., Leverington F., Loh J., McGeoch M.A., McRae L., Minasyan A., Hernández Morcillo M., Oldfield T.E.E., Pauly D., Quader S., Revenga C., Sauer J.R., Skolnik B., Spear D., Stanwell-Smith D., Stuart S.N., Symes A., Tierney M., Tyrrell T.D., Vié J.C., Watson R. 2010 - *Global Biodiversity: Indicators of Recent Declines*. Science 328 (5982): 1164-1168
- Cantarello E., Newton A. 2006 - *Towards cost-effective indicators to maintain Natura 2000 sites in favourable conservation status. Preliminary results from Cansiglio and New Forest*. Forest 3: 574-583.
- Cantarello E., Newton A. 2008 - *Identifying cost-effective indicators to assess the conservation status of forested habitats in Natura 2000 sites*. Forest Ecology and Management 256: 815-826.
- Canullo R., Starlinger F., Granke O., Fischer R., Aamlid D., Neville P. 2011 - *Assessment of ground vegetation. Manual Part VII-SPI*. In: ICP Forests. Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests. UNECE ICP Forests Programme Co-ordinating Centre, Hamburg.
- CBD (Convention on Biological Diversity) 1992 - [Internet site]. Available at: <http://www.cbd.int/> [Cited 22 Sept 2009].
- Crites S., Dale M.R.T. 1998 - *Diversity and abundance of bryophytes, lichens, and fungi in relation to woody substrate and successional stage in aspen mixedwood boreal forests*. Canadian Journal of Botany 76: 641-651.
- EEA (European Environment Agency) 2007 - *Halting the loss of biodiversity by 2010: proposal for a first set of indicators to monitor progress in Europe*. EEA 182 p. [http://www.eea.europa.eu/publications/technical\\_report\\_2007\\_11](http://www.eea.europa.eu/publications/technical_report_2007_11)
- EEA (European Environment Agency) 2012 - *Streamlining European biodiversity indicators 2020: Building a future on lessons learnt from the SEBI 2010 process*. 45 p.
- EEA (European Environment Agency) 2014 - *Digest of EEA indicators 2014*. 44 p. <http://www.eea.europa.eu/publications/digest-of-eea-indicators-2014>
- Evan W., van der Werf A., Thompson K., Roderick M., Garnier E., Eriksson O. 1999 - *Challenging Theophrastus: A common core list of plant traits for functional ecology*. Journal of Vegetation Science 10: 609-620.
- Fahey R.T., Puettmann K.J. 2008 - *Patterns in spatial extent of gap influence on understory plant communities*. For. Ecol. Manage. 255 (7): 2801-2810.
- Fan S., Gloor M., Mahlman J., Pacala S., Sarmiento J., Takahashi T., Tans P. 1998 - *A large terrestrial carbon sink in North America implied by atmospheric and oceanic carbon dioxide data and models*. Science 282: 442-446.
- Felton A., Knight E., Wood J., Zammit C., Lindenmayer D. 2010 - *A meta-analysis of fauna and flora species richness and abundance in plantations and pasture lands*. Biol. Conserv. 143: 545-554.
- Forest Europe 2015 - *State of Europe's Forests 2015*. <http://www.forest-europe.org/docs/fullsoef2015.pdf>
- Franklin J.F., Shugart H.H., Harmon M.E. 1987 - *Tree death as an ecological process*. BioScience 37: 550-556.
- Gitay H., Noble I. R. 1997 - *What are functional types and how should we seek them?* – In: Smith, T. M., Shugart H. H., Woodward, F. (eds), Plant functional types – their relevance to ecosystem properties and global change. IGBP Book Ser. 1, Cambridge Univ. Press: 3-19.
- Graae B.J., Sunde P.B. 2000 - *The impact of forest continuity and management on forest floor vegetation evaluated by species traits*. Ecography 23: 720-731.
- Gutrich J., Howarth R.B. 2007 - *Carbon sequestration and the optimal management of New Hampshire timber stands*. Ecological Economics 62: 441-450.
- Halpern C.B., Spies T.A. 1995 - *Plant species diversity in natural and managed forests of the Pacific Northwest*. Ecol. Appl. 5: 913-934.
- Hamilton J.G., DeLucia E.H., George K., Naidu S.L., Finzi A.C., Schlesinger W.H. 2002 - *Forest carbon balance under elevated CO<sub>2</sub>*. Oecologia 131: 250-260.
- Harmon M.E., Franklin J.F., Swanson F.J., Sollins P., Gregory S.V., Lattin J.D., Anderson N.H., Cline S.P., Aumen N.G., Sedell J.R., Lienkaemper G.W., Cromack Jr K., Cummins K.W. 1986 - *Ecology of coarse woody debris in temperate ecosystems*. Advances in Ecological Research 15: 133-302.
- Hart S.A., Chen H.Y.H. 2006 - *Understory vegetation dynamics of North American boreal forests*. Crit. Rev. Plant Sci. 25: 381-397
- Hayes J.P., Chan S., Emmingham W.H., Tappeiner J.C., Kellogg L.D., Bailey J.D. 1997 - *Wildlife responses to thinning in young forests in the Pacific Northwest*. J. Forestry 95: 28-33.
- Hewitt J.E., Thrush S.F., Halliday J., Duffy C. 2005 - *The importance of small-scale habitat structure for maintaining beta diversity*. Ecology 86: 1619-1626.
- IUCN (International Union for Conservation of Nature) 2015 - *2014 IUCN annual report*. Gland : IUCN, 32 pp. [http://www.iucn.org/knowledge/publications\\_doc/publications/?uPubsID=5207](http://www.iucn.org/knowledge/publications_doc/publications/?uPubsID=5207)
- Keddy P.A. 1992 - *Assembly and response rules: two goals for predictive community ecology*. J. Veg. Sci. 3: 157-164.
- Kovač M., Kutnar L., Hladnik D. 2015 - *Assessing biodiversity and conservation status of the Natura 2000 forest habitat types: tools for designated forestlands stewardship*. Forest Ecology and Management 359: 256-267.
- Kraigher H., Jurc D., Kalan P., Kutnar L., Levanič T., Rupel M., Smolej I. 2002 - *Beech coarse woody debris characteristics in two virgin forest reserves in southern Slovenia*. Zbornik gozdarstva in lesarstva 69: 91-134.



- Kutnar L., Eler K., Marinšek A. 2015 - *Effects of different silvicultural measures on plant diversity - the case of the Illyrian Fagus sylvatica habitat type (Natura 2000)*. iForest (early view) - doi: 10.3832/for1587-008
- Kutnar L., Ódor P., van Doort K. 2002 - *Vascular plants on beech dead wood in two Slovenian forest reserves*. Zbornik-gozdarstva in lesarstva 69: 135-153.
- Larsson T.B.B. (ed.) 2001 - *Biodiversity evaluation tools for European forests*. Ecological Bulletins 50: 1-231.
- Lavorel S., Garnier E. 2002 - *Predicting changes in community composition and ecosystem functioning from plant traits: revisiting the Holy Grail* Funct. Ecology 16: 545-556.
- Lavorel S., McIntyre S., Landsberg J., Forbes T. D. A. 1997 - *Plant functional classifications: from general groups to specific groups based on response to disturbance*. Trends in Ecology and Evolution 12: 474-478.
- Marchetti M. (ed.) 2004a - *Monitoring and indicators of forest biodiversity in Europe - from ideas to operationality*. EFI Proceedings. 51 p.
- Marchetti M., 2004b - *Introduction*. In: Marchetti, M. (ed.) Monitoring and indicators of forest biodiversity in Europe - from ideas to operationality. EFI Proceedings 5: 9-11.
- Martinčič A., Wraber T., Jogan N., Podobnik A., Turk B., Vreš B. 2007 - *Mala flora Slovenije*. Tehniškazaložba Slovenije, Ljubljana.
- MCPFE (Ministerial Conference on the Protection of Forests in Europe) 2002 - [Internet site]. Improved pan-European indicators for sustainable forest management. Available at: [http://www.foresteurope.org/documentos/improved\\_indicators.pdf](http://www.foresteurope.org/documentos/improved_indicators.pdf)
- MCPFE (Ministerial Conference on the Protection of Forests in Europe) 2007 - *State of Europe's Forests 2007*. [Internet site]. The MCPFE report on sustainable forest management in Europe. MCPFE Liaison Unit Warsaw.
- Nabuurs G.J., Schelhaas M.J. 2002 - *Carbon profiles of typical forest types across Europe assessed with CO2FIX*. Ecological Indicators 1: 213-223.
- Neill A.R., Puettmann K.J. 2013 - *Managing for adaptive capacity: thinning improves food availability for wildlife and insect pollinators under climate change conditions*. Canadian Journal of Forest Research 43 (5): 428-440.
- Noble I.R., Slatyer R.O. 1980 - *The use of vital attributes to predict successional changes in plant communities subject to recurrent disturbances*. Vegetatio 43: 5-21.
- Peterken G.F. 1996 - *Natural woodland, ecology and conservation in Northern temperate regions*. Cambridge University Press, Cambridge.
- Piškur M., Krajnc N. 2007 - *The importance of forests and wood use for CO2 balance in Slovenia*. In: Jurc, M. (ed.) Climate changes - impact on forest and forestry. Studia Forestalia-Slovenica 130: 237-250.
- Schuck A., Rois M. 2004 - *Forest biodiversity indicators – a contribution to an EEA core set of biodiversity indicators*. In: Marchetti, M. (ed.) Monitoring and indicators of forest biodiversity in Europe - from ideas to operationality. EFI Proceedings 51: 37-48.
- Søgaard B., Skov F., Ejrnæs R., Pihl S., Fredshavn J.R., Nielsen K.E., Clausen P., Laursen K., Bregnballe T., Madsen J., Baatrup-Pedersen A., Søndergaard M., Lauridsen T.L., Aude E., Nygaard B., Møller P., Riis-Nielsen T., Buttenschøn R.M. 2007 - *Criteria for favourable conservation status in Denmark, Natural habitat types and species covered by the EEC Habitats Directive and birds covered by the EEC Birds Directive*. NERI Technical Report. 647 p.
- Thomas S.C., Halpern C.B., Falk D.A., Liguori D.A., Austin K.A. 1999 - *Plant diversity in managed forests: Understory responses to thinning and fertilization*. Ecol. Appl. 9: 864-879.
- Tutin T.G., Burges N.A., Chater A.O., Edmondson J.R., Heywood V.H., Moore D.M., Valentine D.H., Walters S.M., Webb D.A. 1993 - *Flora Europaea, Vol. 1 - Psilotaceae to Platanaceae (2<sup>nd</sup> ed.)*. Cambridge University Press, Cambridge, MA, USA. 581 p.
- Tutin T.G., Heywood V.H., Burges N.A., Moore D.M., Valentine D.H., Walters S.M. Webb D.A. 1964 - 1980 - *Flora Europaea, Vol. 2-5*. Cambridge University Press, Cambridge, MA.